Chapter 3

Basic Design Controls

Basic Design Controls

3.1 Introduction

Basic design controls serve as the foundation for establishing the physical form, safety, and functionality of the transportation facility. Some design controls are inherent characteristics of the facility (e.g., its physical context and the existing transportation demands placed upon it). Other basic design controls are selected or determined by the designer, working with communities and users to address a project's purpose and need. Selecting appropriate values or characteristics for these basic design controls is essential to achieve a safe, effective, and context sensitive design.

This chapter illustrates these basic design controls and their influence on the physical characteristics of a roadway or other transportation facility:

- Roadway Context (Section 3.2)
- Roadway Users (Section 3.3)
- Transportation Demand (Section 3.4)
- Measures of Effectiveness (Section 3.5)
- Speed (Section 3.6)
- Sight Distance (Section 3.7)

3.2 Roadway Context

The context of a roadway is a critical factor to consider in developing a project's purpose and need, making fundamental design decisions such as cross-section determination, and selecting detailed design elements such as street light fixtures or other construction materials. Development of a roadway design that is sensitive to, and respectful of, the surrounding context is important for project success.

As described in Chapter 2, context-sensitive design refers to both the process and its results. An open community process that begins early in project development is needed to ensure that there is consensus about a project's purpose and need. This process needs to continue through the design phase so that the features of the project are assembled to produce an overall solution that satisfies the project's purpose and need, respects surrounding resources, and is consistent with community values.

Projects within the footprint of an existing, safely operating roadway are sometimes proposed when sensitive environmental and community resources are encountered.

Historically, the highway design process has focused on a project's transportation elements, particularly those associated with motor vehicle travel. A context-sensitive design should begin with analysis of the contextual elements, such as environmental and community resources, of the area through which a roadway passes. As described later in this chapter, the concept of area types has been developed to help the designer understand the users, constraints, and opportunities that may be encountered in different settings.

Once the designer has an understanding of the area surrounding the road and the road's users, the designer should consider the transportation elements of the roadway, its function within the regional transportation system, and the appropriate level of access control. Thus, three main elements of context are considered in design:

- **Area Type** – the surrounding built and natural environment
- **Roadway Type** – the role the roadway plays in terms of providing regional connectivity and local access
- **Access Control** – the degree of connection or separation between the roadway and the surrounding land use

3.2.1 Area Types

The context of a roadway begins with its environmental context, which includes nearby natural resources, terrain, and the manmade environment (development patterns, historic, cultural, and recreational assets). The environmental context can be a determinant of the desired type of accommodation for different users. This context often establishes the physical constraints of the roadway alignment and cross-section, and influences the selection of motor vehicle design speed. Throughout this Guidebook, this environmental context is generalized as ***area type***.

A roadway frequently traverses a variety of changing environs. Additionally, the volume and character of pedestrian, bicycle, public transit, and motor vehicle activity can change considerably along its route. Land use is the fundamental determinant in the function of a road; as land use changes along a road, the road's functions also change. Roadways must be designed in a manner that serves the existing land use while supporting the community's future land use goals. Chapter 15 also discusses land use strategies that a community can use to preserve the functionality of its roads or further support community values.

Traditionally, roadways have been classified either as "rural" or "urban." It is important to recognize that a roadway's formal classification as urban or rural (which is determined from census data using periodically-adjusted criteria adopted by the United States Office of Management and Budget) may differ from actual site circumstances or prevailing conditions. An example includes a rural arterial route passing through a small town. The route may not necessarily be classified as urban, but there may be a significant length over which the surrounding land use, prevailing speeds, and transportation functions are more urban or suburban than rural. For this reason, it is important for the designer, working with the community and project reviewers, to determine an appropriate area type or types for a project early in the planning process.

Area types are illustrative of the broad range of environments that the designer may encounter throughout the Commonwealth. The designer should also identify unique or project-specific contextual elements that will influence the design beyond those generalized for the following area types. These might include, as examples, schools, churches, historic features, environmental resources, area bike facilities, sidewalks, and bus stops.

3.2.1.1 Rural Area Types

Rural areas are generally undeveloped or sparsely settled with development at low densities along a small number of roadways or clustered in small villages, as illustrated in Exhibit 3-1. Rural areas are often distant from large metropolitan centers.

3.2.1.2 Suburban Area Types

Suburban areas vary widely in character and are usually found outside the core of a metropolitan area. Some components of suburban zones may appear rural in character, while others are densely populated and more closely resemble urban areas, as illustrated in Exhibit 3-2. Three different area types characterize the suburban context zone.

3.2.1.3 Urban Area Types

Urban areas are typically found at the core of a large metropolitan area. In many cases, the urban area includes a central business district (CBD) with high density commercial and residential development surrounding the CBD. Open space is generally found in formal parks or urban preserves, as illustrated in Exhibit 3-3. Although individual area types are described below to illustrate the land use variations found in the urban area, the roadway elements described in the subsequent chapters recognize that a consistent design approach is typically applied to urban areas given the similarities in parcel access, pedestrian activity, bicycle activity, and transit availability across these land use variations.

Exhibit 3-1
Rural Area Types

Natural

This is the traditional concept of rural space, where the roadway travels through forest land, farm land, and other open space. There are few access points along the roadway and little or no development. Design constraints tend to involve topographic, environmental, scenic or historic resources. Pedestrian, bicycle and transit activity is usually infrequent and of low volume. However, bicyclists and pedestrians may be attracted to low-volume roadways traversing scenic rural areas.

Village

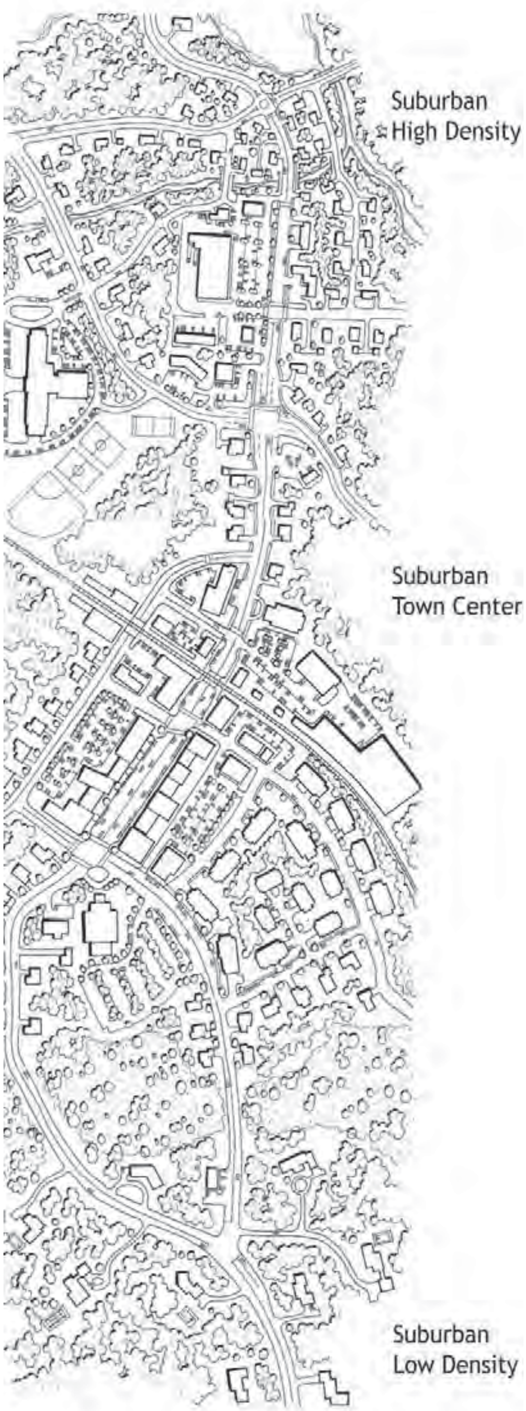
This is an isolated built-up area with storefronts, civic uses, and interspersed housing. Varied building setbacks, and frequent driveways and intersections are common. Individual property frontage is generally less than 200 feet. Right-of-way is usually constrained by the built environment. Pedestrian activity can be moderate to high and bicycle activity is often generated to, from, and within villages. Transit activity may be present, but is uncommon. An important safety consideration for design is the often rapid transition between rural natural or rural developed areas to a rural village.

Developed

This is an area of low-density residential development or occasional commercial uses. Buildings generally have large setbacks from the roadway and are frequently invisible due to tree cover. Occasional driveways require a driver to be more alert for entering and exiting vehicles than in rural natural areas. The consideration of future development and/or desires to retain the rural character of the area are important considerations in project development. Pedestrian and bicycle activity are more frequent than in natural areas, but generally of modest scale. Transit activity is uncommon.

Source: MassHighway

Exhibit 3-2
Suburban Area Types



High Density

This category covers a wide range of suburban development where the majority of the roadside is intensively developed with a mix of property-types and building setbacks. Residential property frontage is often less than 200 feet and intensive commercial development, including strip development, is frequently encountered. Right-of-way is usually restricted to a moderate extent by the built environment. Frequent driveways are usually encountered and influence the operating characteristics of roadway users including the prevailing travel speeds. If facilities are available, pedestrian and bicycle activity can be high, although most properties are often designed primarily for motor vehicle access. Transit service is sometimes present.

Village/Town Center

This is a built-up area of commercial and residential uses. The commercial uses are usually concentrated together and are notable for a uniform building setback. Residential areas consisting of properties with frontage of less than 200 feet often define the edges of a suburban town center. Pedestrian and bicycle activity are the highest in town centers compared to the other suburban settings and sidewalks are usually present. Right-of-way is usually restricted by the built environment. On-street parking is often found in these areas. Travel speeds are usually lower than in other suburban areas.

Low Density

These are transitional areas where roadways have a mix of natural and developed characteristics. Residential development is low to moderate in density, and there are isolated commercial properties. There are generally large setbacks to buildings and individual property frontage usually exceeds 200 feet. Frequent low volume driveways and intersections have an impact on the travel speed and operating characteristics of roadway users. Pedestrian and bicycle activity is higher than in rural developed areas and transit service through these areas is occasionally encountered.

Source: MassHighway

Exhibit 3-3
Urban Area Types

Urban Park

Open space in the urban area is usually found in parks or preserves. Pedestrian and bicycle facilities along roadways usually interconnect with the network of paths and trails through the open space. Roadways are often bounded by sidewalks and often include on-street parking to support use of the open space. Driveways are usually infrequent in open spaces, although path and trail crossings of the roadway may be common.

Urban Residential

Urban residential districts usually consist of multifamily developments at a common scale and setback along roadway corridors. Sidewalks are usually present and on-street parking is common, although not universally found in these areas. Off-street parking is usually located in parking structures or parking lots. Driveways are usually consolidated for entire buildings or blocks. High levels of pedestrian, bicycle, and transit activity are usually found in these areas.

Central Business District (CBD)

The majority of development is usually commercial or mixed-use. Access to property is the primary function of the roadway network. On-street parking is often found along road and structured parking facilities are common. Pedestrian, bicycle and transit activity is nearly always present and of substantial volume. A definitive network of sidewalks and pedestrian routes linking densely developed parcels is usually present. Transit centers where multiple bus routes converge are often found. Rail transit stations and intermodal facilities may also be encountered.

Source: MassHighway

3.2.2 Roadway Types

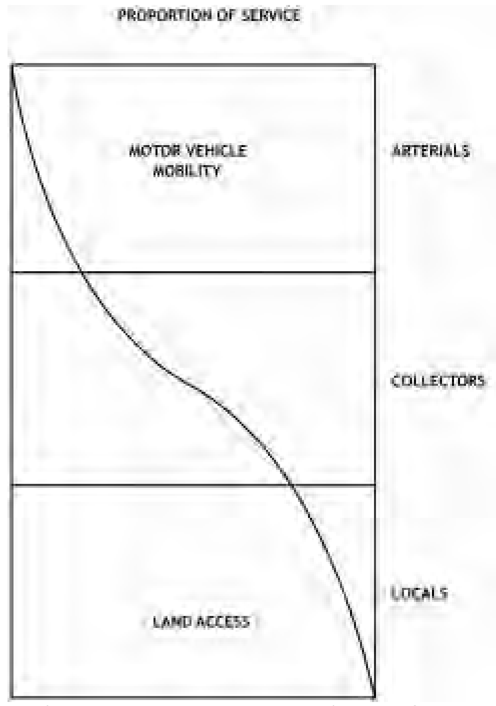
The transportation network is composed of several different types of roadways that provide different functions, traditionally referred to as a it's functional class. The primary purpose of some roads is to facilitate movement of vehicles (bicycles, cars, trucks, buses and light rail) between major cities and towns. The primary purpose of other roads is to provide access to the adjoining land. Most roads provide a combination of these purposes, as illustrated in Exhibit 3-4. ***Roadway type,*** defined by the facility's role in the state and regional transportation system, together with its area type, is an important contextual consideration for design. The roadway type should be selected to reflect the actual role that the roadway plays in the transportation system, as defined through the project development process.

A typical trip will often entail traveling along a variety of roadway types, each of which provides a different degree of local access and a different degree of regional connectivity. The roadway type reflects its degree of local access and regional connectivity as illustrated schematically in Exhibit 3-5 and described below:

- **Freeways** are primarily for interstate and regional travel (high regional connectivity at high speeds with limited access to adjacent land and limited access for pedestrians and bicyclists).
- **Major arterials** service statewide travel as well as major traffic movements within urbanized areas or between suburban centers (high regional connectivity at a wide range of speeds, and a lower level of local access than the following roadway types).
- **Minor arterials** link cities and towns in rural areas and interconnect major arterials within urban areas (high to moderate regional connectivity at a wide range of speeds, and moderate degrees of local access).
- **Major collectors** link arterial roadways and provide connections between cities and towns (moderate to low regional connectivity at a wide range of speeds, and higher degree of local access than arterials and freeways).
- **Minor collectors** connect local roads to major collectors and arterials (lower regional connectivity at lower speeds and higher degrees of local access than the previous roadway types).
- **Local roads and streets** - Not intended for regional connectivity (low speeds with a high degree of local circulation and access).

Exhibit 3-4

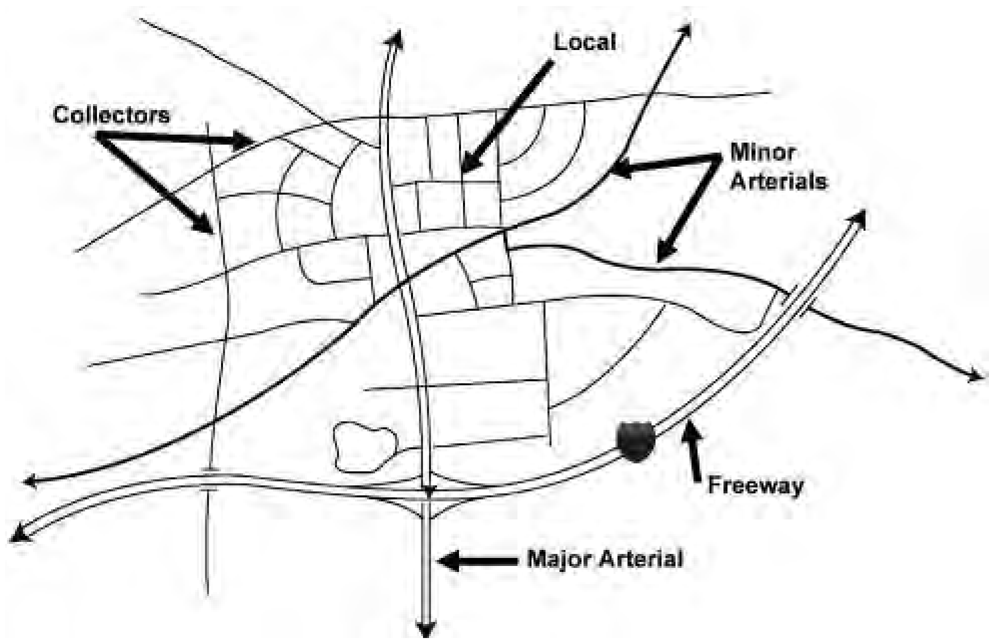
Conceptual Framework of Roadway Type



Source: Adapted from Safety Effectiveness of Highway Design Features, Volume 1, Access Control, FHWA, 1992

Exhibit 3-5

Schematic Representation of Roadway Type



Source: MassHighway

3.2.2.1 Relationship to the Formal Functional Classification System

The functional classification system developed by the Federal Highway Administration and applied to all roadways in the United States remains a key element of system planning so that a safe and efficient transportation network, providing the desired level of regional connectivity and land access, is developed and maintained. This classification system is also used as a determinate of federal funding eligibility. Formal functional classifications include: Interstate, Principal Arterial, Rural Minor Arterial or Urban Principal Arterial, Rural Major Collector or Urban Minor Arterial, and Rural Minor Collector or Urban Collector.

This formal classification often serves as a useful starting point, but the designer should not simply rely on this formal designation as a design control. The roadway type should be selected to reflect the actual role that the roadway plays in the transportation system, as defined through the project development process. For example, a roadway may serve a high number of regional trips, but may pass through a town center with frequent driveways, close intersection spacing, and high levels of pedestrian activity. In this case, the roadway serves as both an arterial and a local road. The designer should work closely with the community, users, and project reviewers to determine the roadway characteristics and appropriate design considerations to serve both the regional purpose of the roadway and its role in the local setting.

3.2.3 Access Control

Access control is a term used to define how access to adjacent properties is regulated and designed along a roadway. Access control is among the most useful tools available to maintain safe and efficient roadway operations for all users. Judicious use of median treatments, driveway permits, and safe driveway geometry can improve roadway safety and enhance the operation of the road without undue burden on accessing bordering property.

The degree of access control is influenced by the roadway type and area type. For example, access controls are usually more stringent on arterials than on collectors and local roads, reflecting the mobility and land access functions of these roadways. Likewise, access controls are often given more consideration in developing areas where there is flexibility for future land use to conform to an access management plan than in developed areas where the pattern of land use has been established. However, the designer should consider existing access points along a roadway and the possibility for changes that are consistent with the project's purpose and need. For example, it may be possible to relocate, redesign, or consolidate driveways along an existing roadway. A thorough understanding of access control will help the designer select an appropriate design speed, planning parameters, and desired level-of-service for the facility's users.

Access control is exercised by statute, zoning, right-of-way purchases, driveway controls, turning and parking regulations, geometric design (e.g., raised medians, grade separations, and frontage roads), and local right-of-way permitting, frequently administered by local Public Works Departments.

Roadways can be designed with the following approaches to access control:

- **Full Control** – Full control gives priority to through traffic by providing access only at grade-separated interchanges with selected public roads. No at-grade crossings or private driveway connections are allowed. "Freeway" is the common term used for this type of highway. Full access control maximizes the capacity, safety, and speeds on the freeway.
- **Partial Control** – Partial control of access is an intermediate level between full control and regulatory restriction. Under partial control of access, priority is given to through traffic, but a few at-grade intersections and private driveway connections may be allowed. Partial control of access may be provided for certain arterial and collector roadways. The proper selection and spacing of at-grade intersections and service connections will provide a safe balance between the regional connectivity and local access functions of the facility.
- **Statute, Zoning and Regulation** – If access points are properly spaced and designed, the adverse effects on roadway capacity and safety will be minimized. The design should enable vehicles to enter and exit safely with a minimum of interference to through traffic. Statutory control may be used, for example, on a rural or urban arterial highway to limit access only to public road crossings. Driveway regulations and permits are often used to control the geometric design of an entrance, driveway spacing, and driveway proximity to public road intersections. Zoning may also be used to effectively control the adjacent property development so that

major generators of traffic will not develop; however, zoning regulations are at the discretion of the local government.

While the designer may have substantial flexibility in defining the access control during the project development process for new roadways, the options may be substantially more complex or limited on projects that are modifying existing roadways. The *Access Management Manual* published by the Transportation Research Board in May of 2003 provides guidance on the application of access management techniques for both existing and new roadways. Access management techniques are also discussed further in Chapter 15.

3.2.4 Parkways

Parkways are a unique category of roadway that have special relationships to the surrounding area, perform unique transportation functions, and illustrate one of the earliest approaches to access control. Parkways, in Massachusetts practice, differ from ordinary state highways because they are understood to be within parklands and are distinguished by their scenic and landscape qualities, or access to such qualities, and for their recreational uses. They fall into three general categories.

Narrow, linear parkways, intended to link larger park or reservations to one another, and originally designed with internal carriage roads and bridle paths for recreational use, make up the first category. Examples of this type in the Boston area are the Riverway, Jamaicaway and West Roxbury Parkway. The parkway layout is sufficiently wide to include scenic and interesting natural features and provide a natural separation from surrounding developed areas; their narrow linear or curvilinear layout accommodated recreational drives through their length from one significant park or reservation to another. In many instances the carriage roads became increasingly integrated with the surrounding roadway network.

The second category of parkways is the group of landscaped boulevards established under the provisions of the Boulevard Act of 1894 and other subsequent, specific enabling legislation. Like earlier parkways, these boulevards were intended as links to outlying Reservations. Examples in the Boston area include the Fellsway, Revere Beach Parkway and Blue Hills Parkway. Boulevards were often laid out with reservations for electric trams and with a deliberate separation between general local access traffic and recreational traffic.

As regional roadways crossing multiple communities, many became important arteries for automobile traffic.

Park access roads characterize the third category of parkways. These parkways were intended initially to provide internal access to a park or reservation's features. Unquity Road in the Blue Hills Reservation and the summit roads at Mount Greylock Reservation are examples of park access roads. Many of these roads serve their original purposes; others have been substantially altered by the construction of extensions or links to other roads.

Special design considerations are often encountered when designing projects on parkways due to their scenic, historic, and recreational value. Many of the context-sensitive design approaches and considerations described in this Guidebook are appropriate for identifying these considerations and suitable design approaches. However, the proponent and designer must also work closely with the parkway's owner to determine appropriate design considerations for the particular parkway.

Many parkways are owned and controlled by the Department of Conservation and Recreation (DCR). The DCR is currently developing guidelines for the preservation of its parkways. When available, these guidelines should be followed for parkway projects. In some cases, MassHighway is involved in parkway projects due to project funding or other circumstances. In these instances, MassHighway will work cooperatively with the proponent and parkway owner to review or develop a design that is suitable for the parkway.

3.3 Roadway Users

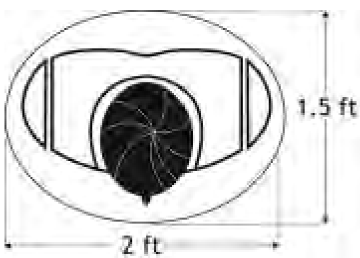
A fundamental expectation in roadway design is that all users will be accommodated safely. Virtually all roadways serve a variety of users including pedestrians, bicyclists, motor vehicle drivers and passengers. In a few cases, such as freeways, roadways serve almost exclusively motor vehicle traffic. Early in the process, the designer needs to determine the composition of users anticipated for the facility. Appropriately accounting for all user characteristics is essential for obtaining a safe and efficient roadway. Experience demonstrates that when human and vehicular factors are properly accommodated, the safety and effectiveness of the highway or road system is greatly enhanced.

Consideration of roadway users' characteristics and selection of appropriate accommodation can also influence on the roadway's effectiveness for businesses and residential users, the economic health of the region, the physical health of the population, and the quality of the built and natural environment.

The characteristics of these varied roadway users are important controls that influence the physical design of a roadway, as described in the following sections.

3.3.1 The Pedestrian

All travelers are pedestrians at some point during their trip, and pedestrians are a part of every roadway environment. In some cases pedestrians are regular users of the roadway while in others, pedestrians may be using the roadway in emergency circumstances, such as accessing a disabled automobile. Pedestrian facilities include sidewalks, paths, crosswalks, stairways, curb cuts and ramps, and transit stops. Depending on the speed and volume of motor vehicle traffic, pedestrians may also share the road or use shoulders to complete a trip.



Pedestrian Body Ellipse

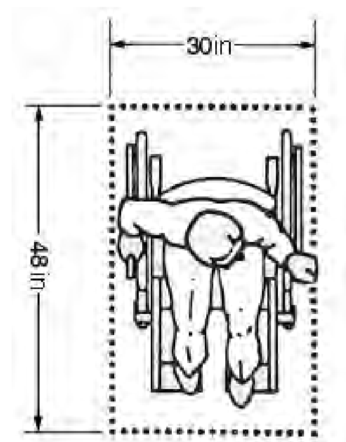
Designers should understand that there is no single "design pedestrian" and that the transportation network should accommodate a variety of pedestrians, including people with disabilities. For example, children perceive their environment differently from adults and are not able to judge how drivers will behave. Children usually walk more slowly, have a shorter gait, and have a lower eye height than adults. On the opposite end of the spectrum, older adults may require more time to cross streets, desire more predictable surfaces, benefit from handrails in steep areas, and may require places to rest along their route. People who are blind or who have limited sight require audible and tactile cues to safely navigate sidewalks and crosswalks. People with limited cognitive abilities may rely on symbols and take longer to cross the street. People using wheelchairs or scooters may travel across an intersection faster than someone walking, but it is more difficult to see them from the seat of a truck, SUV, or car. It is important to recognize that pedestrians exhibit a wide range of physical, cognitive, and sensory abilities, but they all comprise the pedestrians that a designer needs to accommodate. In fact, 20 percent of the pedestrian population has some disability, and that number is growing as a result of the aging of our population.

MassHighway intends to accommodate all pedestrians in the design and construction of pedestrian facilities.

When thinking about likely pedestrian travel between activity centers (i.e., residence to school, parking to store, etc.), distance is the primary factor in the initial decision to walk. Most people are willing to walk 5 to 10 minutes at a comfortable pace to reach a destination, which equates to a distance of about 0.2 to 0.4 mile. Although longer walking trips are possible, a trip of 1.0 mile is generally the longest distance that most people are willing to walk on a regular basis. The designer should ensure that pedestrian network connectivity and safe crossings are provided between activity centers. In addition to the characteristics described above, the spatial dimensions of pedestrians and their operating characteristics are key critical aspects that influence the detailed design elements of pedestrian facilities.

3.3.1.1 Spatial Needs of Pedestrians

Pedestrians require a certain amount of physical space in order to maneuver comfortably. The space requirements of pedestrians influence the ability for individuals to freely select their speed and the carrying capacity of a pedestrian facility. The *Highway Capacity Manual* provides methodologies for evaluating how a pathway serves the demand placed upon it, or how wide a sidewalk should be for a given demand. Space requirements are also influenced by the characteristics of those who use wheelchairs or other assistive devices.



Spatial Needs for Wheelchairs

A simplified body ellipse of 2 by 1.5 feet with a total area of 3 square feet is used as the basic space for a single pedestrian. This represents the practical minimum space required for standing pedestrians. The clear space for a person sitting stationary in a wheelchair is generally understood to be 2.5 feet by 4 feet, although people using scooters and power chairs may require even more space. A person using crutches, a service animal, or a walker typically requires 36 inches clear width. In evaluating a pedestrian facility, an area of 8.0 square feet is typically considered to allow a buffer zone for each pedestrian and approximately twice that is needed for a person using a wheelchair or a white cane. These dimensions indicate that a 3 foot pathway is adequate for single file pedestrian flow in one direction, in the absence of vertical obstructions along the route. To allow free passing of pedestrians, a walkway that is at least five-feet wide and clear of obstructions is required. Walking is often a social activity, and frequently pedestrians walk in pairs or groups. To account for this common behavior, it may be desirable to design facilities that enable two people to walk or ride their chair abreast, requiring approximately 6 feet of width. In areas with high pedestrian traffic, greater widths are desirable as described in Chapter 5.

3.3.1.2 Pedestrian Level-of-Service Measures

The *Highway Capacity Manual (HCM)* provides definitions of level of service based on spatial and delay measurements. The HCM provides level-of-service analysis for a variety of pedestrian facilities, including sidewalks, paths and crosswalks. Pedestrian levels of service are defined similar to traffic operations using a LOS A to LOS F rating system. For conditions such as sidewalks and street corner queuing areas, the level of service is based on the pedestrian demand (flow rates) and density. For shared pedestrian-bicycle facilities, the level of service is based on the number of times bicyclists pass pedestrians. Several new pedestrian level-of-service measures that account for a greater number of environmental factors are being developed through research. In addition to the level of service indicated by the HCM procedures, the designer should also consider geometric, traffic, urban design, and streetscape elements that influence pedestrian comfort.

At signalized intersections, the pedestrian level of service is based on the average delay a person experiences waiting to cross the street. This delay is independent of pedestrian volume and is calculated solely on the signal cycle length and the amount of green time provided to pedestrians.

At unsignalized crosswalks, the pedestrian level of service is related to vehicular volumes, speeds, and the resulting gaps in the traffic stream suitable for pedestrian crossings. Although adherence is not universal, at unsignalized crosswalks, vehicles often yield to pedestrians, as required by law, increasing the level-of-service from that derived using *Highway Capacity Manual* procedures. Careful design review of the crossing locations must be performed during the project development process to ensure adequate visibility exists for compliance with this law.

Chapter 6 of this Guidebook presents specific design advice about how to accommodate pedestrians within the right-of-way at intersection locations.

3.3.2 The Bicyclist

Safe, convenient and well-designed facilities are essential to encourage bicycle use. Roads designed to accommodate bicyclists with moderate skills will meet the needs of most riders. Young children are primarily the bicyclists who may require special consideration, particularly on neighborhood streets, in recreational areas, and close to schools. Moderately skilled bicyclists are best served by:

- Extra operating space when riding on the roadway such as bicycle lanes, usable shoulders, or wide curb lanes;
- Low speed streets (where cars share travel lanes); and
- A network of designated bicycle facilities (bicycle lanes, side-street bicycle routes and shared use paths).

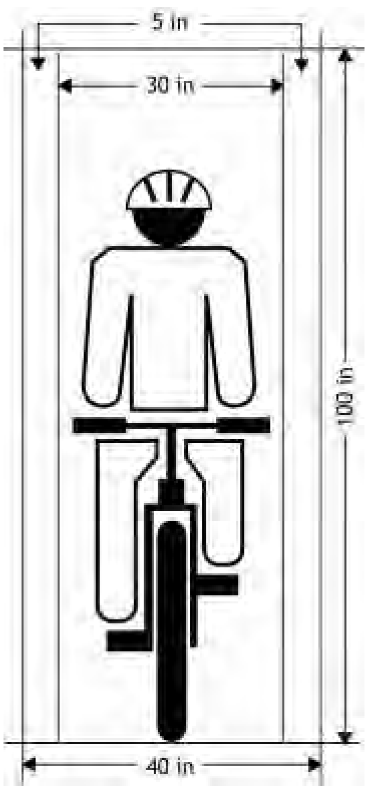
Paths for bicyclists (which generally also serve other non-motorized users) supplement the roadway network and are discussed in detail in Chapter 11. The design of roads for bicycling should consider these factors:


Shared-Use Path Users

- Providing width sufficient for motorists to pass bicyclists without changing lanes on high speed or high volume roadways;
- Removing roadway obstacles that could cause bicyclists to fall;
- Directing bicyclists to scenic and low traffic routes by guide signs and/or pavement markings;
- Providing signalized crossings of major roads when warranted for those who are not comfortable making left-turns in heavy traffic.

When bicycles are used on public streets and roads, bicyclists are subject to the same traffic rules as motor vehicle operators with some exceptions as noted in the Massachusetts General Laws (see Chapter 85 11B). The following sections describe the spatial needs and level-of-service measures for bicyclists.

3.3.2.1 Spatial Needs of Bicyclists



Bicycle Operating Space

The bicyclist's operating characteristics include required width, angle of lean when negotiating curves, sight distances, and clear zones. Clear width requirements may differ somewhat depending on bicycle type. Typically, bicyclists require a clear width of at least 40 inches. A clear width of at least 48 inches is necessary to accommodate bicycles with trailers or adult tri-cycles. The required height of operating space is 100 inches.

An operating space of 4 feet is assumed as the minimum width for one-way bicycle travel. Where motor vehicle traffic volumes, truck and bus volumes, or speeds are high, a more comfortable operating space of 5 to 6 feet is desirable. Also, adjacent to on-street parking, 5 to 6 feet is desirable to provide space for the opening of car doors into the travel lane.

A critical design consideration is the minimal tire surface contact with the ground and the susceptibility of bicycle tires to damage. The minimal tire contact means that longitudinal seams and cracks, sand, mud, wet leaves, metal utility covers and decking, and skewed railroad tracks can precipitate a crash. Longitudinal cracks as narrow as 1/4 inch and surface edges higher than 1/2 inch can cause loss of control. Avoidance of road debris or obstacles forces bicyclists to swerve and these maneuvers are often unexpected by a driver sharing the same lane. Placement of obstacles in the travel path of bicyclists should be avoided.

3.3.2.2 Bicycle Level-of-Service Measures

The level of service for bicyclists on shared use paths (where bicyclists share the path with pedestrians, in-line skaters, etc.) is also evaluated on a LOS A to F scale for different settings. For such paths, the level of service is determined by the nature and number of interactions between bicyclists, pedestrians, in-line skaters, and other obstacles such as dogs and baby strollers.

Bicycle LOS at intersections is similar to that experienced by motor vehicles since bicycles are subject to the same traffic control. These LOS considerations are explored in more detail in Chapter 6.

The level of service for on-road bicycle travel is based on the adjacent traffic volumes, speed and the width of the shoulder or bicycle lane. Other factors, such as vehicle mix and on-street parking, can also influence bicycle level of service for on-road facilities. Procedures for determining bicycle level of service on uninterrupted bicycle facilities are provided in the Highway Capacity Manual. Other tools have been developed to assess level of service for on-road facilities. The two primary sources are the Landis' *Toward a Bicycle Level of Service* (BLOS) methodology and the Federal Highway Administration's Development of the *Bicycle Compatibility Index* (BCI). Although the BCI methodology is the most widely-accepted methodology for determining bicycle LOS, current research is developing new level-of-service models for bicyclists.

3.3.3 The Driver

Roadway design is based on the assumption that motor vehicle drivers are competent and capable; however, the design of a roadway also needs to account for a large variation in driver skill and ability. The *AASHTO Policy on Geometric Design of Highways and Streets* discusses human factors in detail.

3.3.3.1 Spatial Needs of Motorists

When a roadway or intersection is under design, the largest design vehicle likely to use that facility on a regular basis should be used to determine the selected design values. Typically, trucks and buses require larger design values than passenger cars, which makes determining the type of specific design vehicle an important design consideration. Exhibit 3-6 summarizes the range of vehicle dimensions. Actual vehicle widths may vary from the dimensions listed in the table due to manufacturer and aftermarket vehicle variations such as side view mirror extensions.

On local streets the design might fully accommodate smaller trucks with the knowledge that, at intersections, the occasional larger truck can back up while turning and can encroach upon opposing lanes. These types of decisions are situation-specific and depend on the frequency of larger vehicles, the amount of other traffic, the character of the area, and other factors.

Exhibit 3-6
Design Vehicle Dimensions

Vehicle	Vehicle Length	Vehicle Width	Operating Width[1]
Passenger Cars and Light Trucks	19.0 feet	7.0 feet	9.0 ft
School Bus	36.0 feet	8.0 feet	10.0 ft
Transit Bus	40.0 feet	8.5 feet	10.5 ft
Single Unit Truck[2]	30.0 feet	8.0 feet	10.0 ft
Tractor-Trailer	55.0 feet	8.5 feet	10.5 ft

Source: *A Policy on the Geometric Design of Streets and Highways*, AASHTO, 2004. Chapter 2 Design Controls and Criteria
1 Assuming one-foot clearance on both sides of vehicle
2 The SU-30 design vehicle is commonly used to model emergency response vehicle operations

Spatial dimensions and motor vehicle speeds are closely related. The following is a brief discussion of the motor vehicle characteristics used in arriving at design values.

- Stopping sight distances depend on the speed of operation and vehicle braking characteristics.
- Horizontal curvature depends on the side friction between tire and roadway, among other factors.
- Truck acceleration and deceleration rates are factors in the design of highway vertical alignment.
- Vehicles are restricted in how sharply they can negotiate a turn by their physical dimensions and tire friction, which influences curb radii at intersections.
- Another turning characteristic of vehicles is the transitional nature of their turning path. Vehicles cannot immediately turn to their desired turning radius but have an entering and exiting transition into that radius. This has led to the use of compound curves on highways.
- Lane and shoulder widths are derived from the design width of vehicles and horizontal clearances to allow safe operation.

Further discussion of design vehicles is provided in AASHTO's *A Policy on the Geometric Design of Highways and Streets*.

3.3.3.2 Driver Level-of-Service Measures

The level of service for drivers on a facility reflects the speed and capacity provided for motor vehicle travel. Additionally, the vehicular level of service often influences the quality of public transit service provided along a roadway corridor. Different level-of-service measures apply to different components of the roadway. In general, there are two categories of vehicular level-of-service measures:

- Uninterrupted flow (two-lane highways, multi-lane highways, freeway segments, and freeway ramps) for which level of service is based on the concepts of average travel speed, percent time following, and density measures.
- Interrupted flow (signalized intersections, unsignalized intersections, and roundabouts) for which level of service is based on the amount of delay experienced by vehicles using the facility.

Levels of service for motor vehicles range from LOS A to LOS F, with LOS E representative of operation approaching or at capacity. The *Highway Capacity Manual* (HCM) provides procedures for determining levels of service for a variety of facility types.

3.3.4 Public Transit

Public transit within a roadway is usually provided with transit buses. A representative bus used by the local transit agency should be included as a design vehicle on roadways where transit service is provided, or is anticipated during the expected life of the project. The designer should also consider the design characteristics and potential location of bus stops, stations, and other intermodal facilities. Most buses are lift-equipped, generating the need for five-foot (measured at the curb and parallel to the vehicle) by eight-foot (measured from the curb or vehicle edge) level pad adjacent to the accessible sidewalk. This allows for the deployment of the lift and space to maneuver on and off of it. The designer should also ensure that pedestrian connectivity—including curb cut ramps and accessible drop off areas to these facilities are provided.

Articulated Transit Bus

In less frequent circumstances, rail transit is provided along a roadway or within a center median. The detailed clearance, station, and operational needs of rail transit should be integrated into the roadway design in these conditions. Other features such as exclusive lanes and traffic signal pre-emption can improve transit operations within a roadway. Transit design considerations are discussed further in Chapters 5, 6, and 16.

In terms of level of service, there are many measures of transit quality of service as outlined in the *Transit Capacity and Quality of Service Manual.* Most of these, such as vehicle type, operating hours and frequency of service, are independent of roadway design. For the purpose of roadway design, the key considerations are the location and design of bus stops, the travel time through a corridor, the pedestrian and bicycle routes connecting to the facility, and waiting areas to access transit.

For specific projects, there may be transit design elements that influence the roadway design. Where transit operations are present or expected, the designer should coordinate with the transit agency during the project development process to ensure that transit operational requirements are included in the design.

3.4 Transportation Demand

Transportation demands – volume, composition, and patterns – are important design controls. The greater the demand for a facility, the more important are its operational and safety characteristics. The designer must have a good understanding of existing and anticipated demands by pedestrians, bicyclists, and drivers. Community planning goals, the selected design year, and performance measures for a project are key determinants of how the design achieves the project’s purpose and need.

3.4.1 Design Year

Projects are designed to accommodate travel demands likely to occur within the life of the facility under reasonable maintenance. This involves projecting future conditions for a selected planning horizon year. Projections of future demand for major transportation investments are usually made for the 15 to 25 year range. For large projects, the designer should usually select 20 years from the expected facility completion date as the design year. This is a reasonable compromise between a facility's useful life, the uncertainties of long-range projections, and the consequences of inaccurate projections. For smaller, less capital intensive projects, a 5- to 10-year planning horizon is generally used.

Forecasts of future activity levels should reflect community and regional plans, community setting, and the project's purpose and need. Based on these considerations, a future conditions forecast represents a technical analysis and policy consensus on the type and developed intensity of land use, future regional economic activity, presence of transit service, the needs of pedestrian and bicyclists, and many other factors.

Forecasts of future activity levels should include estimates of pedestrian and bicycle activity. Particular care must be used when forecasting pedestrian and bicycle volumes. Many times there is latent demand above observed pedestrian and bicycle volumes because pedestrian and bicycle facilities do not yet exist in the project area, are substandard, or do not provide complete connectivity to attractions. It is important to evaluate future land development, including any potential attractors such as transit stops, schools, parks and retail uses that may be located near moderate and high-density residential development.

Planners and designers need to determine the appropriate estimates of activity levels for design. For the typical project undertaken within a community, such as an intersection improvement or a corridor access management project, the forecast is based on existing conditions. First, traffic counts (including pedestrian and bicycle trips) are conducted to determine when the peak hour(s) of traffic occurs. Second, seasonal adjustments are made, if necessary, to ensure the count data are representative of at least average annual conditions. Lastly, future conditions are estimated by adding to or subtracting from the existing traffic volumes to account for known development and transportation projects, and an annualized factor is generally applied to account for potential areawide growth or decline. Regional travel demand models are often used in planning larger transportation projects.

To evaluate the future conditions, planners and designers first collect and evaluate existing conditions' data to establish a baseline.

Although the typical process for forecasting traffic volumes assumes that traffic will increase over time, there are situations where traffic volumes may decline or remain relatively constant over time. It is important that traffic forecasts for a roadway design project reflect likely conditions over the project's life and are not selected arbitrarily. Municipal planning departments, regional planning agencies, EOT planning, as well as MassHighway, can provide assistance in seasonal adjustments and in validating the assumptions regarding future traffic estimates.

3.4.2 Volume and Composition of Demand

The composition of transportation demand is an important element in the design of roadways. The designer should develop a realistic design scenario including the volume and mix of activity for all modes as described below.

3.4.2.1 Pedestrian Demands

Pedestrian counts should be completed to determine pedestrian flows and patterns. The pedestrian counts should include sidewalk demands, crossing demands, and storage demands at corners, traffic islands, and medians (total number of pedestrians waiting to cross the street).

In addition to relying on counts of pedestrians, the designer should also evaluate the project area to determine if there is latent demand for pedestrian accommodation due to an uncomfortable existing walking environment, missing links in the pedestrian network, or expected changes in development patterns. The likelihood of latent demand can be assessed by looking at surrounding land uses and their propensity to generate pedestrian activity. One can also look for conditions like pathways worn along the roadside to determine if pedestrian connectivity is underserved.

It may be important to complete pedestrian counts for other times of the day (beyond the typical morning and evening peak hours) and/or on weekends, depending on the project area. For example, if a project area is heavily influenced by a school, it is be important to observe pedestrian flows during morning and mid-afternoon periods. Public assembly facilities and transit stops or stations also merit special consideration because they can produce high volumes of pedestrians over short durations.

To determine the appropriate locations for pedestrian counts (including project area intersections), it is important to review current pedestrian routes between activity centers. Informal paths or crossing locations may warrant supplemental pedestrian observations during project planning.

3.4.2.2 Bicycle Demands

Bicycle demands should be counted during peak hours concurrent with vehicle turning movement counts. As with pedestrian activity, the designer should also evaluate the project area to determine if there is potential latent demand for bicycle accommodation. Additional consideration of bicycle demands during other periods of the day and/or on weekends may warrant supplemental counts, as discussed in the prior section. Methods for forecasting bicycle demand are still evolving through national transportation research. Common practices to gage future demands currently include sampling demand at similar settings or facilities and evaluating surrounding land uses for their propensity to generate bicycle activity.

3.4.2.3 Motor Vehicle Traffic Volumes

Daily, peak hour, and patterns of motor vehicle traffic are needed as input to the planning and design of roadway facilities. Some key definitions of traffic volume measures are listed below:

- **Average Annual Daily Traffic (AADT)** — The total yearly volume of automobiles and trucks divided by the number of days in the year.
- **Average Daily Traffic (ADT)** — The calculation of average traffic volumes in a time period greater than one day and less than one year. (ADT is often incorrectly used interchangeably with AADT.)
- **Peak-Hour Traffic (PH)** — The highest number of vehicles passing over a section of highway during 60 consecutive minutes. **T(PH)** is the PH for truck traffic only.
- **Peak-Hour Factor (PHF)** — A ratio of the total volume occurring during the peak hour to the maximum rate of flow during a given time period within the peak hour (typically is 15 minutes).
- **Design Hourly Volume (DHV)** — The one-hour volume in the design year selected for determining the highway design. (In many cases, designers look at the typical worst case weekday morning or evening peak hour or the 30th highest hour of the year to assess the geometric requirements of their design.)
- **K-factor (K)** — The K-factor is the percent of daily traffic that occurs during the peak hour.

Manual turning movement counts (TMCs), including heavy vehicle movements, at intersections, and automatic traffic recorder/vehicle classification counts (ATRs) counts along roadways are generally needed for planning and design of transportation projects and can be used to provide estimates of the values listed above. These counts should also include pedestrian and bicycle activity, where present. Pedestrian and bicycle counts should be performed in fair weather.

3.4.2.4 Design Volumes and Traffic Composition

The design hourly volume (DHV), or daily peak hours, will affect many design elements including the desired number of travel lanes, lane and shoulder width, and intersection layout. The design volume may also influence the level of service provided and the accommodation appropriate for pedestrians and bicyclists.

Daily traffic estimates are also useful in making design decisions related to the total user benefit of a proposed improvement. For example, the benefit of highway safety roadside improvements is directly related to the crash exposure (expressed in ADT) on the road.

Sometimes selection of the design hour entails judgment regarding the conversion of daily traffic to peak hour traffic volumes. Other times, when data from continuous traffic count stations are used, the design hourly volume is based on the peaking characteristics of the facility over an entire year. For rural areas, the DHV is typically based on the 30th or 50th highest hour. In urban areas, the DHV typically represents the 100th highest hour. In some circumstances, a lesser design hour is appropriate. These design hour volumes are usually selected since they capture operating conditions expected to occur on a regular basis and have been shown to have dependable statistical relationships to measured ADT on a roadway.

The choice of the design hour volume has a significant impact on the characteristics of a project. Designers should ensure that the design hour volume is selected such that the facility is well-matched to the traffic volumes it will carry on a regular basis and is not "over-designed." For example, accommodating a high volume expected to occur infrequently will result in a project that is costly and has significant adverse impacts. Likewise, accommodating a lower design volume that is frequently exceeded may result in significant congestion and not meet the level-of-service expectations for various users.

Large or heavy vehicles, such as trucks and buses, have different operating characteristics from passenger cars and bicycles and can affect traffic operations. Therefore, the number of trucks and buses expected to use a facility needs to be estimated for both the daily and peak hour conditions, in planning and design.

For highway capacity purposes, "heavy vehicles" are typically defined as all buses, single-unit trucks, and truck combinations other than light delivery trucks. (Light delivery trucks have two axles with four tires). In addition, the impact of transit operations (such as buses making stops along a roadway) must be considered in operational analysis of the roadway.

3.5 Measures of Effectiveness

Through the project development process and with public input, the designer should evaluate the project (and its alternatives, if applicable) using several measures of effectiveness. Suggested measures of effectiveness and analysis techniques for consideration during project planning and design are described below. Many of these measures of effectiveness are included in the transportation evaluation criteria (see Appendix 2-A-2) used by transportation agencies or MPOs for project evaluation and prioritization. The following sections discuss transportation or contextual measures of effectiveness.

3.5.1 Transportation Measures of Effectiveness

The following measures of effectiveness are related specifically to the transportation function of a facility and how the facility accommodates its users.

3.5.1.1 Condition of Facilities

State transportation policy places an emphasis on improving the condition of existing facilities. Projects on existing facilities should return a facility to a state of good repair by addressing existing structural, pavement surface, or other deficiencies. Techniques such as pavement testing and bridge inspections can be used to identify existing deficiencies.

3.5.1.2 Safety

The safety of transportation facilities is a primary concern in planning and design. Some projects are specifically proposed to address known safety problems; however, all projects should result in a facility that safely accommodates its users. Corridor safety audits and analysis of crash records can be useful for identifying existing safety hazards. Project design elements should be selected based on their historic safety performance and expected operating characteristics.

3.5.1.3 Mode Choice

Many projects result in improved accommodation for particular modes. The effectiveness of these projects can be measured by the degree to which they allow users to choose the mode best-suited to their trip purpose and personal values within the broader framework of the community, the region, and the environment. The traditional level-of-service measures described below can also be useful tools for evaluating the improvement in accommodation for each user group.

3.5.1.4 Network Connectivity

In many instances, projects are proposed to fill in missing links within a network so that connections by a particular mode are possible. The effectiveness of these projects can be evaluated based on the demand for the connection and how well the facility satisfies that demand using the traditional level-of-service measures described below.

3.5.1.5 Level of Service

To characterize the quality of movement through a transportation network, level-of-service (LOS) objectives are broadly used. Levels of service traditionally relate to the project's context and the demand characteristics of the facility. A single level of service for a transportation facility that reflects the quality of service provided to all users would be ideal; however, a multimodal LOS framework is still at the preliminary stage of development. Therefore, the designer should evaluate the LOS provided to each user group separately and should test design alternatives as necessary to meet the LOS goals for all users of the project. Several analytical methodologies and computer software packages are available to estimate LOS for facility users.

The overall objective of the design process is to provide the desired level of service for each roadway user, therefore achieving a safe and efficient facility for all users.

The designer should also carefully consider the level-of-service interactions between different user groups when designing a roadway. A good design will provide a reasonable level of service to all users, within the context of the project. As the design is refined, the resulting levels of service may differ from the goals selected at the beginning of the project development process.

Particular care must be taken when determining desired levels of service and how that level of service meets the needs of roadway users and helps meet the purpose and need of a project. In general, the desired level of service is determined through consensus of the affected community and the facility owner. Like many elements, the designer should ensure that project participants have a thorough understanding of the resulting level of service from the design so that expectations are met, or the project's purpose and need is refined.

3.5.2 Contextual Measures of Effectiveness

The following measures of effectiveness are associated with how the transportation facility relates to its context including its physical surroundings and community function.

- **Environmental and Community Resource Preservation** – Projects can impact environmental and community resources to different degrees. In many cases, highly-effective projects minimize their impacts to these resources. GIS and landscape analysis are helpful for considering the environmental and cultural resource implications of a project. Traditional planning and design tools such as plan, and cross-section analyses can also be helpful.
- **Aesthetics and Community Enhancement** – Aside from impacts to nearby resources, transportation projects are an important aesthetic element within their context. Well-designed facilities can complement their surroundings while poorly-designed projects can be a detriment to the visual experience of users and facility neighbors. Some community enhancement projects are proposed specifically to improve the aesthetics of a facility within a community. Visualization techniques including three-dimensional modeling and landscape analysis are helpful for considering the aesthetic implications of a project. Traditional planning and design tools such as plan, and cross-section analyses can also be helpful.
- **Economic Development** – Economic development is often an important consideration in project planning and design. Some projects are proposed specifically to spur economic development. In other cases, there is concern around the development implications of a project, such as sprawl. Economic impact and land use analyses can help in the evaluation of the economic development potential and land use implications of projects.
- **Environmental Justice** – Projects can serve or impact individual communities and demographic groups disproportionately. Demographic analyses based on race, income, and other factors can be helpful to understand and address these differential impacts. A project should provide a choice of modes based on the economic conditions and typical incomes of specific communities.
- **Impact Mitigation** – Some projects are proposed specifically to address environmental or community impacts of existing transportation facilities. For example, noise walls are often proposed to shield sensitive land uses from highway noise. Many of

the planning and visualization techniques described above are available to assess the effectiveness of these project elements. Additionally, environmental monitoring and modeling techniques for noise, vibration, and air quality can be helpful.

- **Accessibility** – The federal Americans with Disabilities Act requires that public entities such as the Commonwealth and municipalities provide accessible sidewalks and curb cut ramps. Access features are an important part of any MassHighway project that includes pedestrian facilities.

3.6 Speed

Speed is an important factor considered by travelers in selecting a transportation mode or route. Speed can also influence the physical characteristics of the transportation infrastructure. Many design elements such as horizontal and vertical curvature and superelevation are directly related to speed. Other features, such as lane and shoulder width, and the width of the roadside recovery clear zones for errant vehicles, can vary with, but are not a direct function of the design speed.

The objective in the planning and design of a roadway is to determine a speed that is appropriate for the context (as described in Section 3.2), results in a safe facility for all users, is consistent with the community's goals and objectives for the facility, and meets user's expectations. Once an appropriate speed is selected, the designer needs to tailor design elements to that speed.

Speed is defined as the distance traveled by an object in a certain period of time. Speed is commonly expressed in miles-per-hour or feet-per-second in the context of transportation planning and design. Several measures and characteristics of speed are important to understand when designing a roadway, as described in the following sections. These measures are most often used to describe motor vehicle operations, although they are also applicable to pedestrian and bicycle movement.

3.6.1 Speed Limits

Speed limits in Massachusetts are determined in accordance with Section 17 and Section 18 of Chapter 90 of the Massachusetts General Laws. Speed limits are established in one of two ways:

- Section 18 addresses how ***posted speed limits*** are established. The posted speed limit is generally determined based on an evaluation of the observed operating speeds according to the criteria in the *Manual on Uniform Traffic Control Devices*. (The current accepted practice is to establish the posted speed based on existing speed information. The posted speed should be the speed at which the majority of existing motorists are traveling at or below.)
- Section 17 defines ***"reasonable and proper" speed limits*** for roadways not otherwise posted. For these roadways, the speed limit is as follows:
  - 50 mph on a divided highway outside of a thickly settled district or a business district;
  - 40 mph on any other roadway outside of a thickly settled district or a business district; and
  - 30 mph within a thickly settled district or a business district.

According to Chapter 90 of the Massachusetts General Laws, a "thickly settled district" is an area in which houses or buildings are, on average, less than 200 feet apart for a distance of one-quarter mile or more.

3.6.2 Motor Vehicle Running Speed

Running speed characterizes the time necessary to travel a predetermined distance along a roadway (incorporating both time while moving and stopped delays). Measures of running speed can vary substantially by day of week and time of day based on traffic conditions. Average running speed is usually used to characterize conditions on a roadway for analytical (planning, route selection, air quality analyses, etc.) purposes rather than for the design of roadway geometrics.

3.6.3 Motor Vehicle Operating Speed

Operating speed is the measured speed at which drivers are observed operating their vehicles in fair weather during off-peak hours. Operating speed is measured at discrete points along a roadway. Operating speeds are usually reported using percentile speeds with the 50^{th} percentile (average) and 85th percentile (the speed at which 85 percent of vehicles are traveling at or below) speeds are often used to characterize the operating speed on a roadway.

The roadway's features such as curves and topography, width, access to adjacent properties, presence of pedestrians and bicyclists, parking, traffic control devices, lighting, etc., affect the operating speed. During peak periods, when traffic congestion or intersection operations are controlling movement along a corridor, observed operating speeds may be substantially lower than the operating speed measured during off-peak conditions when the roadway's design and context are controlling speed. Numerous studies have indicated that drivers will not significantly alter what they consider to be a safe operating speed, regardless of the posted speed limit unless there is constant heavy enforcement.

3.6.4 Target Speed for Motor Vehicles

The ***target speed*** is the desired operating speed along a roadway. The appropriate target speed is determined early in the project development process, and should consider:

- The context of the roadway including area type, roadway type, and access control;
- The volume, mix, and safety of facility users; and
- The anticipated driver characteristics and familiarity with the route.

The designer should balance the benefits of high speeds for long-distance, regional motor vehicle travel with environmental, community, right of way, and cost constraints. When high speeds are selected, the designer should also include design elements to maintain the safety of pedestrians and bicyclists, as described in Section 3.6.7.

3.6.5 Selecting Motor Vehicles Design Speed

Design speed is the selected speed used to determine various geometric features of the roadway. The design speed should be a logical one with respect to the target speed and existing operating speed. When selecting a design speed, understanding the existing operating speed and target speed addresses: (1) the need to meet the expectations of drivers based on the roadway environment, and (2) the ways in which the setting influences the desired speed.

It is important to understand the inter-relationship between speed and roadway geometry. Selection of a design speed influences the physical geometrics of the roadway. Similarly, the physical geometrics of the roadway are important determinants of the operating speeds that will result on the facility.

Typically, the higher the functional classification, the higher the design speed. Exhibit 3-7 provides recommended ranges of values; however, where significant constraints are encountered, other appropriate values may be employed. The relatively wide range of design speeds recognizes the range of roadway types, context, and topography. The provision of a range in design speeds, combined with general guidance on selection of a design speed as noted above, represents perhaps the greatest flexibility afforded the designer. Designers should exercise judgment in the selection of an appropriate design speed for the particular circumstances and conditions. In general, an appropriate design speed should be within approximately 5 mph of travel speeds.

When determining the appropriate design speed the designer should also consider the volumes and composition of the expected non-vehicular and vehicular traffic, the anticipated driver characteristics, and driver familiarity with the route. The designer should consider expected operations throughout the day, including both peak and non-peak hours. Indeed, non-peak traffic flow will generally control the selection of a reasonable design speed. The design speed may vary for any given route as it traverses rural, suburban, and urban areas.

Once these factors have been evaluated and an appropriate design speed determined, the geometric elements should be designed consistently to that level. The designer should document the factors leading to the selection of an appropriate design speed. This documentation is particularly important for selected design speeds below the existing posted speed limit, below the "reasonable and proper" speed for the type of roadway and area as discussed in Section 3.6.1, or below the measured operating speed. Where it is not possible to meet the selected design speed for one location or design element along a corridor, a design exception and appropriate warning signage may be justified, as discussed later in this section.

Exhibit 3-7
Design Speed Ranges (Miles per Hour)

	Roadway Type					
		Arterials		Collectors		Local
Area Type	Freeway	Major*	Minor	Major	Minor	Roads
Rural Natural	50 to 75	40 to 60*	35 to 60	30 to 60	30 to 55	20 to 45
Rural Developed	50 to 75	40 to 60*	35 to 60	30 to 60	30 to 55	20 to 45
Rural Village	N/A	30 to 45	30 to 40	25 to 40	25 to 35	20 to 35
Suburban Low Intensity Development	50 to 75	30 to 60*	30 to 55	30 to 55	30 to 55	20 to 45
Suburban High Intensity Development	50 to 75	30 to 50*	30 to 50	25 to 50	25 to 40	20 to 40
Suburban Town Center	N/A	25 to 40	25 to 40	25 to 40	25 to 35	20 to 35
Urban	50 to 75	25 to 50	25 to 40	25 to 40	25 to 35	20 to 35

N/A Not Applicable
* A higher design speed may be appropriate for arterials with full access control
Source: Adapted from A Policy on Geometric Design of Highways and Streets, AASHTO, 2004 – Chapter 3 Elements of Design

Higher design speeds impose greater challenges and constraints on designers. Designers faced with difficult or constrained conditions may consider selecting a lower design speed for an element or portion of the highway. This practice can cause problems in that a large number of drivers may not “behave” as the designer desires or intends them to. Designs based on artificially low speeds can result in inappropriate geometric features that violate driver expectations and degrade the safety of the highway. The emphasis should be on the consistency of design so as not to surprise the motorist with unexpected features. Therefore, the design speed should only be based on the speed limit if the speed limit is consistent with existing operating speeds or physical constraints of the built environment.

Designers should not propose an alternative design speed for a highway or segment of a project as a design exception. A serious fundamental problem with accepting or allowing a design exception for design speed is based on its importance relative to all features of the highway. A reduction in the design speed may be unlikely to affect overall operating speeds. It will potentially result in the unnecessary reduction of all of the speed-related design criteria rather than just the one or two features that led to the need for the exception. The acceptable alternative approach to a design speed exception is to evaluate each geometric feature individually, addressing exceptions for each feature within the context of the appropriate design speed.

Occasionally, projects retain geometric elements, such as tight curves, superelevation, or restricted sight distances that are designed for a speed lower than the design speed for the corridor. This may be due to adjacent land use, or to environmental or historic constraints. In these cases, the designer should recommend a posted speed consistent with the geometric features. Where it is desirable to maintain a higher consistent speed throughout a corridor, the designer should install appropriate cautionary signing at locations with design elements that do not meet the criteria for the posted speed.

3.6.6 Design Speed and Traffic Calming

The term traffic-calming refers to a variety of physical measures to reduce vehicular speeds primarily in residential neighborhoods. The lowering of operating speeds is often the appropriate solution to addressing safety problems. Such problems typically involve vehicle conflicts with pedestrians, bicyclists, and school children.

Research has shown that measurable reductions in operating speeds are possible through traffic-calming. A local road or street, and in some instances other roadways that function as a local road or street, may have an existing operating speed far in excess of the speed limit or the target speed. In these cases it may be acceptable, and consistent with good engineering practice, to develop a design that will lower the operating speed.

Generally, the design speed selected for traffic calming elements should be consistent with the target speed for the corridor as a whole. The traffic calming elements should not result in operating speeds substantially lower than the target speed at certain points along the corridor and higher speeds elsewhere. Selection of a reasonable design speed for traffic calming elements, selection of type of elements, and the spacing of traffic calming elements can help achieve the desired uniform reduction in operating speed along a roadway.

Great care must be exercised to ensure that the proposed design will actually reduce the operating speeds to levels consistent with the design. The burden is on the individual designer of a traffic-calming feature to document a reasonable expectation that the proposed measures will reduce the operating speed. Once traffic calming has been implemented, monitoring of the performance of the project should be undertaken to assure that speeds have indeed been reduced, and to provide valuable lessons for future traffic-calming projects. Chapter 16 provides more detail on tools and techniques for traffic calming.

3.6.7 High Speeds and Safety for Pedestrian and Bicyclists

In every case, the designer should seek to maintain or improve safety for all user groups. Safety is often measured both in terms of the likelihood of a crash and the expected severity of a crash. As motor vehicle speeds increase, the severity of crashes between motor vehicles and bicycles or pedestrians increases. In the high speed environment, safety for pedestrians and bicyclists can be enhanced by reducing the exposure of bicyclists and pedestrians to motor vehicle traffic, thereby reducing the likelihood of crashes.

Along roadway segments, greater separation of motor vehicle and non-motorized users can be provided by including shoulders, bicycle lanes, or buffered sidewalks. These design elements are explored in more detail in Chapter 5. At crossings, the exposure of bicyclists and pedestrians to high speed motor vehicle traffic can be mitigated through signal-controlled crossings, grade separation, and installation of crossing islands or medians. These measures are explored in Chapters 6 and 16.

3.6.8 Selecting Bicycle Design Speed

Bicycle design speed is also an important consideration. In most cases, the design speed for bicycles is no more than 20 mph; thus, for on-road travel, the design speed chosen for motor vehicles appropriately accommodates bicycles. Shared use paths should be designed for a selected speed that is at least as high as the preferred speed of the faster bicyclists. Current practice suggests a design speed of 20 mph for bicyclists. (Although bicyclists can travel faster than this, to do so would be inappropriate for this type of shared use setting.) Design and traffic controls can be used to deter excessive speed and encourage faster bicyclists to use the roadway system; however, lower design speeds should not be selected to artificially lower user speeds. When a downgrade exceeds four percent, or where strong prevailing tailwinds exist, a design speed of 30 mph is advisable. Downgrades in excess of six percent should be avoided on shared use paths.

On unpaved paths, where bicyclists tend to ride more slowly, lower design speeds of 15 mph for most conditions, and 20 mph where there are grades, are appropriate.

3.6.9 Selecting Pedestrian Design Speed

Much like other roadway users, the speed at which people walk varies considerably; however, walking speed usually does not have a substantial influence on the geometric design of roadways. A critical exception to this is the pedestrian's influence on the design of intersections and crosswalks, and the timing of traffic signals. The choice of walking speed for intersections and traffic signal design is discussed in the *Manual on Uniform Traffic Control Devices (MUTCD)* and is further discussed in Chapter 6.

3.7 Sight Distance

Sight distance is the length of roadway ahead that is visible to the roadway user. In most cases, specific sight distance measures apply to motor vehicles and bicyclists. The four following aspects are commonly discussed for motor vehicle sight distance:

- Stopping sight distance,
- Passing sight distance,
- Decision sight distance, and
- Intersection sight distance.

All of these sight distances are related to the design speed of the roadway. The designer should refer to AASHTO's *A Policy on Geometric Design of Highways and Streets* for detailed information for the use and calculation of sight distances.

3.7.1 Stopping Sight Distance

The provision of adequate *stopping sight distance* (SSD) is a critical sight distance consideration for design and is described in more detail below.

3.7.1.1 Motor Vehicle Stopping Sight Distance

Stopping sight distance is the distance necessary for a vehicle traveling at the design speed to stop before reaching a stationary object in its path. The sight distance at every point along a roadway should be at least the stopping sight distance. Exhibit 3-8 provides stopping sight distances for a range of design speeds and grades.

Exhibit 3-8
Motor Vehicle Stopping Sight Distances

	Stopping Sight Distance (ft) by Percent Grade (%)						
		Downgrade			Upgrade		
Design Speed	0	3	6	9	3	6	9
20	115	116	120	126	109	107	104
25	155	158	165	173	147	143	140
30	200	205	215	227	200	184	179
35	250	257	271	287	237	229	222
40	305	315	333	354	289	278	269
45	360	378	400	427	344	331	320
50	425	446	474	507	405	388	375
55	495	520	553	593	469	450	433
60	570	598	638	686	538	515	495
65	645	682	728	785	612	584	561
70	730	771	825	891	690	658	631
75	820	866	927	1003	772	736	704

Source: A Policy on Geometric Design of Streets and Highways, AASHTO, Washington DC, 2004. Chapter 3 Elements of Design

3.7.1.2 Bicycle Stopping Sight Distance

For on-road travel, the stopping sight distance for motor vehicles appropriately accommodates bicycles. However, bicycle stopping sight distance is an important consideration in the design of off-road facilities such as shared use paths. Detailed information on the design of these facilities, including stopping sight distance, is provided in Chapter 11.

3.7.1.3 Sight Distance for Pedestrians

There is not a parallel "stopping sight distance" consideration for pedestrians since they usually travel at lower speeds and can stop within a few feet. However, the designer must consider the importance of pedestrians' ability to view and react to potential conflicts. The designer should provide adequate sight lines at street crossings, around corners, and at other locations where pedestrians interface with other users. For example, at street crossing locations, pedestrians should be able to see a sufficient portion of the traffic stream to judge the suitability of gaps for crossing the street. More detailed information regarding the design of street crossings is presented in Chapter 6.

3.7.2 Passing Sight Distance

For two-lane highways, passing maneuvers in which faster vehicles move ahead of slower vehicles must be accomplished on lanes regularly used by opposing traffic. If passing is to be accomplished safely, **passing sight distance** is necessary to allow the passing driver to see a sufficient distance ahead, clear of traffic, to complete the passing maneuver without cutting off the passed vehicle and before meeting an opposing vehicle that appears during the maneuver. The AASHTO's *A Policy on Geometric Design of Highways and Streets* includes detailed information for the use and calculation of passing sight distances.

3.7.3 Decision Sight Distance

Decision sight distance adds a dimension of time to stopping sight distance to allow a driver to detect and react to an unexpected condition along a roadway. Decision sight distance is suggested when there is evidence that it would be prudent to provide longer sight distance, such as when complex decisions are needed or when information is difficult to perceive. It is the distance needed for a driver to detect an unexpected or otherwise difficult-to-perceive information source or condition in a roadway environment that may be visually cluttered, recognize the condition or its potential threat, select an appropriate speed and path, and initiate and complete the maneuver safely and efficiently. Exhibit 3-9 provides decision sight distances for a range of design speeds.

Exhibit 3-9
Decision Sight Distances

	Decision Sight Distance (ft)				
	Avoidance Maneuver				
Design Speed	A	B	C	D	E
30	220	490	450	535	620
35	275	590	525	625	720
40	330	690	600	715	825
45	395	800	675	800	930
50	465	910	750	890	1030
55	535	1030	865	980	1135
60	610	1150	990	1125	1280
65	695	1275	1050	1220	1365
70	780	1410	1105	1275	1445
75	875	1545	1180	1365	1545

Avoidance Maneuver A: Stop on rural road: time (t) = 3.0 sec
Avoidance Maneuver B: Stop on urban road: time (t) = 9.1 sec
Avoidance Maneuver C: Speed/path/direction change on rural road: time (t) varies between 10.2 and 11.2 sec
Avoidance Maneuver D: Speed/path/direction change on suburban road: time (t) varies between 12.1 and 12.9 sec
Avoidance Maneuver E: Speed/path/direction change on urban road: t varies between 14.0 and 14.5 sec
Source: *A Policy on Geometric Design of Streets and Highways*, AASHTO, Washington DC, 2004. Chapter 3 Elements of Design

3.7.4 Intersection Sight Distance

Sight distance is provided at intersections to allow drivers to perceive the presence of potentially conflicting vehicles. This should occur in sufficient time for a motorist to stop or adjust their speed, as appropriate, to avoid colliding in the intersection. Sight distance also allows drivers of stopped vehicles with a sufficient view of the intersecting roadway to decide when to enter or cross the intersecting roadway. If the available sight distance for an entering or crossing vehicles is at least equal to the appropriate stopping sight distance for the major road, then drivers have sufficient sight distance to anticipate or avoid collisions. However, in some cases, this may require a major-road vehicle to slow or stop to accommodate the maneuver by a minor-road vehicle.

To enhance traffic operations, intersection sight distances that exceed stopping sight distances are desirable. The *Highway Capacity Manual* provides guidance on gap acceptance for vehicles departing from minor approaches which can be used to calculate one measure of intersection sight distance. Additionally, AASHTO's *A Policy on the Geometric Design of Highways and Streets* provides procedures to determine desirable sight distances at intersections for various cases are described below and include:

- Case A – Intersections with no control on any approach
- Case B – Intersections with stop control on the minor street
- Case C – Intersections with yield control on the minor street
- Case D – Intersections with traffic signal control
- Case E – Intersections with all-way stop sign control
- Case F – Left turns from the major road

3.7.4.1 Intersection Sight Triangle

Clear sight triangles are those areas along the intersection approach legs that should be clear of obstructions that can block road user's view of oncoming traffic. The dimensions of the triangle are based on the design speed of the intersecting roadways and the type of traffic control used at the intersection, grades on the roadways, and the roadway width. Two types of clear sight triangles are used at each intersection: approach sight triangles and departure sight triangles. Approach sight triangles are applicable for when the minor road driver is in motion while departure sight triangles apply when the minor road vehicle is accelerating from a stop position.

3.7.4.2 Identification of Sight Obstructions within Sight Triangles

Within a sight triangle there are many obstructions that can obscure the driver's view of oncoming vehicles. These may include buildings, vegetation, longitudinal barriers or retaining walls, side slopes, etc. The horizontal and vertical alignment of the intersecting roadways and any visual obstructions should be considered. For design purposes, the driver's eye is assumed to be 3.5 feet above the roadway. The object that is used for design approximates the height of an automobile and is assumed to be 3.5 feet above the roadway.

Where the sight distance value used in design is based on a single-unit or combination truck as the design vehicle, it is also appropriate to use the eye height of a truck driver in checking sight obstructions. The recommended value of a truck driver's eye height is 7.6 feet above the roadway surface.

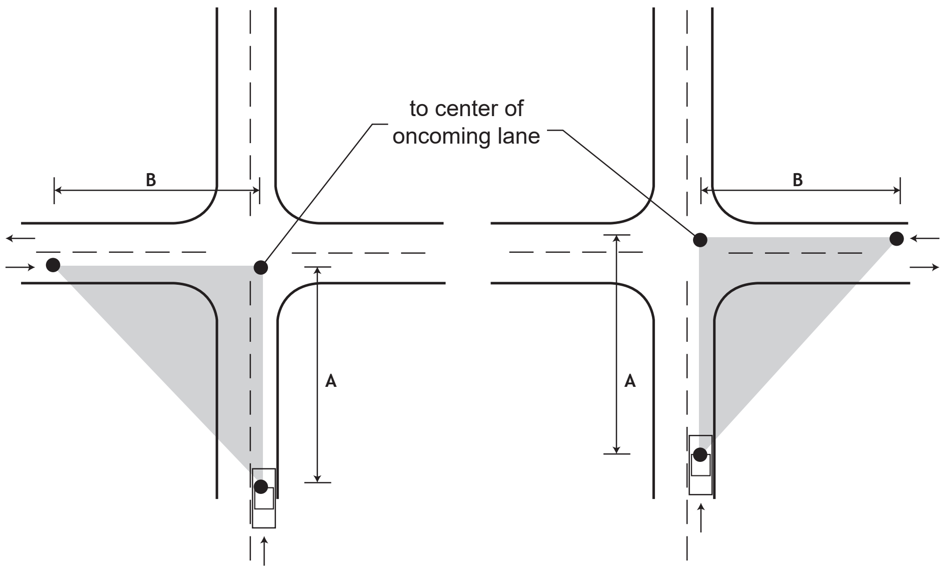
3.7.4.3 Case A - Intersections with No Control on Any Approach

Where intersection movements are not controlled by a traffic control device (i.e., signal, STOP or YIELD sign), drivers approaching the intersection from any direction must be able to see potentially conflicting vehicles in sufficient time to stop before reaching the intersection.

The intersection sight triangle, as illustrated in Exhibit 3-10 is formed by the sight distance along the minor street (indicated as Distance A) and the intersection sight distance along the major street (indicated as Distance B). The corresponding distances, arrayed by design speed are based on the distance traveled as the approaching driver perceives and reacts to the presence of a possibly conflicting vehicle, and brings their own vehicle to a stop. For example, based on the values Exhibit 3-10, an intersection of a major street with a design speed of 40 miles per hour with a minor street with a design speed of 25 miles per hour would require a sight distance defined by an intersection sight distance of 195 feet (major street) and 115 feet (minor street). If the minor street was on a 6 percent grade then the intersection sight distance would be 127 feet (115 feet multiplied by the 1.1 grade adjustment factor) for the downgrade and 104 feet for the upgrade.

Exhibit 3-10
Sight Triangle Case A

Approach Sight Triangles



Sight Triangle Legs: Case A – No Traffic Control

Design Speed (mph)	Length of Legs, both major and minor streets, A and B (feet)
15	70
20	90
25	115
30	140
35	165
40	195
45	220
50	245
55	285
60	325
65	365
70	405
75	445

For approach grades greater than 3 percent, apply factors below.

Approach Grade Adjustments to Sight Distance

Design Speed (mph)	Approach Grade						
	-6	-5	-4	-3 to +3	+4	+5	+6
15-20	1.1	1.0	1.0	1.0	1.0	1.0	1.0
25-30	1.1	1.1	1.0	1.0	1.0	1.0	0.9
30-40	1.1	1.1	1.1	1.0	1.0	0.9	0.9
40-45	1.1	1.1	1.1	1.0	0.9	0.9	0.9
50+	1.2	1.1	1.1	1.0	0.9	0.9	0.9

Source: A Policy on Geometric Design of Streets and Highways, AASHTO, Washington DC, 2004. Chapter 3 Elements of Design

3.7.4.4 Case B – Stop Control on Minor Street

At an intersection with stop control on the minor street, as illustrated in Exhibit 3-11, the stopped minor-street driver must be able to see motor vehicles and bicycles approaching on the major street from either direction, at sufficient distance to allow crossing or turning maneuvers from the minor street. The leg of the intersection sight triangle on the minor street (Dimension A) is the distance between the driver's eye and front of vehicle (8 feet) plus distance from front of vehicle to edge of pavement (6.5 feet, prefer 10 feet) plus the distance from edge of pavement to middle of lane of interest (e.g., 6 feet for a right turn, 18 feet for a left turn on an undivided 2-lane highway, etc.) The major street leg of the triangle is the intersection sight distance along the major road (Dimension B).

Left Turns from Stop Controlled Minor Street

For motor vehicles making a left turn, the intersection sight distance along the major street (Dimension B) is given for an intersection of 2-lane streets in Exhibit 3-11. For example, at a design speed of 35 miles per hour on the major street, and with the minor street driver's eye at 14.5 feet from the edge of the major street travel lane, the intersection sight distance (Dimension B) is 390 feet. It is recommended that this intersection sight distance (Dimension B) be applied along the major street in both directions from the intersection.

Right Turns from Stop Controlled Minor Street

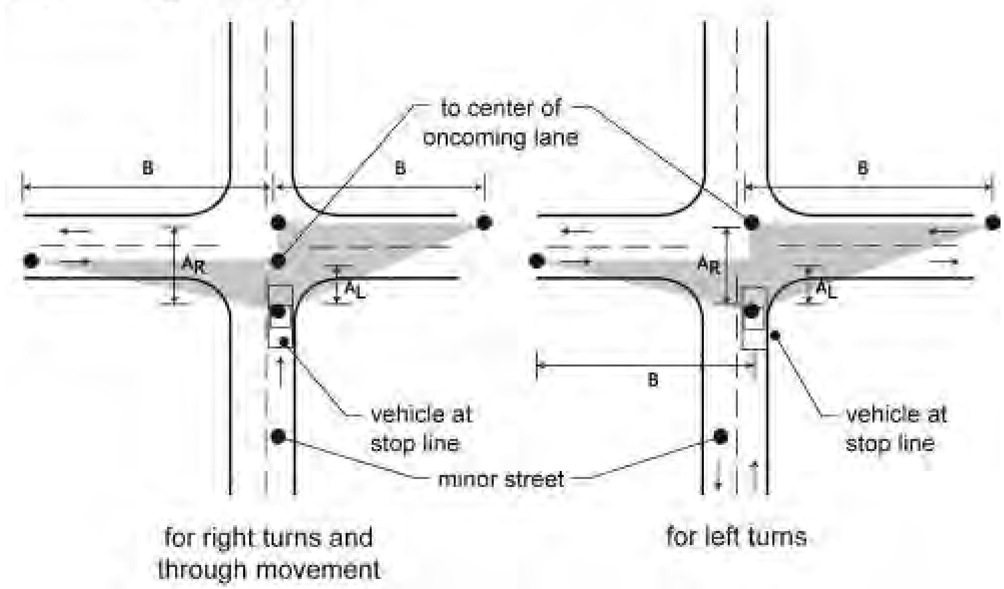
For motor vehicles making a right turn from the minor street, the intersection sight distances are given in Exhibit 3-11.

Through Movement from Stop Controlled Minor Street

For motor vehicles crossing the major street from a stop-controlled minor street, the intersection sight distances are given in Exhibit 3-11.

Exhibit 3-11
Sight Triangle Case B

Departure Sight Triangles



Sight Triangle Legs: Case B – Stop Control on Cross Street

Major Street Design Speed (mph)	Length of Sight Triangle Legs (feet)			
	Minor Street for Vehicles Approaching From Right (A_R, feet)	Minor Street for Vehicles Approaching From Left (A_L, feet)	Major Street For Left Turns (B, feet)	Major Street for Right Turns or Through (B, feet)
15	32.5	20.5	170	145
20	32.5	20.5	225	195
25	32.5	20.5	280	240
30	32.5	20.5	335	290
35	32.5	20.5	390	335
40	32.5	20.5	445	385
45	32.5	20.5	500	430
50	32.5	20.5	555	480
55	32.5	20.5	610	530
60	32.5	20.5	665	575
65	32.5	20.5	720	625
70	32.5	20.5	775	670
75	32.5	20.5	830	720

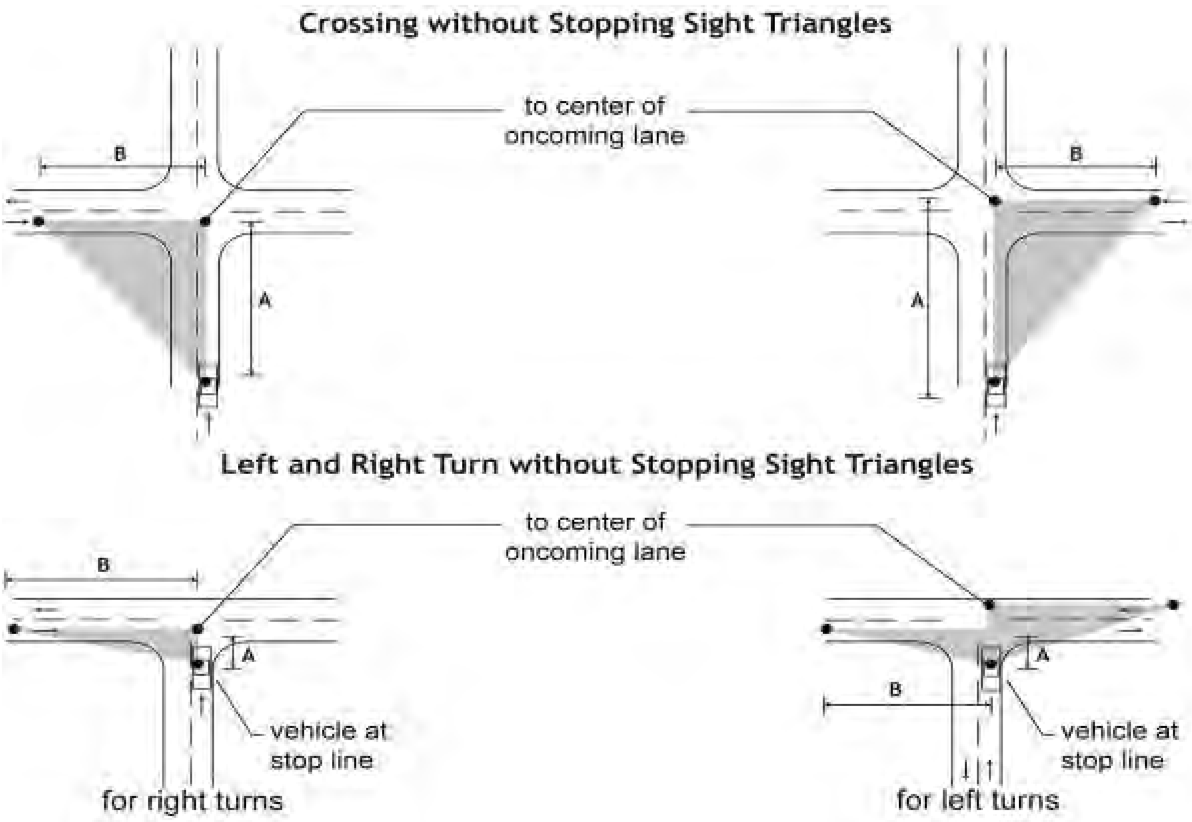
Sight triangle legs shown are for passenger car crossing or turning into a two-lane street, with grades (all approaches) 3 percent or less. For other grades and for other major street widths, recalculate using AASHTO *Green Book* formulas.

Source: *A Policy on Geometric Design of Streets and Highways*, AASHTO, Washington DC, 2004. Chapter 3 Elements of Design

3.7.4.5 Case C - Yield Control

At intersections with yield control on the minor street, the minor street driver are permitted to enter or cross the major road without stopping, if there are no potentially conflicting vehicles. Yield-controlled approaches generally need greater sight distance than stop-controlled approaches. For four-leg intersections with yield control on the minor road, two separate pairs of approach sight triangles should be provided – one set to accommodate crossing the major road and the other to accommodate left and right turns. Both sets of sight triangles should be checked for potential sight obstructions. For three-leg intersections with yield control on the minor road, only the sight triangles to accommodate left and right turns need to be checked. The major and minor street legs of the sight triangle are shown in Exhibit 3-12.

Exhibit 3-12
Sight Triangle Case C



Sight Triangle, Case C: Yield Control on Cross Street

Design Speed (Major Street, mph)	Crossing Without Stopping Sight Triangle Legs[a] (feet)		Left and Right Turn Without Stopping Sight Triangle Legs[a] (feet)	
	Minor Street (A, feet)	Major Street[b] (B, feet)	Minor Street (A, feet)	Major Street (B, feet)
15	75	145	82	180
20	100	195	82	240
25	130	240	82	295
30	160	290	82	355
35	195	335	82	415
40	235	385	82	475
45	275	430	82	530
50	320	480	82	590
55	370	530	82	650
60	420	575	82	710
65	470	625	82	765
70	530	670	82	825
75	590	720	82	885

a Sight triangle legs shown are for passenger car crossing or turning into a two-lane street, with grades (all approaches) 3 percent or less. For other grades and major street widths, recalculate length of legs from AASHTO *Green Book* formulas.

b Lengths are for design speeds of 20 to 50 mph on minor road. For other minor road design speeds, recalculate length of legs from AASHTO *Green Book* formulas.

Source: A Policy on Geometric Design of Streets and Highways, AASHTO, Washington DC, 2004. Chapter 3 Elements of Design

Case C - Yield Control at Roundabouts

At roundabouts, the location needing evaluation of intersection sight distance is at the entries. The entry sight distance evaluation uses two conflicting approaches: entering stream (i.e., those vehicles entering from the immediate upstream entry) and circulating stream (i.e., those vehicles on the circular roadway). The length of the conflicting leg is shown in Exhibit 3-13 for a range of conflicting approach speeds. The sight distance legs for roundabouts follow the curvature of the roadway, therefore distances should be measured not as straight lines but as distances along the vehicular path. The FHWA *Roundabout Guide* recommends limiting the length of the approach leg of the sight triangle to 49 feet.

Exhibit 3-13
Roundabout Intersection Sight Distance: Computed Length of Conflicting Leg

Conflicting Approach Speed (mph)	Computed Distance (ft)
10	95.4
15	143.0
20	190.1
25	238.6
30	286.3

Source: Roundabouts: An Informational Guide, FHWA, Washington DC, 2000.

3.7.4.6 Case D - Intersections with Traffic Signal Control

At signalized intersections, the first vehicle stopped on one approach should be visible to the driver of the first vehicle stopped on each of the other approaches. Where right turns on red are permitted, the sight distance triangle for a right turn from stop applies (Case B). Left-turning motor vehicles and bicycles should have sufficient sight distance, into the opposing roadway, to be able to select gaps sufficient to make their left-turn movement (Case B). Where this distance is insufficient, most likely due to vertical or horizontal curvature, the remedies can include confining the left turn to a protected signal phase, or prohibiting the left turn.

3.7.4.7 Case E - Intersections with All-Way Stop Control

At intersections with all-way stop control, the first stopped vehicle on one approach should be visible to the drivers of the first stopped vehicles on each of the other approaches. For this reason, all-way stop control may be a preferable option at intersections where, due to topographic or man-made constraints, sight distances for other types of control cannot be obtained.

3.7.4.8 Case F – Left Turns from the Major Road

Drivers turning left across oncoming traffic of a major roadway require sufficient sight distance to determine when there is time to complete the maneuver. If stopping sight distance has been provided continuously along the major road and if sight distance for Case B (stop control) or Case C (yield control) has been provided for each minor-road approach, sight distance will generally be adequate for left turns from the major roads. Therefore, no separate check of sight distance for Case F may be needed. However, at three-leg intersections or driveways located on or near a horizontal curve or crest vertical curve on the major road, the availability of adequate sight distance for left turns from the major road should be checked. In addition, the availability of sight distance from divided highways should be checked because of the possibility of sight obstructions in the median. Intersection sight distances for Case F is listed in Exhibit 3-14.

Exhibit 3-14
Case F Intersection Sight Distance

Design Speed (mph)	Sight Triangle Leg (feet)
15	125
20	165
25	205
30	245
35	285
40	325
45	365
50	405
55	445
60	490
65	530
70	570
75	610
80	650

Intersection sight distances shown are for passenger car making a left turn from an undivided highway. For other conditions and design vehicles, recalculate length of legs using AASHTO *Green Book* formulas.

Source: *A Policy on Geometric Design of Streets and Hi*ghways, AASHTO, Washington DC, 2004. Chapter 3 Elements of Design

3.8 For Further Information:

- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004.
- *Guide for the Development of Bicycle Facilities*, AASHTO, 1999.
- *Guide for the Planning and Design of Pedestrian Facilities,* AASHTO, 2004
- *A Guide to Achieving Flexibility in Highway Design*, AASHTO, 2004.
- *Highway Capacity Manual*, Transportation Research Board, 2000.
- *Manual on Uniform Traffic Control Devices*, Federal Highway Administration, 2003.
- *Real-Time Human Perceptions: Toward a Bicycle Level of Service,* Landis, Bruce, Transportation Research Record 1578, Washington DC, Transportation Research Board, 1997.
- *Development of the Bicycle Compatibility Index: A Level of Service Concept, Final Report,* FHWA-RD-98-072, 1998.
- *Development of the Bicycle Compatibility Index: A Level of Service Concept, Implementation Manual,* FHWA-RD-98-095, 1998.
- *Transit Capacity and Quality of Service Manual*, Transportation Research Board, Transit Cooperative Research Program. Report 100, 2nd Edition, 2003.
- *TRB Special Report 254 Managing Speed: Review of Current Practices for Setting and Enforcing Speed Limits*, Transportation Research Board, Washington DC, 1998.
- *Flexibility in Highway Design*, Federal Highway Administration, Washington, DC.
- *A Guide to Best Practices in Context Sensitive Solutions*, Transportation Research Board, National Cooperative Highway Research Program. Report 480. Washington DC, 2002.
- *ADAAG Manual: A Guide to the Americans with Disabilities Act Accessibility Guidelines,* The U.S. Architectural and Transportation Barriers Compliance Board (The Access Board). Washington, DC, 1998.
- *Standards and Anthropometry for Wheeled Mobility,* The U.S. Architectural and Transportation Barriers Compliance Board (The Access Board). Washington, DC, 2005.