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16. Abstract

Intersections are an important part of a highway facility because the efficiency, safety, speed, cost of operation, and capacity of the facility depend on their design to a great extent. Each intersection involves through- or cross-traffic movements on one or more of the highways and may involve turning movements between these highways. Such movements may be facilitated by various geometric designs and traffic controls, depending on the type of intersection. The main objective of intersection design is to facilitate the convenience, comfort, and safety of people traversing the intersection while enhancing the efficient movement of motor vehicles, buses, trucks, bicycles, and pedestrians. In order to design intersections that are both functional and effective, designers need current information regarding intersection design that is easily accessible and in a user-friendly format. The prime objective of the Texas Department of Transportation Project 0-4365 is to produce this reference document, the *Urban Intersection Design Guide*, to provide this information.

This document is presented in two volumes:

- Volume 1 – Guidelines and
- Volume 2 – Applications.

This project is designed to provide TxDOT and other interested parties with useful and practical information on operations and design for intersections.

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URBAN INTERSECTION DESIGN GUIDE: VOLUME 1 – GUIDELINES

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation. The engineer in charge was Kay Fitzpatrick, P.E. (TX-86762).

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Overview

The American Association of State Highway and Transportation Officials (AASHTO), publishes information on geometric design in the following documents:

- *A Policy on Geometric Design of Highways and Streets*[1] (commonly known as the *Green Book*),
- The *Guide for the Development of Bicycle Facilities*[2] (commonly known as the *Bike Guide*), and
- The *Guide for the Planning, Design, and Operation of Pedestrian Facilities*[3] (commonly known as the *Pedestrian Guide*).

The *Green Book* defines an intersection as the general area where two or more highways join or cross, including the roadway and roadside facilities for traffic movements within the area. Intersections are an important part of a highway facility because the efficiency, safety, speed, cost of operation, and capacity of the facility depend on their design to a great extent. Each intersection involves through- or cross-traffic movements on one or more of the highways and may involve turning movements between these highways. Traffic may include vehicles, pedestrians, and bicyclists. Such movements may be facilitated by various geometric design and traffic control, depending on the type of intersection.

Design Considerations and Objectives

The main objectives of intersection design are to facilitate the safe and efficient movements of motor vehicles, buses, trucks, bicycles, and pedestrians. Intersection design should be fitted closely to the operating characteristics of its users. Basic elements to consider in intersection design are discussed in the *AASHTO* documents and include the following:

- Human Factors:
  - driving habits,
  - ability of drivers, pedestrians, and bicyclists to make decisions,
  - driver, pedestrian, and bicyclist expectancy,
  - decision and reaction time of various users,
  - conformance to natural paths of movement,
  - pedestrian use, ability, and habits, and
  - bicyclist use, ability, and habits;
- Traffic Considerations:
  - design and actual capacities,
  - design-hour turning movements,
  - size and operating characteristics of vehicles,

- variety of movements (diverging, merging, weaving, turning, and crossing),
- vehicle speeds,
- crossing distance,
- signal complexity,
- transit involvement,
- light rail operations,
- freight rail operations,
- crash experience,
- bicycle movements, and
- pedestrian movements;

♦ Physical Elements:

- character and use of abutting property,
- vertical alignments at the intersection,
- sight distance,
- angle of the intersection,
- conflict area,
- speed-change lanes,
- geometric design features,
- traffic control devices,
- lighting equipment,
- utilities,
- drainage features,
- safety features,
- environmental factors,
- pedestrian facilities (sidewalk, curb ramps, crosswalks), and
- medians and islands;

♦ Economic Factors:

- cost of improvements,
- effects of controlling or limiting rights of way (ROWs) on abutting residential or commercial properties where channelization restricts or prohibits vehicular movements,
- energy consumption,
- vehicular delay cost,
- pedestrian delay,
- air quality cost,
- functional intersection area,

- right of way available,
- number of approach lanes, and
- number of legs.

The Intersection Development Process

The development of intersections typically follows a path that includes planning, design, construction, and operations. The development process also is influenced by feedback from other projects and research findings. Figure 1-1 illustrates the continuous, integrated series of steps that form the intersection development process. The process must be able to reflect changes in goals and objectives, travel patterns, safety emphasis, geometric restrictions, and capacity needs. Recent emphasis in society is on the better accommodation of pedestrians and bicycles in the transportation network. All phases of the roadway development process must be able to integrate the changes needed to reflect this evolving society goal. Additionally, laws require design and construction that are usable by pedestrians who have disabilities. Improvements (curb ramps, limited grade and slope, etc.) important to those with mobility impairments are well known. However, treatments that are effective in providing information to pedestrians with vision impairment are less understood.

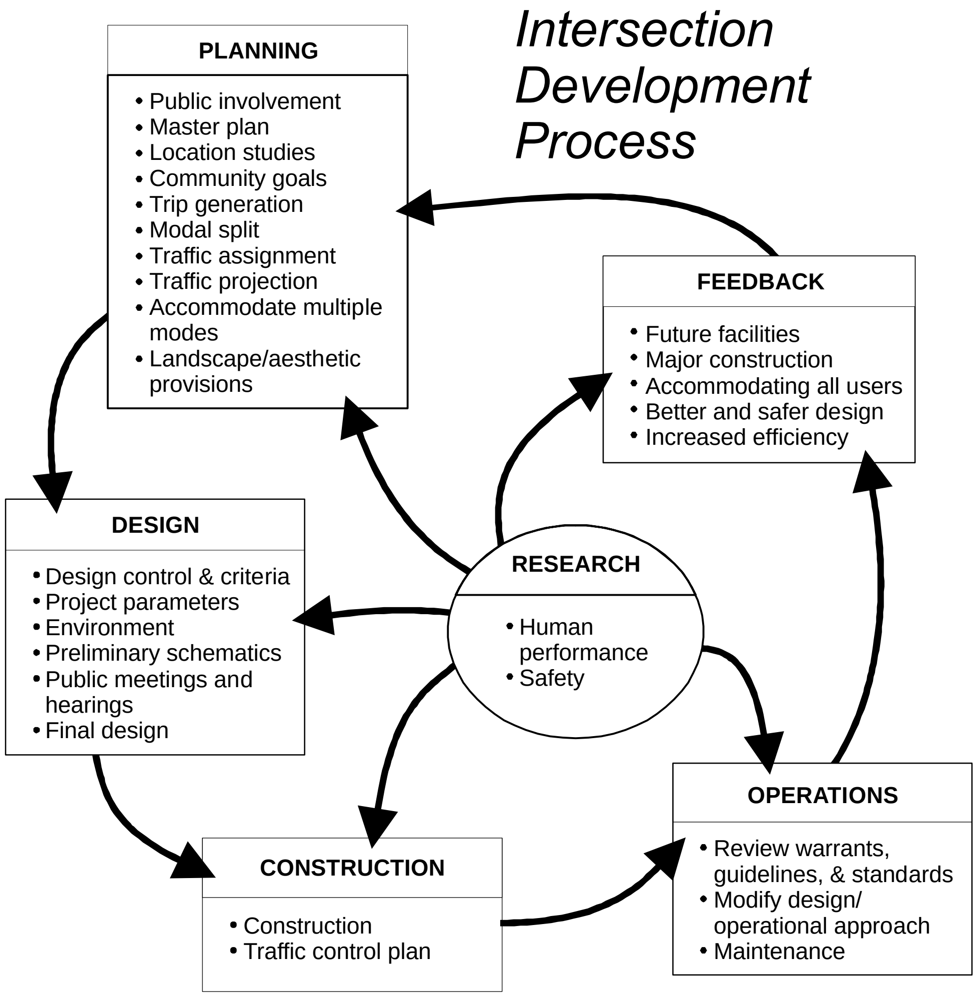


Figure 1-1. The Intersection Development Process.

Planning is conducted in conjunction with an overall regional plan and with public involvement that reflects the community goals. At this stage the facilities are classified and basic corridor requirements are identified. Consideration of all modes should occur, including transit, bicycle, and pedestrian facilities. Understanding the constraints presented by intersections can assist in developing a network that meets the basic needs of all modes. If the intersection is identified as being in a historic district or if there are historic buildings near the intersection, contact the District Environmental Coordinator for information. The presence of historic resources may affect development of project plans. Coordination with the Texas Historical Commission will be needed.

Design involves the development of the project plans while considering the design control and criteria applicable to the setting. The intersection type, lane configuration, basic geometric form, pedestrian improvements, and right-of-way requirements are all developed during design. Due to public interest in the development of transportation projects, the design stage routinely includes public participation in some form.

Construction involves the building of all parts of the intersection as designed. An element of construction is the consideration of how to accommodate the safe movement of vehicles, pedestrians, and other users during the work.

Operations of the intersection include consideration of all users when selecting the traffic control devices and evaluating how the devices are functioning. During operations, the traffic control plan can be reviewed to determine if changes are desired. These changes could result in revisions to the operational approach or in changes to the design of the intersection.

Feedback from existing intersections can improve the planning, design, and operations process. Feedback can come in many forms such as volumes, operating speed, and complaints/comments from users. Crash records can be a valuable source of additional information on the performance of a site.

Research can also provide valuable information on how to better plan, design, or operate an intersection. It is an integral part of the process as it provides information on the various users of the system, what techniques have worked in other areas, and how to improve the system.

Policy and Procedures

The Texas Department of Transportation (TxDOT) has developed a series of manuals that can assist with the development of roadways and intersections. These online manuals include the following:

- ***Project Development Policy Manual***[4] <link> – provides a one-stop location for all project development-related policies and practices and facilitates research of project development policy-related issues/requirements. The manual is also intended to provide an overview of policy hierarchy, descriptions of various federal, state, and departmental policy documents as well as a discussion on engineering ethics.

- ***Project Development Process Manual***[5] <link> – facilitates uniform communication of information so that the department can avoid overlooking tasks necessary for timely project development. It provides the tasks that need to be performed, who is responsible for them, and when they should be performed. It should result in improved coordination to avoid situations that may result in delaying projects scheduled for letting.
- ***PS&E Preparation Manual***[6] <link> – provides information on the tasks necessary for completion of Plans, Specifications, & Estimate (PS&E) packages. It also discusses how to use specifications and develop the engineer's estimates. PS&E submissions and processing along with pre-letting and post-letting procedures are included.
- ***Roadway Design Manual***[7] <link> – provides guidance in the selection of geometric design criteria for highway and street project development. This manual represents a synthesis of current information and operating practices related to the geometric design of different classifications of roadway facilities.
- ***Access Management Manual***[8] <link> – provides guidance for the design and location of access to the state highway system and includes procedures for municipalities to be granted permitting authority.

Design Exceptions, Variances, and Waivers

The design criteria contained in the *Roadway Design Manual*[7] are applicable to all classes of roadway. When the controlling criteria for a particular category of work (i.e., 4R, 3R, 2R, or Special Facilities) cannot be met, design exceptions must be requested. The controlling criteria are listed in Chapter 1 of the *Roadway Design Manual* <link>.

When criteria in noncontrolling categories are not met, design waivers must be handled at the district level. The noncontrolling categories are provided in the *Roadway Design Manual* <link>.

Finally, design variances must be sought when requirements in the Texas Accessibility Standards (TAS) are not met (requirements are discussed in the *Roadway Design Manual* Chapter 1 <link> and Chapter 2 (Sidewalk and Pedestrian Elements section), <link>). Design variances should be sent to the Design Division for forwarding to the Texas Department of Licensing and Regulation for approval.

Ultimate Design

Intersection operation is generally considered to be the greatest influence on the level of service on urban roadways, which contrasts greatly with rural design. Consideration of future expansion needs at intersections is a critical aspect of creating successful sustainable designs in urban areas. ***Application 1-1*** <link> provides an example of a subdivision entrance design so that the ultimate cross section can be constructed without affecting the subdivision entrance.

Obtaining traffic projections is a normal part of beginning a roadway design and provides designers with information necessary to determine specific characteristics of the roadway design. Those traffic projections, while prepared with great care, should be reviewed with a critical eye. Designers should consider the possibility that projected turning movement volumes could be underestimated.

In other cases, roadway designs may be "standardized" in certain aspects. For example, some agencies provide for dual left-turn movements at all intersections between major roadways even though traffic projections for specific intersections may not be high enough to justify their use at the projected design volume. This provides motorists with a strong sense of what types of intersections will be encountered along a corridor, thereby enhancing safety and reducing erratic operations. However, the impacts on non-motorized users need to be evaluated when considering such policies.

Another consideration in urban design is the accommodation of pedestrians. Designing urban roadways with a sidewalk or with the consideration that a sidewalk will be added at a later date can result in overall cost savings for the corridor. Designing for a future sidewalk can save costly reconstruction of driveways and moving of utilities.

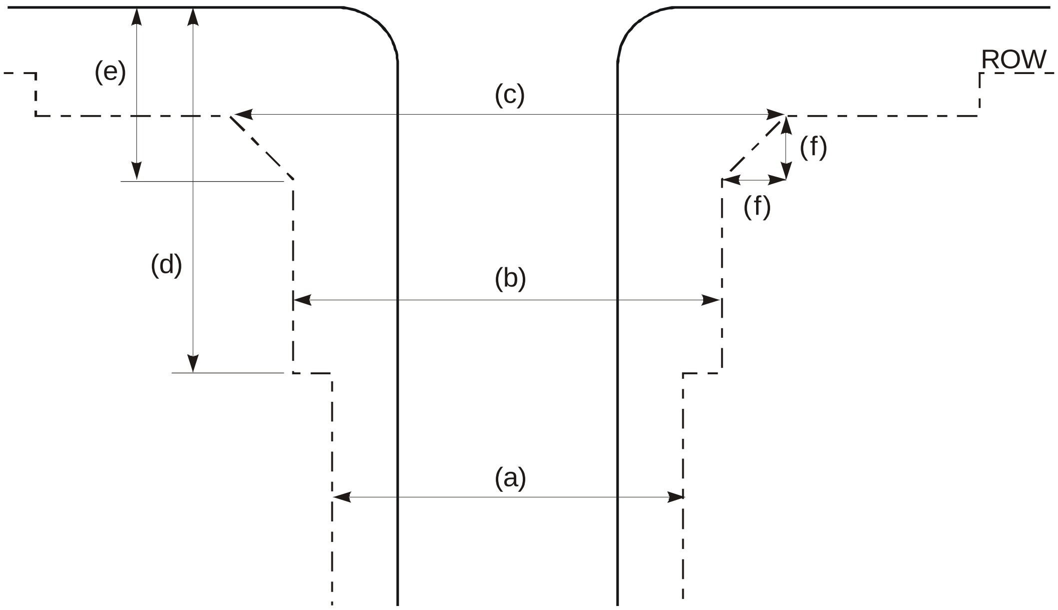
Arterial to Arterial Intersection Design

Arterial to arterial intersections should be designed with the concept that geometric features should be used to:

- ♦ maximize efficiency for all modes,
- ♦ accommodate turning vehicles, and
- ♦ balance the requirements of all modes so they interact in a safe and efficient manner.

Traffic Efficiency. Urban arterials are expected to (and should be designed to) accommodate high vehicular traffic volumes at relatively high speeds. When arterial streets intersect, a large number of vehicles are likely to need the same intersecting area. Also sharing the space are pedestrians and bicyclists. The high demands often cause operational bottlenecks or points of congestion. The most desirable geometric design for arterial to arterial intersections is to eliminate the intersection by providing a grade separation or interchange. However, factors such as right-of-way availability and construction costs often prohibit the possibility of constructing a grade separation or interchange.

Arterial to arterial intersections must be designed and constructed for high capacity volumes in order to eliminate, or at least alleviate, the bottlenecks. Two multilane arterials operating at or near capacity volumes will create a bottleneck at their intersection unless the cross sections of the arterials become wider at and on the approaches to the intersection. In order to provide for the widened cross section, ROW widths must be increased at and on the approaches to the intersection. Figure 1-2 illustrates how the ROW could be widened (or flared) to accommodate the addition of turn lanes, pedestrian facilities, and transit needs at an intersection. Arterial roadways generally serve as transit routes. Transit stops will generate pedestrian traffic, as will the development that generally occurs at arterial intersections.



(A) Typical cross section ROW adequate to include sidewalks & bicycle facilities
(B) Approach to intersection ROW
(C) ROW for corner clip adequate for pedestrian queuing and curb ramps at corners
(D) Length of approach to intersection to allow for turn bays
(E) Length of approach to intersection to allow for corner clips
(F) Offsets for corner clips

Figure 1-2. Right-of-Way Widths to Accommodate Intersection Needs.

Arterial to arterial intersections must be designed to accommodate high volumes of traffic and to provide opportunities for pedestrian crossing movements (e.g., median refuge, crosswalk design, curb ramp design, etc.). The initial design or reconstruction of an intersection may also need to accommodate:

- illumination,
- transit stops and shelters,
- signage,
- drainage structures,
- streetscaping,
- landscaping, and
- crosswalk and curb ramp design.

Additionally, as noted in Section 4 of this chapter <link>, the increasing number of utilities due to growth in both population and technology may be a consideration in determining the amount of right of way needed. Further, because arterial to arterial intersections are typically signalized, it is also important to design an intersection to accommodate for traffic signals and the related hardware, without interfering with the other modes of travel.

Turn Lanes. Turning maneuvers are accommodated by providing left- and right-turn lanes. The number and lengths of turning lanes affect the ability of the intersection to accommodate turning maneuvers and storage of turning vehicles. Through-traffic efficiency is maximized when:

- The number of through lanes is maximized.
- Turning lanes are provided with long tapers and storage areas.
- Driveways, median openings, and street intersections are located at considerable distances from the intersection.
- The time required for pedestrian movements provides for safe and efficient movement.

The provision of left-turn lanes provides greater capacity (particularly at signalized intersections) and increased safety at intersections. Consideration of the possibility of providing left-turn lanes in the future can influence the choice of median width.

On roadways with raised medians, median width should be selected to accommodate future expansion possibilities. By selecting a median width that could accommodate future pedestrian storage, the installation of left-turn lanes, dual left-turn lanes, or offset left-turn lanes, an entire corridor could be provided with a higher level of service with minimal disruption.

"Flaring" an intersection to provide turn lanes (both left and right) is frequently used to improve traffic operations in urban locations (see Figure 1-2). Consideration of ROW needs to accommodate such an improvement in the future could greatly reduce the cost of such a design improvement. Flaring will increase the crossing time for pedestrians so adequate space should be considered for pedestrian refuge.

Consideration of providing a right-turn lane in the future could lead to the acquisition of more ROW at critical intersections. Because development frequently occurs around intersections, those intersections should be carefully evaluated for the future need to install right-turn lanes. Development can also result in increased pedestrian activities so the design and resulting ROW needs of pedestrian facilities should be included in the evaluation. Controlling the access within the area where turning vehicles and pedestrians queue will improve the operation of the intersection.

Pedestrian Movements. The safety and efficiency of pedestrian movements at an intersection may be improved by providing:

- good sight distances;
- marked crosswalks;
- accessible pedestrian signals;
- push button actuations with locator tones;
- short, direct crossings;
- adequate time for crossing at the signal;
- protected crossing phase at the signal;
- low speeds;

- no right turn on red;
- clear, visible, multi-format information;
- pedestrian storage/refuge areas; and
- accessible curb ramps and landings.

Additional information on accommodating pedestrians is provided in Chapters 7 and 8 of this *Guide* <link>.

Bicycle Movements. Bicycle movements should also be considered at intersections. Chapter 4, Section 6 of this *Guide* <link> provides information on:

- bicycle lanes and
- shared roadways.

Section 2
Types of Intersections

Overview

At each particular location, selecting an intersection type is influenced by:

- functional class of intersecting streets;
- design level of traffic;
- number of intersecting legs;
- topography;
- access requirements;
- traffic volumes, patterns, and speeds;
- all modes to be accommodated;
- availability of right of way; and
- desired type of operation.

Although many of the intersection design examples are located in urban areas, the principles involved apply equally to design in rural areas. Some minor design variations occur with different kinds of traffic control, but all of the intersection types lend themselves to the following types of control:

- cautionary or non-stop control,
- stop control for minor approaches,
- four-way stop control, and
- both fixed-time and traffic-actuated signal control.

Types of Intersections

When two or more roads intersect, there is potential for conflict between vehicles and between various modes of travel. A priority in the design of at-grade intersections is to reduce the potential severity of conflicts and at the same time, assure the convenience and ease of all users in making the necessary maneuvers.

The basic types of intersections are:

- T-intersection (with variations in the angle of approach),
- four-leg intersection,
- multileg intersection, and
- roundabouts.

A brief discussion of these intersection types follows. The basic intersection types vary greatly in scope, shape, and degree of channelization. More detailed information regarding intersection type and additional examples are provided in Chapter 9 of AASHTO's *A Policy on Geometric Design of Highways and Streets.*[1] Additionally, information on channelization may be found in the National Cooperative Highway Research Project (NCHRP) Report 279, *Intersection Channelization Design Guide*.[9]

Three-Leg or T-Intersections. The normal pavement widths of both highways should be maintained at T-intersections except for the paved returns or where widening is needed to accommodate the selected design vehicle. Typical T-intersections are shown in Figure 1-3, and an aerial photograph of a channelized T-intersection is shown in Figure 1-4.

Four-Leg or Cross Intersections. Four-leg intersections vary from a simple 90-degree intersection of two lightly traveled local roads to a complex intersection of two main highways. The overall design principles, island arrangements, use of auxiliary lanes, and many other aspects of three-leg intersection design also apply to four-leg intersections. Patterns at four-leg intersections are shown in Figure 1-5 and aerial photographs in Figure 1-6.

Multileg Intersections. Multileg intersections are seldom used and should be avoided where possible. Most often they are found in urban areas where volumes are light and stop control is used. At other than minor intersections, safety and efficiency are improved by rearrangements that remove some conflicting movements from the major intersection. Information on intersection realignment is provided in Chapter 3, Section 4, of this *Guide* <link>.

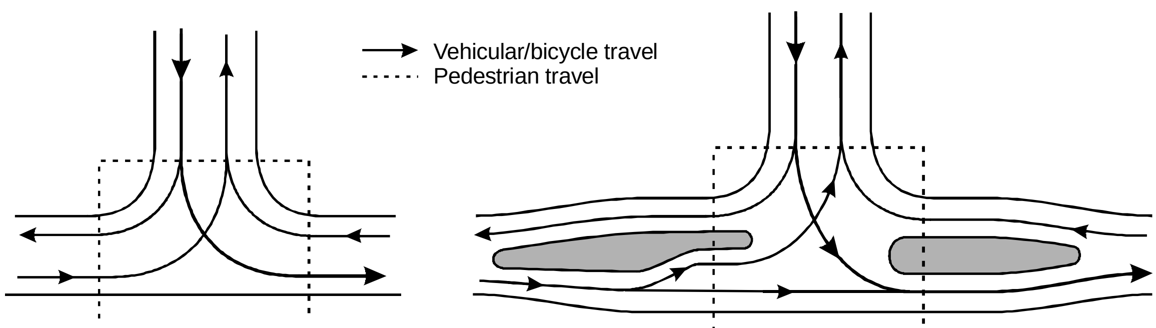


Figure 1-3. Typical Three-Leg Intersection.

Figure 1-4. Aerial Photograph of a Channelized T-Intersection.

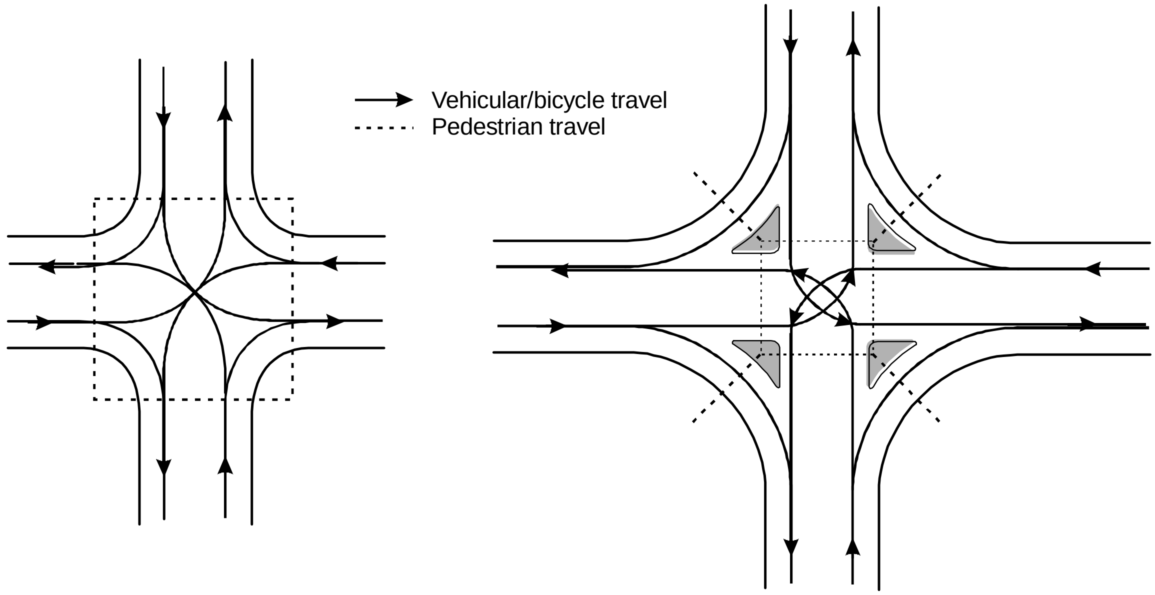


Figure 1-5. Typical Four-Leg Intersections.

(A) **(B)**

Figure 1-6. Aerial Photographs of Four-Leg Intersections.

Roundabouts. There has been an emergence of interest in modern roundabouts in some parts of the United States since 1990. The term "modern roundabout" is used in the United States to differentiate them from traffic circles and rotaries that have been in use for many years. Two basic operational and design principles define modern roundabouts:

- ♦ yield-at-entry where entering vehicles must yield to crossing pedestrians and to vehicles on the circulatory roadway of the roundabout and
- ♦ deflection of entering traffic where entering traffic is deflected to the right by a central island on each approach to the roundabout.[1]

Additional information on roundabouts is provided as ***Application 1-2*** <link>.

Innovative Designs

Information on innovative intersection designs is included in the *Applications* document as ***Application 1-3*** <link>. The following designs are discussed:

- unconventional left-turn alternative designs:
  - median U-Turn,
  - bowtie,
  - superstreet,
  - paired intersections,
  - jug handle,
  - continuous flow, and
  - continuous green T;
- quadrant roadway intersection;
- flyovers, and
- echelon.

Section 3
Components of an Intersection

Overview

An intersection consists of several components. This Section will review two major components: right-of-way needs and intersection area. It will also discuss principles in designing an intersection.

Principles of Intersection Design

A prime function of intersections is to provide for changes in travel direction. Intersection design goals may include the following:

- Consider all modes: bicycles, pedestrians, transit, and motor vehicles.
- Reduce number of conflict points.
- Control relative speed.
- Coordinate design and traffic controls.
- Minimize skew angle.
- Avoid multiple and compound merging and diverging maneuvers.
- Separate conflict points.
- Favor the predominant flow.
- Segregate nonhomogeneous flows.
- Be consistent with local/neighborhood objectives.

Right-of-Way Needs

Right-of-way (ROW) needs for intersections vary with:

- type of intersection;
- type of traffic control;
- number of intersecting legs;
- number of lanes on each approach;
- angle of the intersection;
- provision of sidewalks, curb ramps, and landings; and
- provision of bicycle lanes.

When adequate right of way is available both at and in advance of an intersection, the desirable geometric features that contribute to a high level of safety, along with maximum intersectional capacity and operational efficiency, can be constructed. Figure 1-2 illustrated the varying right-of-way widths to consider on an approach to an intersection. When right of way is restricted, less desirable and less efficient intersection operations will result. Therefore, the final design chosen for a new or reconstructed intersection will often be a compromise between what is desirable and what can be provided, because adequate right of way cannot always be obtained in a cost-effective manner.

Right-of-Way Acquisition

Procedures for acquiring right of way vary from agency to agency. TxDOT's procedures are included in the TxDOT *Right of Way* collection of online manuals. The *Right of Way* collection includes the following:

- Real Estate Acquisition Guide for Local Public Agencies[10] <link>,
- Vol. 1 – ROW Procedures Preliminary to Release[11]<link>,
- Vol. 2 – ROW Acquisition[12] <link>,
- Vol. 3 – ROW Relocation Assistance[13] <link>,
- Vol. 4 – ROW Eminent Domain[14] <link>,
- Vol. 5 – ROW Property Management[15] <link>,
- Vol. 6 – ROW Miscellaneous[16] <link>, and
- Vol. 7 – ROW Beautification[17] <link>.

These manuals are available on the TxDOT Web site at: http://manuals.dot.state.tx.us/dynaweb.

Intersection Area

Both functional and physical areas define an intersection (see Figure 1-7). The functional area of an intersection extends both upstream and downstream from the physical intersection area and includes any auxiliary lanes and their associated channelization. The functional area on the approach to an intersection or driveway consists of three basic elements as shown in Figure 1-8:

- perception-reaction distance (d_1),
- maneuver distance (d_2), and
- queue-storage distance (d_3).

The distance traveled during the perception-reaction time will depend upon vehicle speed, driver alertness, and driver familiarity with the location. Where there is a left- or right-turn lane, the maneuver distance includes the length needed for both braking and lane changing. In the absence of turn lanes, it involves braking to a comfortable stop. The storage length should be sufficient to accommodate the queues expected during a typical peak period.

Ideally, driveways should not be located:

- within the functional area of an intersection, or

- in the influence area of an adjacent driveway.

For additional information on the spacing between access points, consult the TxDOT *Access Management Manual*[8] <link> or the Design Division.

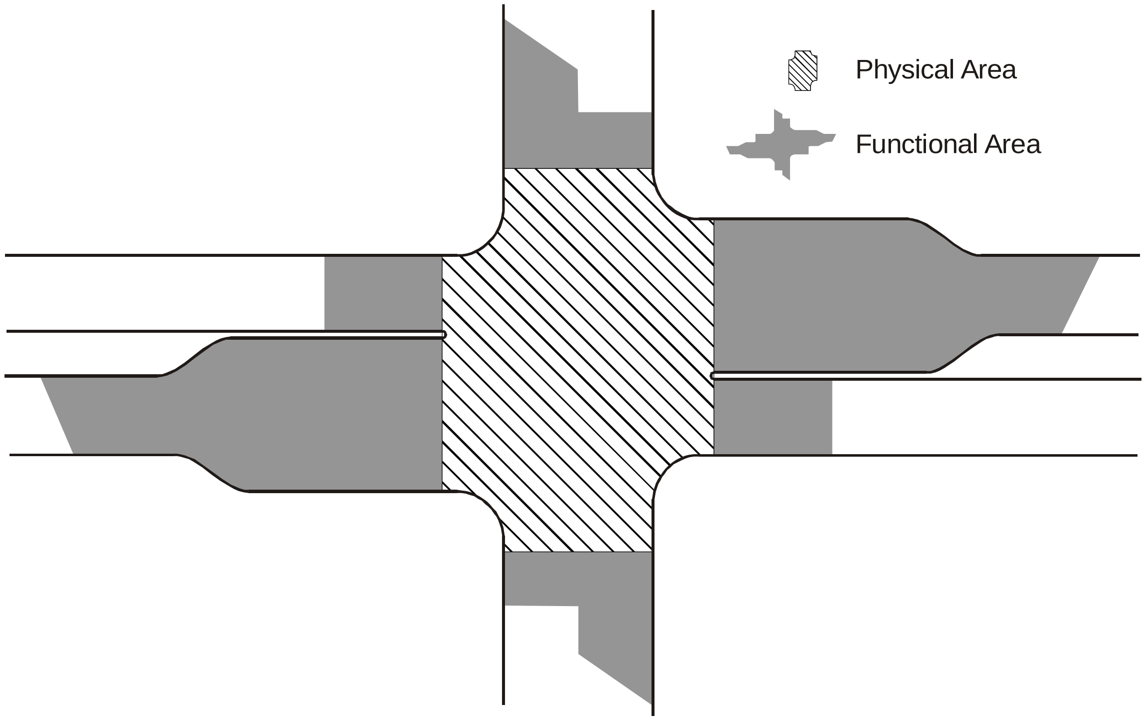


Figure 1-7. Functional Area of an Intersection.[18]

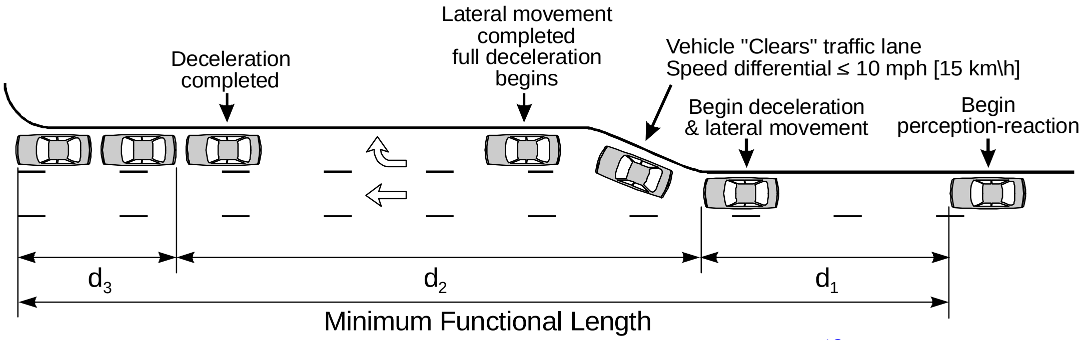


Figure 1-8. Elements of the Functional Area of an Intersection.[18]

Section 4

Utility Accommodation

Overview

Public utilities have located facilities on federal-aid highway right of way in the United States since 1916,[19] with individual states controlling the access and use of that right of way through laws and regulations administered through their departments of transportation (DOTs). Over time, right-of-way issues materialized as the network of roadways across the U.S. expanded and grew. When Congress created the National System of Interstate and Defense Highways in the mid-1950s, issues regarding access control of right of way emerged as one of the safety factors of concern. As a result, the American Association of State Highway and Transportation Officials developed *A Policy on the Accommodation of Utilities on the National System of Interstate and Defense Highways.*[20] States were required to adopt guidelines and regulations that were at least as restrictive as those outlined in the AASHTO guide. By 1966 these regulations had expanded to include all federal-aid highways operated by state DOTs.[21]

As required by federal mandate, Texas adopted guidelines for accommodating public utilities in highway right of way. The Texas Utility Accommodation Policy, as contained in the Texas Administrative Code[22] and the TxDOT Utility Manual issued by the ROW Division, outlines the manner in which utilities may be accommodated along and across highway right of way. The Texas Utilities Code[23] grants utilities the right to access to the right of way. These public utilities include lines that transport natural gas, water, electricity, telecommunications, cable television, salt water, and common carrier petroleum and petroleum-related products. Additionally, privately owned lines are normally allowed to cross highway right of way.

Growing Demand for Utility Accommodation

As new public utilities form, the number of public utilities vying for space within the state's right of way increases. However, right of way is a finite resource and is quickly reaching its capacity, creating congestion, pedestrian accessibility, and safety problems. Although utilities have a right to access TxDOT right of way, the department determines whether room is available to safely accommodate a particular utility installation. Costs to relocate a public utility are inevitably borne by the utility rate and tax-paying citizens of our state.

As technology and the population grow, the need for expanding existing and adding new utility lines increases. With the explosion in the telecommunications industry, both public and private interests are building new networks and upgrading existing networks at an unparalleled pace.[24]

Interstates and other federal-aid highways often link major metropolitan centers and smaller outlying cities. As a result, there is increasing interest by utility companies to occupy the right of way of controlled access highways. In 1995 the AASHTO Board of Directors revised its long maintained policy in opposition to the longitudinal use of freeway rights of way for utilities by stating that there is a distinction between buried fiber-optic cables and other types of utilities and deemed permissible the longitudinal use for buried fiber-optic cables under appropriate guidelines.[24]

Alternative Installation Methods

Just as the demand for utility accommodation has increased, the cost of right-of-way purchase has also increased in recent years. With the proliferation of utilities in limited right of way, the complexity of detecting and relocating utility lines during transportation infrastructure projects has become a more complex issue. In order to successfully accommodate utilities in congested right-of-way conditions, alternative installation methods are being considered and used. These methods include trenching, joint trench encased utilities, and utility corridors. TxDOT Report 0-4149-1 (*Utility Corridor Structures and Other Utility Accommodation Alternatives in TxDOT Right-of-Way*[25]) provides more detailed information and recommendations on the use of these methods.

Subsurface Utility Engineering

Subsurface Utility Engineering (SUE) is the non-destructive process of accurately locating, identifying, and mapping underground utilities. SUE is an interdisciplinary service, involving professional engineers, geologists, and licensed land surveyors. It is a professional service resulting in signed and sealed deliverables. SUE includes three major activities: designating, locating, and data management. Additional information on SUE is contained in the TxDOT *Project Development Process Manual*[5] <link>.

The district utility coordinator should be contacted to determine the need for SUE. The district utility coordinator coordinates the work with the Right-of-Way Division.

Inclusion of Utility Relocation in Construction Contract

Generally the highway right of way should be clear of the need for utility relocation before construction projects are let, but in some cases it may be determined that utility adjustments are to be included in the highway construction contract. In the preparation of the PS&E, the designer must give consideration for who will be responsible for the costs and who will perform the adjustments. TxDOT's *Utility Manual*[26] provides guidance on the appropriate manner in which the work can be included in the PS&E.

Potential Impacts on Intersection Design

Any utilities located within intersection ROW may have an impact on the design of that intersection. Utilities will require manholes, markers, and other appurtenances that may present challenges to designing the intersection. While TxDOT accommodates utilities within the ROW so that they do not adversely affect safety, design, construction, operation, or maintenance,[22] designers should be aware of certain features related to utilities that may impact the intersection. Careful coordination is needed to ensure that utility installations do not negatively impact pedestrian features such as sidewalk width, curb ramps, and landings. These specific features are discussed in Chapter 5, Section 8 of this *Guide* <link>.

Section 5

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Chapter 2
Design Control and Criteria

Contents:

Section 1
Modes of Travel

Overview

There are many different modes of travel at an intersection including the following:

- motorized vehicles,
- transit and light rail,
- bicycles, and
- pedestrians.

Characteristics of each of these users are discussed below.

Motorized Vehicles

The physical characteristics and proportions of vehicles provide key controls in the design of an intersection. The type of vehicle that influences critical elements of a design is known as the "design vehicle." For purposes of geometric design, each design vehicle has larger physical dimensions and a larger minimum turning radius than most vehicles in its class. The AASHTO *Green Book*[1] has four general classes of design vehicles: passenger cars, buses, trucks, and recreational vehicles. Dimensions and minimum turning paths templates for the following design vehicles representing these four general classes are discussed and included in the *Green Book*:

- passenger car,
- single-unit truck,
- intercity bus,
- city transit bus,
- conventional school bus (65 passengers),
- large school bus (84 passengers),
- articulated bus,
- intermediate semitrailer (WB-40 [WB-12]),
- intermediate semitrailer (WB-50 [WB-15]),
- interstate semitrailer (WB-65 [WB-20] or WB-67 [WB-20]),
- double-bottom-semitrailer/trailer,
- triple-semitrailer/trailers,
- turnpike double-semitrailer/trailer,
- motor home,

- car and camper trailer,
- car and boat trailer,
- motor home and boat trailer, and
- farm tractor.

The *Green Book* recommends that the design consider the largest design vehicle likely to use the facility with considerable frequency or a design vehicle with special characteristics appropriate to a particular intersection in determining the design of such critical features as corner radii at intersections and median nose location. It also provides the following advice:

- A single-unit truck may be used for intersection design of residential streets and park roads.
- A city transit bus may be used in the design of state highway intersections with city streets that are designated bus routes and that have relatively few large trucks using them.
- Depending on expected usage, a large school bus (84 passengers) or a conventional school bus (65 passengers) may be used for the design of intersections of highways with low-volume county highways and local roads under 400 average daily traffic (ADT). The school bus may also be appropriate for the design of some subdivision street intersections.
- The WB-65 or 67 [WB-20] truck should generally be the minimum size design vehicle considered for intersections of two arterials.

The TxDOT *Roadway Design Manual*[2] Chapter 7, Section 7 <link> also presents information on minimum designs for truck and bus turns. It notes that corner radii at intersections on arterial streets should satisfy the requirements of the drivers using them to the extent practical and in consideration of the following:

- amount of right of way available,
- angle of the intersection,
- numbers of and space for pedestrians,
- width and number of lanes on the intersecting street, and
- amounts of speed reductions.

Another consideration in the selection of a corner radii is the trade-off with pedestrian crossing distance. Large radii can improve vehicle operations; however, pedestrians will need a longer crossing interval due to additional pavement to cross. Smaller radii can benefit pedestrians through slower vehicle right-turn speeds and smaller street distance to be crossed. Guidance on turning radii is provided in Chapter 3, Section 3 <link>.

An operational measure that appears promising is to provide guidance in the form of edge lines to accommodate the turning paths of passenger cars, while providing sufficient paved area beyond the edge lines to accommodate the turning path of an occasional large vehicle.

Transit and Light Rail

Transit vehicles include buses, light rail, and heavy rail. Light and heavy rail operates on a fixed guideway of two rails. Transit vehicles are typically larger than highway vehicles and have poorer stopping capabilities. When in a semi-exclusive alignment, they operate in a separate right of way where road users have limited access and cross at designated locations only. Mixed-use environments have the transit vehicle operating with other road users and the roadway is shared by all modes. The transit system must be integrated into the everyday life of a community to realize its full potential. Consideration should be given to long-term design and system performance, which can enhance the interaction of transit with communities. The efficient placement of transit stops near major destinations and within easy access provides a viable transportation alternative to the automobile by making the entire transit trip shorter and more pleasant.

Reports or material available on light rail transit (LRT) systems includes:

- Transit Cooperative Research Program (TCRP) Report 69, *Light Rail Service: Pedestrian and Vehicular Safety,* [3]
- TCRP Report 17, *Integration of Light Rail Transit into City Streets*, [4] and
- *TMUTCD* Part 10. Traffic Controls for Highway-Light Rail Transit Grade Crossings.[5]

TCRP Report 69 presents the results of a study to improve the safety of light rail transit in semi-exclusive rights of way where light rail vehicles (LRVs) operate at speeds greater than 35 mph [56 km/h] through crossings with streets and pedestrians pathways. The report discusses the effectiveness of presignals and presents recommended guidelines. The application guidelines focus on six principal areas:

- LRT system design,
- LRT system operation and maintenance,
- traffic signal placement and operation,
- automatic gate placement,
- pedestrian control (including specific guidelines for selecting among the various pedestrian control devices), and
- public education and enforcement.

TCRP Report 17 addresses the safety and operating experience of LRT systems operating on shared rights of way at speeds generally under 35 mph [56 km/h]. The principal findings of the study were:

- LRT system design should respect and adapt to the existing urban environment.
- LRT system design should comply with motorist and pedestrian expectations.
- Decisions by motorists and pedestrians who interact with the LRT should be kept as simple as possible.
- Traffic control devices related to LRT operations should clearly communicate the level of risk associated with the LRT system.

- LRT system design should provide recovery opportunities for erratic motor vehicle and pedestrian movements.

Transit stops are typically located at or near intersections to provide greater access to buildings located along both streets. Transit use is closely connected with the need for pedestrian access and improvements. How those transit stops function can have a great impact on the operations of the intersection. The use of transit priority systems, such as extending the green signal at an intersection when a transit vehicle is near, can also impact the performance of an intersection.

TCRP Project D-09[6] is developing a handbook to provide the following:

- Comprehensive geometric design guidelines for accommodating transit vehicles and facilities on highways and streets.
- A decision-making process and guidelines for selecting appropriate transit facilities to accommodate current and future transit demand – based on local conditions – in a manner that improves transit travel times and reliability. The handbook will include geometric guidelines associated with transit facilities on or immediately adjacent to streets and highways. This project will build on and implement recommendations from NCHRP Project 20-7/Task 135, *Interim Geometric Design Guide for Transit Facilities on Highways and Streets – Phase1*.[7]

Exclusive busways in separate rights of way frequently have at-grade crossings with roadways or pedestrian and bicycle facilities. Buses are sometimes given preferential crossing priority, similar to that given for light rail transit. Although individual transit systems have developed their own design criteria, no generally accepted guidelines exist. Research will be conducted as part of TCRP Project D-11[8] to determine what operational planning and functional design treatments are appropriate to enhance safety and to maximize throughput of transit passengers for at-grade crossings of exclusive busways. The research may also contribute to the development of national guidelines on operational planning and functional design of busways.

Several universal concerns of both users and providers of transit services include the following:

- ***Transit system performance:*** Travel time for a transit trip has four components — the time it takes to walk to the transit stop, the wait time for the transit, the actual in-vehicle travel time, and the time to walk to the destination. Each is affected by the transit stop location and the frequency of the transit stops.
- ***Traffic flow:*** Transit stop location and design affect the flow and movement of other vehicles. A well-designed transit stop can allow passengers to board and alight without significantly impeding or delaying adjacent traffic and without blocking the sidewalk.
- ***Safety:*** In the transit environment, safety includes an individual's relationship to the transit vehicle and the relationship between the transit vehicle and general traffic. Pedestrian safety issues include the nearness of a bench to the flow of traffic on a busy street or safely crossing the street to reach the transit stop. Safe transit reentry into the flow of traffic is an example of an operational safety concern. Thus, pedestrians,

passengers, transit vehicles, and private vehicles can all be involved in concerns for safety at or near a transit stop.

- ***Security:*** Security refers to an individual's feeling of well being. Security is affected by the amount of lighting at the transit stop, and the visibility of the transit stop from the street and from nearby land uses. The amount of real or perceived locations with hiding places at or near the transit stop also influences an individual's feeling of how secure the facility is.

Bicycles

Roadway improvements can considerably enhance the safety of a street or highway for bicycle traffic. The *Green Book*[1] lists the following low to moderate cost improvements:

- paved shoulders;
- wider outside traffic lanes, if no shoulder exists;
- bicycle-safe drainage grates;
- adjusting manhole covers to the grade; and
- maintaining a smooth, clean riding surface.

For guidance on bicycle dimensions and operating characteristics and acceptable turning radii, grades, and sight distance, see Chapter 4, Section 6 of the *Guide* <link>. Other documents that provide information include:

- AASHTO *Guide for the Development of Bicycle Facilities*,[9]
- Federal Highway Administration (FHWA) report *Selecting Roadway Design Treatments to Accommodate Bicycles*,[10] and
- Institute of Transportation Engineers (ITE) report *Innovative Bicycle Treatments.*[11]

Pedestrians

The current designs for streets and highways provide an efficient network for moving motor vehicles; however, much of the system does little to accommodate pedestrians. AASHTO's *Green Book,*[1] however, states:

> "Because of the demands of vehicular traffic in congested urban areas, it is often extremely difficult to make adequate provisions for pedestrians. Yet this must be done, because pedestrians are the lifeblood of our urban areas, especially in the downtown and retail areas.[1]"

AASHTO published a guide for the development of pedestrian facilities in 2004 entitled the *Guide for the Planning, Design, and Operation of Pedestrian Facilities.*[12] The guide identifies pedestrian design measures that are appropriate for streets and highways. Other documents that can provide information on pedestrians include the following:

- *Americans with Disabilities Act Accessibility Guidelines* (ADAAG);[13]

- Texas Department of Licensing and Regulation's *Architectural Barriers Texas Accessibility Standards*;[14]
- an FHWA report, *Designing Sidewalks and Trails for Access*: *Part 2*;[15]
- U.S. Access Board's *Draft Guidelines for Accessible Public Rights of Way*[16] and other technical assistance materials available at www.access-board.gov;
- Pedestrian and Bicycle Information Center (PBIC) Web site[17] <link>. The PBIC is a clearinghouse for information about health and safety, engineering, advocacy, education, enforcement, and access and mobility. The PBIC serves anyone interested in pedestrian and bicycle issues, including planners, engineers, private citizens, advocates, educators, police enforcement, and the health community.
- an FHWA report, *Pedestrian Facilities User Guide – Providing Safety and Mobility*[18] that contains information regarding how to create walking environments, the main causes of pedestrian crashes and ways to counter them, and engineering improvements that can be made to improve the quality of life for all citizens; and
- an ITE report, *Alternative Treatments for At-Grade Pedestrian Crossings.*[19]

Section 2
Users

Overview

The ability of the public to safely and efficiently use an intersection reflects on the suitability of a design. A design that is incompatible with the capabilities of the public increases the chance for errors, crashes, or inefficient operations.

Driving Task

The driving task depends upon drivers receiving and using information correctly. The information received by drivers as they travel is compared with the information they already possess. Decisions are then made based on the information available. Driving tasks when grouped by performance are in three levels:

- control,
- guidance, and
- navigation.

Figure 2-1 shows the levels of the driving task.

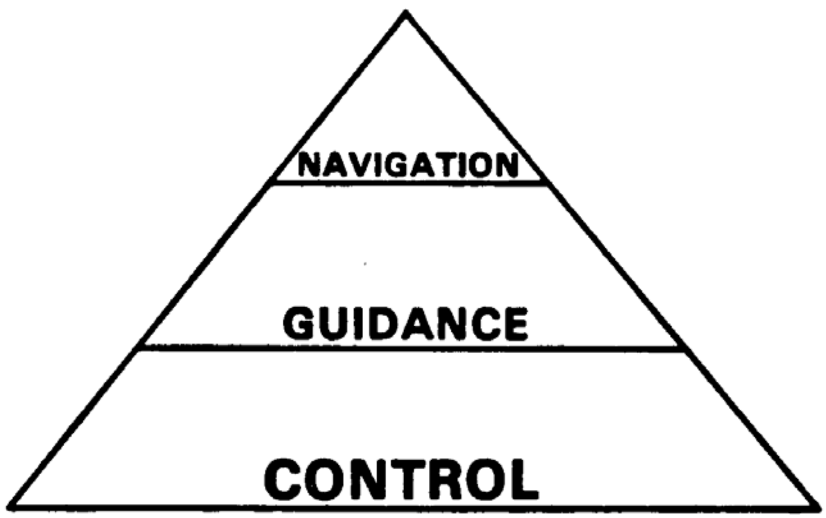

Figure 2-1. Levels of the Driving Task.

Simple steering and speed control are examples of control and are considered to be at the lowest complexity end of the scale. Guidance tasks are at the midlevel of the scale and include road-following and safe path maintenance in response to road and traffic conditions. At the other end of the scale are navigation activities such as trip planning and route following.

Many driver errors occur because:

- Drivers may not always recognize what particular responses are required of them.
- Situations may lead to task overload or inattentiveness.
- Deficient or inconsistent designs or information displays may cause confusion.

Driver errors may also result from pressures of time, complexity of decisions, or information overload. Control and guidance errors by drivers may also contribute directly to crashes. In addition, navigational errors resulting in delay contribute to inefficient operations and may lead indirectly to crashes.

Additional information on the driving task is contained in the *Green Book*[1] which drew heavily from two documents: *A User's Guide to Positive Guidance*[20] and "Human Factors and Safety Research Related to Highway Design and Operations."[21]

Older Drivers

Older drivers are a significant and rapidly growing segment of the highway user population with a variety of age-related diminished capabilities. The 65 and older group accounted for 15 percent of the driving population in 1986 and is expected to increase to 22 percent by the year 2030. Older drivers have special needs that should be considered in highway design and traffic control. For example, for every decade after age 25, drivers need twice the brightness at night to receive visual information. Hence, by age 75, some drivers may need 32 times the brightness they did at age 25.

Some of the more important observations from recent research studies concerning older drivers are summarized below from information provided in the *Green Book.*[1]

Characteristics of the Older Driver. In comparison to younger drivers, older drivers often have deteriorated driving skills that are caused by:

- slower information processing;
- slower reaction times;
- slower decision-making;
- visual deterioration;
- hearing deterioration;
- decline in ability to judge time, speed, and distance;
- limited depth perception; and
- limited physical mobility.

The *Highway Design Handbook for Older Drivers and Pedestrians*[22] provides recommendations to enhance the performance of diminished-capacity drivers as they approach and travel through intersections. Comparisons of responses from drivers ages 66 to 68 versus those age 77 and older showed that the older group had more difficulty following pavement markings, finding the beginning of the left-turn lane, and driving across intersections. Similarly, the level of difficulty for reading street signs and making left turns at intersections increased with increasing senior driver age. Turning left at intersections was perceived as a complex driving task. This was made more difficult when raised channelization providing visual cues was absent, and only pavement markings designated which were through lanes versus turning lanes ahead. For the oldest age group, pavement markings at intersections were the most important item, followed by the number of left-turn lanes, concrete guides, and intersection lighting. A study of older road users completed in 1996 provides evidence that the single most challenging aspect of intersection negotiation for this group is performing left turns during the permitted (green ball) signal phase.

Additional insight into the problems older drivers experience at intersections was provided by focus group responses from 81 older drivers in a 1977 study.[23] The most commonly reported problems are listed below:

- difficulty in turning more than 90 degrees to view intersecting traffic;
- difficulty in smoothly performing turning movements at tight corners;
- hitting raised concrete barriers such as channelizing islands in the rain and at night due to poor visibility;
- finding oneself positioned in the wrong lane—especially a "turn only" lane—during an intersection approach due to poor visibility (maintenance) of pavement markings or the obstruction of roadside signs designed to inform drivers of intersection traffic patterns;
- difficulty at the end of an auxiliary (right)-turn lane in seeing potential conflicts well and quickly enough to smoothly merge with adjacent-lane traffic; and
- merging with adjacent-lane traffic after crossing an intersection, when a lane drop occurs near the intersection (e.g., when two lanes merge into one lane within 500 ft [152 m] after crossing the intersection).

Although these problems are by no means unique to older drivers, the various functional deficits associated with aging result in exaggerated levels of difficulty for this user group.

Specific Recommendations for Intersections. Research findings show that enhancements to the highway system to improve its usability for older drivers and pedestrians can also improve the system for all users. A Federal Highway Administration report, entitled *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians,*[24] provides information on how geometric design elements and traffic control devices can be modified to better meet the needs and capabilities of older road users. Recommendations for intersections are included for the following design elements:

- intersecting angle (skew);
- receiving lane (throat) width for turning operations;
- channelization;
- intersection sight distance requirements;
- offset (single) left-turn lane geometry, signing, and delineation;
- treatments/delineation of edgelines, curbs, medians, and obstacles;

- curb radii;
- traffic control for left-turn movements at signalized intersections;
- traffic control for right-turn-on-red (RTOR) movements at signalized intersections.
- street name signing;
- one-way/wrong-way signing;
- stop- and yield-controlled intersection signing;
- devices for lane assignment on intersection approach;
- traffic signals;
- fixed lighting installations;
- pedestrian crossing design, operations, and control; and
- roundabouts.

Pedestrian

The decision to walk usually takes into account the following:

- the availability of an alternate mode,
- the distance of the trip,
- perceived safety of the route, and
- the comfort and convenience of walking versus an alternative mode.

Distance is a factor in the initial decision to walk although some people have no other choice. The majority of pedestrian trips are 0.5 mi [0.8 km] or less,[25] with 1 mi [1.6 km] generally being the limit that most people are willing to travel on foot. Impacts on the perceived and actual safety of the pedestrian users include sidewalks that are too narrow or adjacent to moving lanes of traffic, pedestrian crossings that are intimidating because of confusing signal indications, excessive crossing distances, or fast-turning vehicles. The immediate physical environment impacts comfort and convenience of walking. For example, are there shade trees; do the street and adjacent buildings, landscape, or public art provide a pleasant visual environment; is lighting adequate; and are there places to sit and rest?

Pedestrians have a wide range of needs and abilities. Following are characteristics of pedestrians:

- The *TMUTCD*[5] includes a speed of 4 ft/sec [1.2 m/sec] for calculating pedestrian clearance intervals for traffic signals. It also includes a comment that where pedestrians who walk slower than normal or who use wheelchairs routinely use the crosswalk, a walking speed of less than 4 ft/sec [1.2 m/sec] should be considered in determining the pedestrian clearance times. Children, older pedestrians, and persons with disabilities may travel at slower speeds. Walking speeds as low as 2.5 ft/sec [0.8 m/sec] have been recommended for some user groups.

- Two people walking side-by-side or passing one another generally require 4.7 ft [1.4 m] of space. Two people in wheelchairs need a minimum of 5 ft [1.5 m] to pass one another.
- The 2001 Nationwide Household Travel Survey found trips to be distributed as: 8.6 percent walking, 86.6 percent private vehicles, 1.5 percent transit, 1.7 percent school bus, and 1.7 percent other.[26]
- A 1995 survey[25] determined trips by trip purposes (see Table 2-1). For the four categories used, most trips either as a pedestrian or for all modes combined were for personal/family business (43 percent and 46 percent, respectively). Only 7 percent of the walking trips were for earning a living, while 20 percent of the trips for all modes combined were for earning a living.

Table 2-1. 1995 Survey Results.[25]

Reason	Walking Trips (%)	All modes (%)
Personal/family business	43	46
Social recreational	34	25
School/church/civic	14	9
Earning a living	7	20

Disabled Users

The Americans with Disabilities Act (ADA)[27] defines a disability as "a physical or mental impairment that substantially limits one or more of the major life activities of an individual." Impairment includes any mental disorders or physiological conditions that interfere with daily life functions. In 2000, persons with disabilities comprised 17.3 percent of the Texas population five years of age and older, mirroring the 17.7 percent of U.S. population with disabilities.[28]

In August to November 1997 the Survey of Income and Program Participation (SIPP) was administered to gather information about the number and characteristics of individuals with disabilities in the United States. Table 2-2 lists the number and percent of individuals with specified characteristics. In 1997, 52.6 million people (19.7 percent) had some level of disability, and 33.0 million people (12.3 percent of the population) had a severe disability. The U.S. Census Bureau defines *severe disability* in its 2000 population report as the need for mobility assistance; Alzheimer's disease, mental retardation, or other developmental disability; or any mental or emotional condition which seriously interferes with or prevents independently conducting everyday activities.[29] Of the population aged 15 years and older, 2.2 million (1 percent of the population) used a wheelchair. Another 6.4 million (3.1 percent) used some other ambulatory aid such as a cane, crutches, or a walker, while 9.4 million (4.5 percent) were either blind or visually impaired.[29] The likelihood of having a disability increases with age as shown in Figure 2-2.

The 2000 Census counted 49.7 million people with some type of long lasting condition or disability.[30] They represented 19.3 percent of the 257.2 million people who were aged 5 and older in the civilian non-institutionalized population – or nearly one person in five. Table 2-3 presents the findings by type of disability.

Table 2-2. Selected Disability Measures in the United States: 1997.[29]

Categories	Number with Specified Characteristics (in Thousands)	Percent with Specified Characteristics
All Ages	267,665	100.0
With a disability[a]	52,596	19.7
Severe disability[b]	32,970	12.3
Needed personal assistance with an ADL[c] or IADL[d]	10,076	3.8
Age 15 years and over	208,059	100.0
Used a wheelchair	2155	1.0
Used a cane, crutches, or walker (not a wheelchair)	6372	3.1
Had difficulty seeing	7673	3.7
Unable to see	1768	0.8
Had difficulty hearing	7966	3.8
Unable to hear	832	0.4

Source: U.S. Census Bureau, 1996 Survey of Income and Program Participation: August-November 1997

a. Disability is defined as “a physical or mental impairment that substantially limits one or more of the major life activities of an individual. Impairment includes any mental disorders or physiological conditions that interfere with daily life functions.”

b. Severe disability is the need for mobility assistance; Alzheimer’s disease, mental retardation, or other developmental disability; or any mental or emotional condition which seriously interferes with or prevents independently conducting everyday activities.

c. ADL is having difficulty with activities of daily living such as bathing, dressing, or eating.

d. IADL is defined as having difficulty with instrumental activities of daily living such as going outside the home, keeping track of money and bills, and preparing meals.

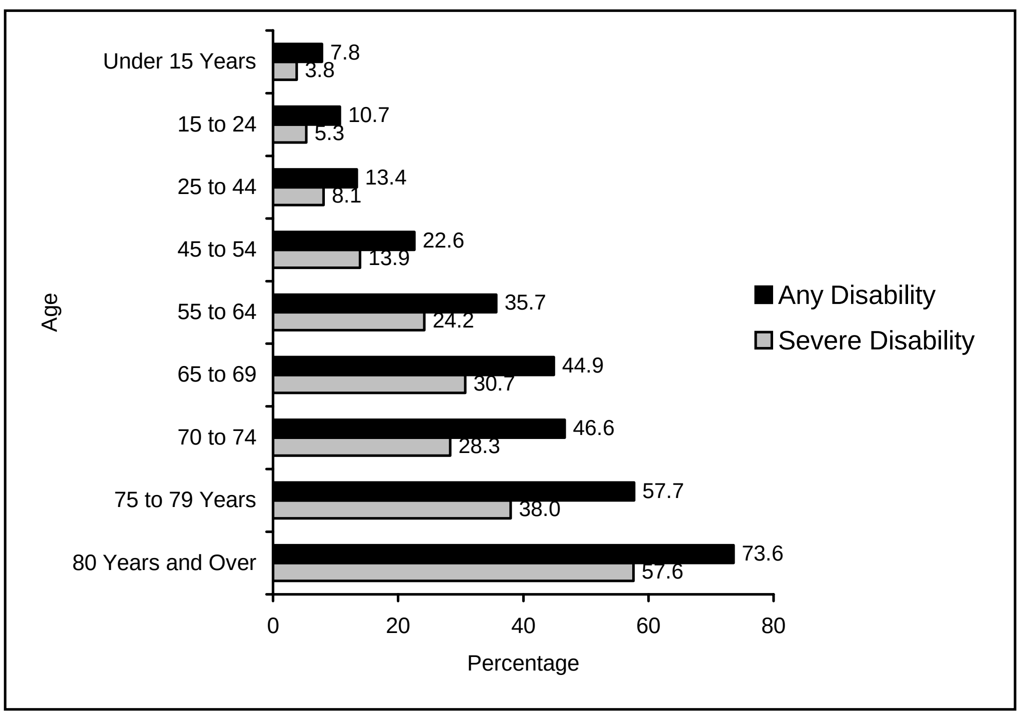

Figure 2-2. 1997 United States Disability Prevalence by Age (Percent with Specified Level of Disability).[29]

Table 2-3. Characteristics of the Civilian Non-Institutionalized Population by Age, Disability Status, and Type of Disability: 2000.[30]

Characteristic	Total	
	Number	Percent
Population 5 and older	257,167,527	100.0
With any disability	49,746,248	19.3
Population 5 to 15	45,133,667	100.0
With any disability	2,614,919	5.8
Sensory	442,894	1.0
Physical	455,461	1.0
Mental	2,078,502	4.6
Self-care	419,018	0.9
Population 16 to 64	178,687,234	100.0
With any disability	33,153,211	18.6
Sensory	4,123,902	2.3
Physical	11,150,365	6.2
Mental	6,764,439	3.8
Self-care	3,149,875	1.8
Difficulty going outside the home	11,414,508	6.4
Employment disability	21,287,570	11.9
Population 65 and older	33,346,626	100.0
With any disability	13,978,118	41.9
Sensory	4,738,479	14.2
Physical	9,545,680	28.6
Mental	3,592,912	10.8
Self-care	3,183,840	9.5
Difficulty going outside the home	6,795,517	20.4
Source: U.S. Census Bureau, Census 2000 Summary File 3.		

Bicyclist Characteristics

AASHTO's *Guide for the Development of Bicycle Facilities*[9] provides information on bicycle facilities and characteristics. Bicyclists have the same mobility needs as other users of the transportation system and use the highway system to access jobs, services, and recreational activities. Planning for existing and potential bicycle use should be integrated into the overall transportation planning process.

As Figure 2-3 shows, bicyclists require at least 40 inches [1 m] of essential operating space based solely on their profile. An operating space of 4 ft [1.2 m] is assumed as the minimum width for any facility designed for exclusive or preferential use by bicyclists. Where motor vehicle traffic volumes, motor vehicle or bicyclist speed, and the mix of truck and bus traffic increase, a more comfortable operating space of 5 ft [1.5 m] or more is desirable.

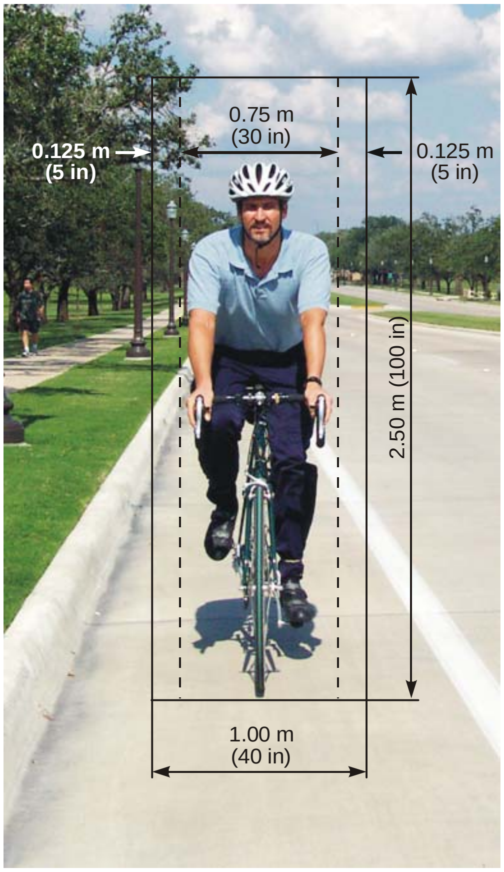

Figure 2-3. Bicyclist Operating Space (Based on Data in the AASHTO Guide for the Development of Bicycle Facilities[9]).

Although their physical dimensions may be relatively consistent, the skills, confidence, and preferences of bicyclists vary dramatically. Some riders are confident riding anywhere they are legally allowed to operate and can negotiate busy and high-speed roads that have few, if any, special accommodations for bicyclists. Most adult riders are less confident and prefer to use roadways with a more comfortable amount of operating space, perhaps with designated space for bicyclists, or shared use paths that are away from motor vehicle traffic. Children may be confident riders and have excellent bicycle handling skills, but have yet to develop the traffic sense and experience of an everyday adult rider. All categories of rider require smooth riding surfaces with bicycle-compatible highway appurtenances, such as bicycle-safe drainage inlet grates.

Section 3

Intersection Characteristics

Traffic

Information on traffic characteristics is important in selecting the appropriate geometric features of a roadway. Necessary traffic data are discussed in the *Roadway Design Manual*[2] <link> and include the following:

- traffic volume,
- traffic speed, and
- type and percentage of trucks or large vehicles.

Community

Many planners are taking an approach that considers a broader range of community values beyond the accommodation of traffic. Once the community has determined what type of facility meets community goals, the designer can ensure their design meets those needs.

Capacity

Capacity analysis is a set of procedures for estimating the traffic-carrying ability of facilities over a range of defined operational conditions. It provides tools to assess facilities and to plan and design improved facilities. The capacity of a facility is the maximum hourly rate at which persons or vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions. Level of service (LOS) is a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience. To determine the capacity or level of service for an intersection, the designer should refer to the most recent edition of the *Highway Capacity Manual* (HCM)[31] for guidance.

Access Management

Access management is a set of tools used to balance the needs of mobility on a roadway with the needs of access to adjacent land uses. Access management includes not only the physical treatments on the ground, but the guidance to implement an access management program as well. A successful access management program will provide several types of benefits to the traveling public and the community in general. The benefits will be to:

- Provide a safer roadway network.
- Improve mobility on the road.
- Protect the infrastructure investment.

More information on access management can be obtained from the following sources:

- TxDOT Design Division,
- Transportation Research Board (TRB) *Access Management Manual,*[32] and
- TxDOT *Access Management Manual.*[33]

Aesthetics

Aesthetics is most often associated with a sense of beauty. With respect to the practice of transportation design, the TxDOT *Landscape and Aesthetics Design Manual*[34] states that aesthetics may be defined as dealing with the visual integration of highways and other transportation modes into the fabric of a landscape in a way that blends with or complements that setting. The manual also states:

> "…The aesthetic properties of a transportation facility have purpose beyond simply creating a pleasant view. Aesthetics is intertwined with the function of the facility. An aesthetically pleasing highway or other transport mode is one that provides its users with a clear picture of what is going on around them and what is expected of them. This is accomplished by using techniques and materials to provide better definition of the elements of the facility, to visually highlight important information, and to reduce the stress on users that results from operating a vehicle in a complex environment."

This online manual provides guidance in the selection of landscape and aesthetic design criteria for highway and street project development.[34]

ADA Guidelines/TAS

To ensure that buildings and facilities are accessible to and usable by people with disabilities, the Americans with Disabilities Act establishes accessibility requirements for state and local government facilities, places of public accommodation, and commercial facilities. Under the ADA, the Access Board has developed and continues to maintain design guidelines for accessible buildings and facilities known as the ADA Accessibility Guidelines. The ADAAG covers a wide variety of facilities and establishes minimum requirements for new construction and alterations. The ADAAG and other technical assistance materials are available at www.access-board.gov.

The TAS are similar to, but sometimes more restrictive, than the ADAAG. Refer to www.license.state.tx.us/ab/abtas.htm or contact the Design Division for more information. As part of complying with Texas requirements, the proposed plans must be submitted to the Texas Department of Licensing and Regulation (TDLR) for projects where the estimated cost of pedestrian elements is over $50,000. Failure to submit the plans can result in a disciplinary action by the appropriate professional licensing board.

The Access Board is undertaking rulemaking to supplement the ADA Accessibility Guidelines, which primarily cover facilities on sites, by adding new provisions specific to public rights of way. The ADA requires that access for persons with disabilities is provided wherever a pedestrian way is newly built or altered, and that the same degree of convenience, connection, and safety afforded the public is available to pedestrians with disabilities. The ADA applies where a pedestrian route or facility is altered as part of a planned project to improve existing public rights of way.

Building a True Community Report. The Board chartered an advisory committee in 1999 to develop recommendations on guidelines for accessible public rights of way. The committee included many industry representatives and its work resulted in the January 2001 report *Building a True Community.* [35] This document provides recommendations to the Access Board for guidelines covering construction or alteration of public rights of way. The report includes advisory notes, figures, and discussion of issues that merit further study or special attention in the Board's rulemaking. It covers the following components of public streets and sidewalks:

- sidewalks,
- curb ramps and landings,
- street crossings,
- pedestrian signals and walk phasing,
- street fixtures and furnishings,
- vehicular ways,
- parking, and
- other components of public rights of way.

Draft Guidelines. The Access Board reviewed the committee's report in depth and wrote a set of draft guidelines based on the committee's recommendations. The draft guidelines departed from the advisory committee's report in several areas[36] so an advance draft of the guidelines was released for comment on June 17, 2002. After reviewing comments from the public, industry groups, state and local governments, and advisory committee members, the Board will develop a proposed rule to add requirements for public rights of way projects to the ADAAG. The ADA has required accessible construction since 1991. The new guidelines will make it easier for engineers to comply with the requirements on public right-of-way projects.

Section 4
Safety

Overview

The *Green Book* notes that crashes seldom result from a single cause — usually several influences affect the situation at any given time. These influences can be separated into three groups:

- the human element,
- the vehicle element, and
- the highway element.

Roadways and intersections should be designed to minimize decisions and to reduce unexpected situations for all modes. The number of crashes increases with an increase in the number of decisions required of the driver. Uniformity of roadway design features and traffic control devices plays an important role in reducing the number of required decisions. Uniformity helps all users become aware of what to expect at certain types of intersections.

Intersection Crash Statistics

In the year 2000, more than 2.8 million intersection-related crashes occurred in the United States, representing 44 percent of all reported crashes.[36] Other national statistics include the following:

- About 8500 fatalities (23 percent of the total fatalities) and almost one million injury crashes occurred at or within an intersection. Of the fatal crashes at intersections, 47 percent involve left turns (or U-turns), 2 percent involve right turns, and 51 percent involve no turning maneuver.
- At intersections 8 percent of the crashes involve alcohol.

Table 2-4 lists a comparison of the Texas intersection crashes with the values published by the National Highway Traffic Safety Administration (NHTSA). A notable difference between the Texas and NHTSA values is the percent of injury crashes. Texas is much higher (65 percent) than the national value of 32 percent. Correspondingly, the property-damage-only (PDO) crashes represent a much smaller percent of all crashes in Texas as compared to the national data. Presumably this difference is a reflection of the thresholds used in Texas for reporting crashes.

For Texas, approximately 55 percent of crashes are at or related to an intersection or driveway (see Table 2-5). Nationally, 44 percent of crashes occur at intersections or are intersection related. A slightly higher percentage of fatal crashes are occurring at Texas intersections and driveways (26 percent) as compared to the national data (23 percent).

Of on-system urban crashes in the year 2000, 26 percent occurred at intersections and 20 percent were intersection related. A crash in an urban area is more likely to be at or related to an intersection or driveway than a crash in a rural area. Only 51 percent of the urban crashes were at or near an intersection as compared to 37 percent for rural crashes.

Table 2-4. Intersection Safety Comparison.

	2000 NHTSA[a]		2000 TEXAS[b]		2000 TEXAS[d] URBAN	
	Freq	**%**	**Freq**	**%**	**Freq**	**%**
ALL CRASHES						
Fatality Crashes	37,409	0.6	3247	1.0	1405	0.6
Injury Crashes	2,070,000	32.4	205,569[c]	64.5	160,584[c]	66.9
PDO Crashes	4,286,000	67.0	110,174	34.5	78,163	32.5
All Crashes	**6,394,000**	**100.0**	**318,990**	**100.0**	**240,152**	**100.0**
INTERSECTION AND INTERSECTION-RELATED CRASHES						
Fatality Crashes	8474	22.6	844	26.0	464	33.0
Injury Crashes	995,000	48.1	120,477[c]	58.6	101,880[c]	63.4
PDO Crashes	1,804,000	42.1	53,928	48.9	42,946	54.9
All Crashes	**2,807,000**	**43.9**	**175,249**	**54.9**	**145,290**	**60.5**

[a] Data from 2000 Motor Vehicle Crash Data from Fatality Analysis Reporting System (FARS)[37]

[b] Data reflect statewide crashes (both on and off system) for 2000

[c] Includes class A, B, and C injury categories

[d] Data reflect statewide crashes for intersection codes of: intersection, intersection related, and driveways

Table 2-5. Distribution of 2000 On-System Texas Urban Crashes by Relationship to Intersections.

Intersection	Urban		Rural		Total	
	Frequency	**Percent**	**Frequency**	**Percent**	**Frequency**	**Percent**
Intersection	31,592	26	9085	17	40,677	23
Intersection-Related	23,429	20	5970	11	29,399	17
Driveway Access	10,062	8	5183	9	15,245	9
Non-Intersection	54,500	46	34,654	63	89,154	51
Total	**119,583**	**100**	**54,892**	**100**	**174,475**	**100**

Older Driver Crashes

The U.S. Census Bureau[38] projects that by 2030, one in five Americans will be aged 65 years and over. Automobile fatalities are expected to increase 45 percent for drivers over age 75, and pedestrian fatalities are also expected to increase as the population ages.[39]

The single greatest concern in accommodating older road users, both drivers and pedestrians, is the ability of these persons to safely maneuver through intersections. The findings of one widely cited analysis of nationwide crash data reveal the percent of injuries and fatalities at intersections in the United States. For drivers 65 years and older, 37 percent of fatal crashes occur at intersections, compared with 16 percent or less for drivers up to 65 years of age.[38] Figure 2-4 illustrates the findings for Texas during the period 1998 to 2000 as a function of age and road user type (driver or pedestrian). The Texas data revealed trends similar to the earlier national study. A disproportionate number of fatalities for older drivers are associated with intersections. In Texas, 41 percent of the older driver fatalities are associated with intersections as compared to only 19 percent of drivers age 26 to 64. Both findings reinforce a long-standing recognition that driving situations involving complex speed-distance judgments under time constraints—the typical scenario for intersection operations—are more problematic for older drivers than for their younger counterparts.

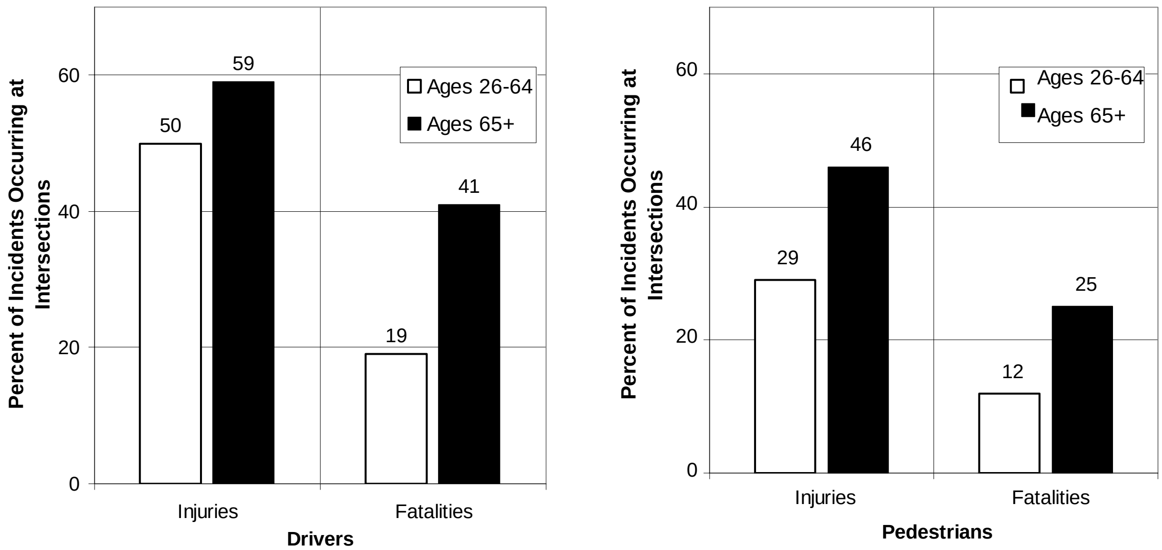

Figure 2-4. Percentage of Injuries and Fatalities at Intersections or Intersection Related for Drivers and Pedestrians (1998–2000 Texas Urban Data).

Crash Frequency. Older drivers are involved in a disproportionate number of crashes where there is a higher-than-average demand imposed on driving skills. The driving maneuvers that most often precipitate higher crash frequencies among older drivers include:

- making left turns across traffic,
- merging with high-speed traffic,
- changing lanes on congested streets in order to make a turn,
- crossing a high-volume intersection,
- stopping quickly for queued traffic, and
- parking.

Countermeasures. The following countermeasures may help to alleviate the potential problems of the older driver and may improve overall driver behavior:

- Improve sight distance by modifying designs and removing obstructions, particularly at intersections and interchanges.
- Assess sight triangles for adequacy of sight distance.
- Provide decision sight distances as appropriate.
- Simplify and redesign intersections and interchanges that require multiple information reception and processing.

- Increase use of protected left-turn signal phases.
- Increase vehicular clearance times at signalized intersections.
- Use offset left-turn lanes.
- Provide wider and brighter pavement markings.
- Provide larger and brighter signs.
- Reduce sign clutter.
- Provide more redundant information such as advance guide signs for street name, indications of upcoming turn lanes, and right-angle arrows ahead of an intersection where route turns or where directional information is needed.

Before implementing a countermeasure, the impact on all modes of travel should be considered.

Pedestrian Crashes

The Roadway Safety Foundation predicts that pedestrian fatalities will increase as the population ages.[39] Older pedestrians are more likely to have some vision loss and also may have mobility impairments that cause them to need more time to cross the street. Characteristics of national pedestrian crashes include:

- Based on an analysis of more than 8000 crashes, from six states, the most frequent crash types are:[40]
  - dart-out first half (i.e., the pedestrian is struck in the first half of the street being crossed) (24 percent),
  - intersection dash (13 percent),
  - dart-out second half (10 percent),
  - midblock dart (8 percent), and
  - turning-vehicle crashes (5 percent).
- A 1999 report stated that individuals at both extremes of age were more likely to be victims of pedestrian accidents.[41]
- Pedestrians between the ages of 25 and 44 have been found to be involved in a higher rate of alcohol-related incidents.[42]
- Speeding is another major contributing factor in pedestrian crashes, being a factor in 29 percent of all fatal crashes involving pedestrians in 2000.[40]
- Pedestrian crashes are most likely to occur during daytime traffic peaks, but fatal crashes are more likely to occur between 5 pm and 11 pm. Elderly pedestrians however, are more likely to become involved in daytime incidents.[43]
- The majority of pedestrian fatalities occurred in urban areas (69 percent).[44]
- A 1992 analysis included an examination of pedestrian crashes and the collision types for older pedestrians. The results showed older pedestrians to be overrepresented in both right- and left-turn accidents. The young-elderly (ages 65 to 74) were most likely

to be struck by a vehicle turning right, whereas the old-elderly (age 75 and older) were more likely to be struck by a left-turning vehicle.[22]

- Roadway/environmental factors were identified in one-fourth of the pedestrian crashes. The most common factor cited was blocked vision, most often the result of bushes, trees, or other vegetation growing near the edge of the roadway or driveway.[45]

Bicyclist Crashes

Characteristics of national bicyclist crashes available from a 1996 report that evaluated 3000 bicycle-motor vehicle crashes from six states include the following:[45]

- Bicycle-motor vehicle crashes were distributed as:
  - parallel paths (36 percent),
  - crossing path (57 percent), and
  - specific circumstances (6 percent);
- Most frequent parallel path crashes were:
  - motorists turn/merge into bicyclist’s path (34 percent),
  - motorist over-taking (24 percent), and
  - bicyclists turn/merge into motorist’s path (21 percent);
- Most frequent crossing path crashes were:
  - motorist failed to yield (38 percent),
  - bicyclist failed to yield at an intersection (29 percent), and
  - bicyclist failed to yield midblock (21 percent).

Texas Pedestrian and Bicyclist Crashes

Characteristics of Texas pedestrian and bicyclist (called pedal cyclist in the Texas crash database) crashes occurring between 1998 and 2000 include:

- Although pedestrian crashes account for only 2 percent of Texas crashes and pedal cyclists account for 1 percent (see Table 2-6), their severity is much greater compared to other collisions. In Texas, 7 percent of the pedestrian crashes end in death as compared to 1 percent for all urban crashes (see Figure 2-5). The remaining 93 percent of pedestrian crashes end in some form of injury. For bicyclists, 99 percent of the crashes end in injury or fatality.
- For pedestrian crashes, 61 percent were non-intersection related. The intersection or driveway crashes were 10 percent at an intersection, 22 percent intersection related, and 7 percent driveway access. While most of the pedestrian crashes are non-intersection, most of the cyclist crashes are at or near an intersection or driveway. Only 29 percent of the bicyclist crashes were non-intersection.

Table 2-6. Distributions of 1998 – 2000 Texas Urban On-System and Off– System Crashes by First Harmful Event.

Collision With	On System		Off System		All Urban	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Animal	718	0	288	0	1006	0
Another Vehicle In Transport	288,027	81	264,879	75	552,906	78
Fixed Object	49,897	14	50,176	14	100,073	14
Other Non-Collision	1660	0	1370	0	3030	0
Other Object	1361	0	759	0	2120	0
Overturned	8676	2	4850	1	13,526	2
Parked Car	2702	1	14,648	4	17,350	2
Pedal Cyclist	***1356***	***0***	***5015***	***1***	***6371***	***1***
Pedestrian	***3007***	***1***	***9033***	***3***	***12,040***	***2***
RR Train	69	0	302	0	371	0

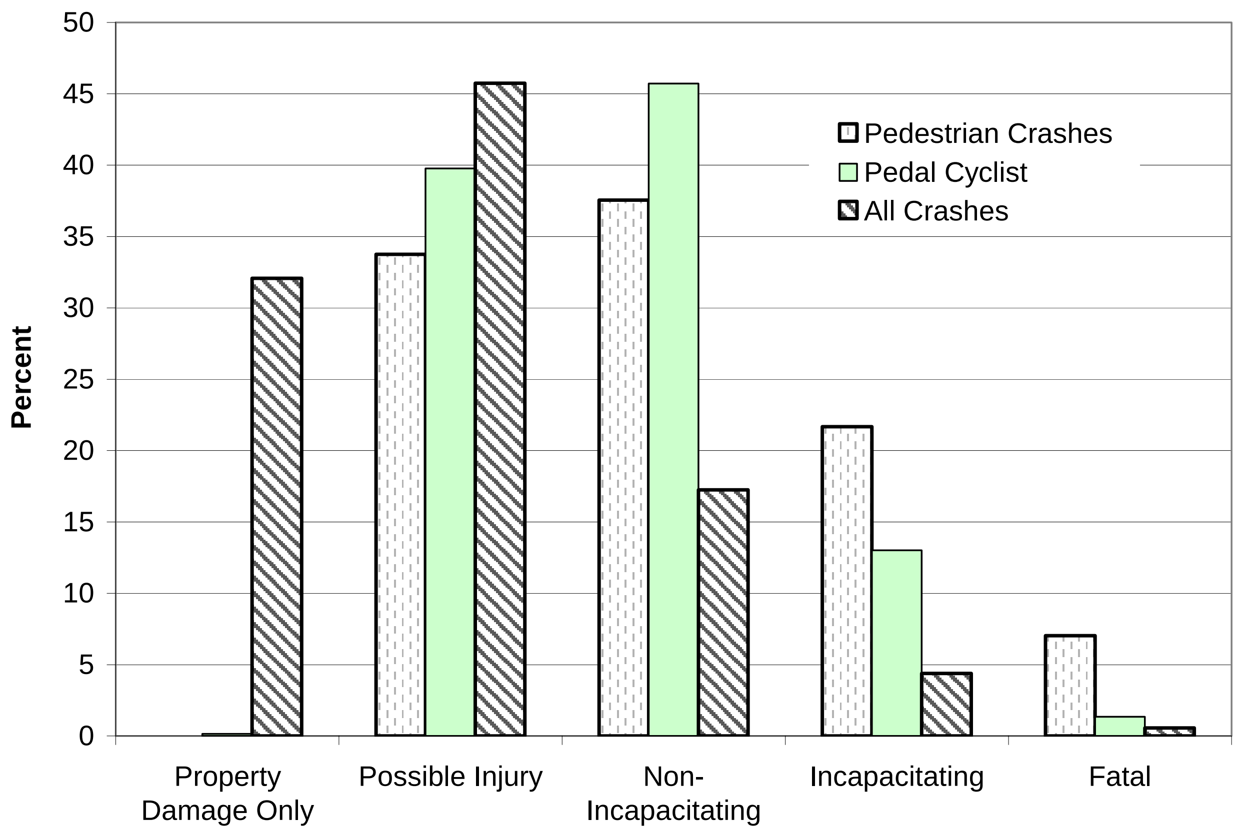

Figure 2-5. Pedestrian and Bicyclist Accident Severity (Texas Urban On- and Off-System Roadways 1998–2000).

- Most crashes and most pedestrian and bicyclist crashes occur between the hours of 3:00 pm and 7:00 pm. Another peak occurs in the morning between 7:00 am and 8:00 am (see Figure 2-6).
- The highest percent of pedestrian crashes occur on a Friday (18 percent), while Sunday is the least likely day for a pedestrian crash (11 percent). The other days of the week

had: Monday (14 percent), Tuesday (14 percent), Wednesday (14 percent), Thursday (15 percent), and Saturday (14 percent). Bicyclists followed a similar pattern with most crashes on Friday (16 percent) and least on Sunday (11 percent).

- ♦ The highest percent of pedestrian crashes occurs in October and April (see Figure 2-7). For pedal cyclists, the highest percent occurs in April and May followed by June, July, August, and September. Months with the lowest bicyclist crashes are November, December, and January.
- ♦ Other characteristics of pedestrian (and bicyclist) crashes in Texas are: 62 percent (77 percent) occurred in the daylight, 94 percent (97 percent) occurred in clear weather, 91 percent (95 percent) occurred on dry surfaces, and 98 percent (99 percent) involved one vehicle.

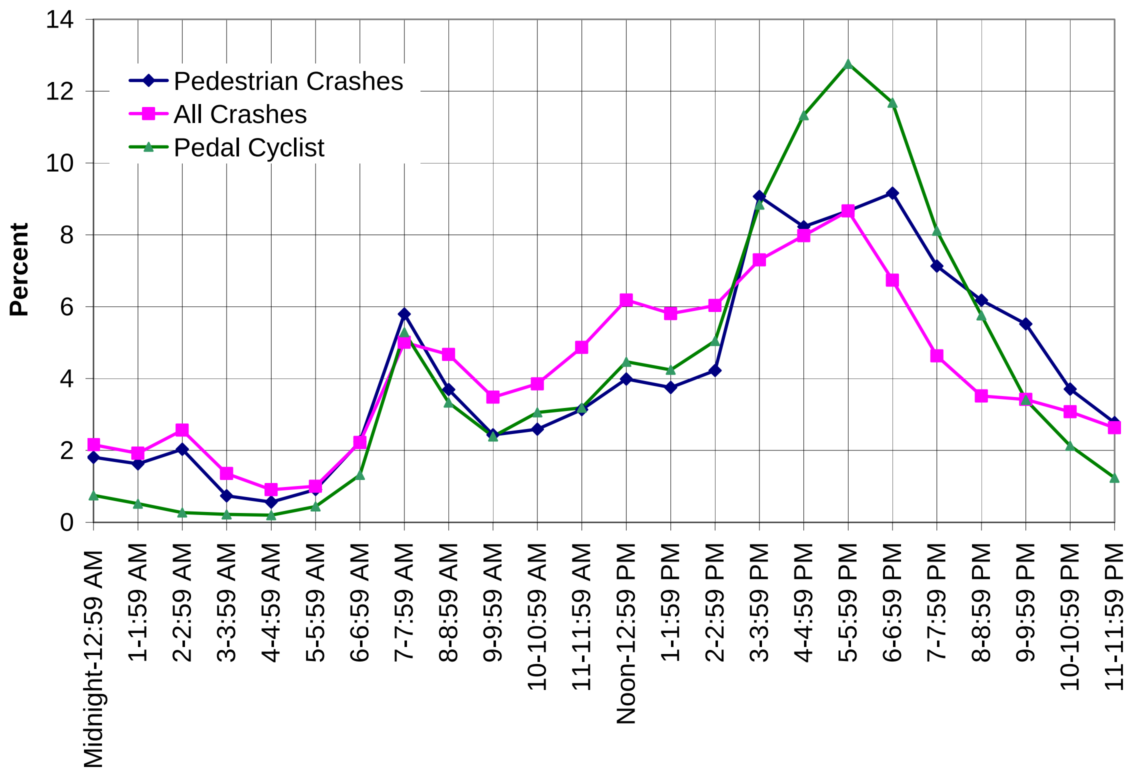

Figure 2-6. Pedestrian and Bicyclist Crashes versus All Crashes (1998–2000 Texas Urban On- and Off-System Roadways by Time of Day).

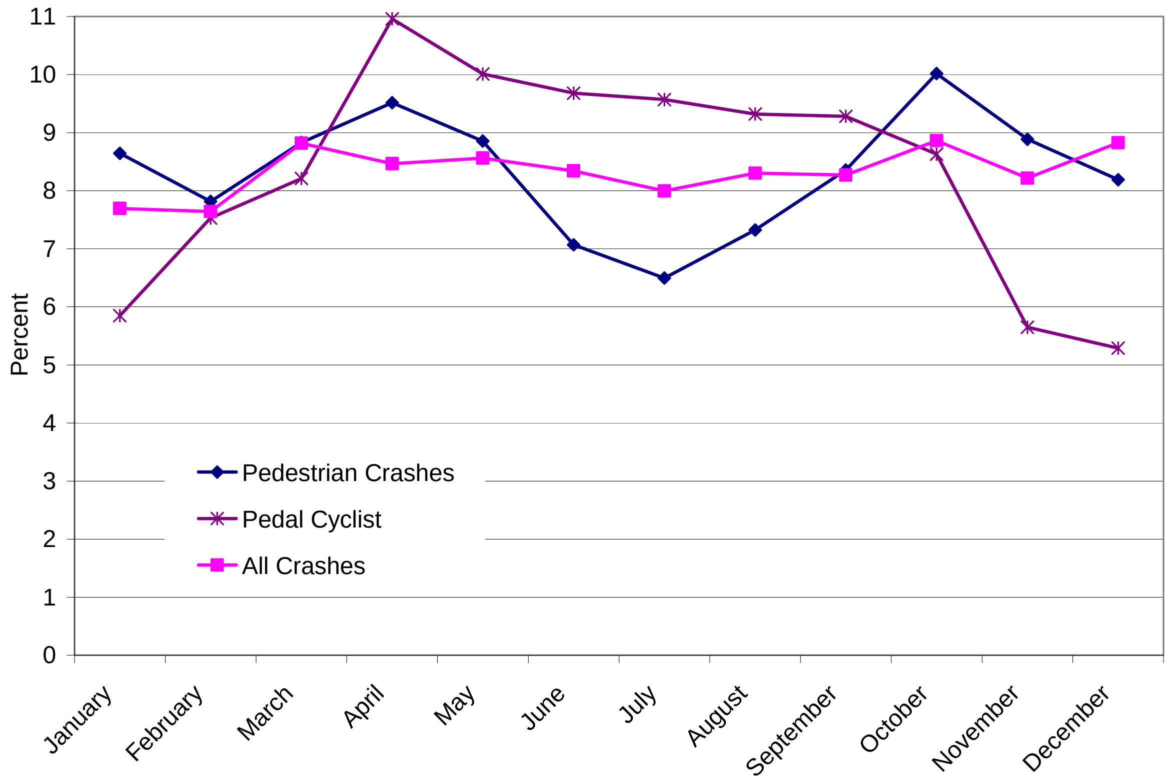

Figure 2-7. Pedestrian and Bicyclist Crashes versus All Crashes (1998–2000 Texas Urban On- and Off-System Roadways by Month).

AASHTO Strategic Highway Safety Plan

In 1998, AASHTO approved its Strategic Highway Safety Plan, which was developed by the AASHTO Standing Committee for Highway Traffic Safety with the assistance of the Federal Highway Administration, the National Highway Traffic Safety Administration, and the Transportation Research Board Committee on Transportation Safety Management. The plan includes strategies in 22 key emphasis areas that affect highway safety. The goal is to reduce the annual number of highway deaths by 5000 to 7000. NCHRP Project 17-18(3) is developing a series of guides to assist state and local agencies in reducing injuries and fatalities in targeted areas. The guides correspond to the emphasis areas outlined in the AASHTO Strategic Highway Safety Plan. Each guide includes a brief introduction, a general description of the problem, the strategies/countermeasures to address the problem, and a model implementation process. The fifth volume of the NCHRP Report 500, *Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*[46] provides strategies that can be employed to reduce the number of unsignalized intersection collisions. An expanded version of each volume, with additional reference material and links to other information sources, is available on the AASHTO Web site at http://transportation+1.org/safetyplan.

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Chapter 3
Design Elements

Contents:

Section 1
Intersection Sight Distance

Overview

The provision of appropriate intersection sight distance (ISD) reduces the potential for conflicts at intersections.

General Considerations

As a motorist approaches an intersection, the right of way is established by the traffic control devices or by state traffic laws. The *Texas Drivers Handbook*[1] should be consulted for motorist responsibilities at intersections without traffic control devices.

The operator of a vehicle approaching an intersection should have an unobstructed view of the entire intersection and an adequate view of the intersecting highway to permit control of the vehicle to avoid a collision. When designing an intersection, the following factors should be considered:[2]

- Adequate sight distance should be provided along both highway approaches to allow drivers and other road users to anticipate and avoid potential collisions.
- Gradients of intersecting roadways should be as flat as practical on sections that are to be used for storage of stopped vehicles.
- Combination of vertical and horizontal curvature should allow adequate sight distance of the intersection.
- Traffic lanes should be clearly visible at all times.
- Lane and crosswalk markings and signs should be clearly visible and understandable from a desired distance.
- Intersections should be evaluated for the effects of barriers, rails, retaining walls, landscaping, curbside parking, and other vertical elements on sight distance.

Sight distance is also provided at intersections to allow the drivers of stopped vehicles a sufficient view of the intersecting highway. If the available sight distance of an entering or crossing vehicle is at least equal to the appropriate stopping sight distance for the major road, then drivers have sufficient sight distance to anticipate and avoid collisions. To enhance traffic operations, intersection sight distances that exceed stopping sight distances are desirable along the major road.

Sight Triangles

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 traffic on the opposing roadway. The dimensions of the triangle are based on the design speed of the intersection 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.

Approach Sight Triangles. Approach sight triangles are those visually clear areas on either side of an approach to an intersection that allow drivers approaching an intersection enough time to slow or stop to avoid vehicles approaching on the crossing roadway. Figure 3-1A shows typical clear sight triangles to the left and to the right for a vehicle approaching an uncontrolled or yield-controlled intersection. The dimension “a” represents the sight distance along the minor road while “b” represents the sight distance along the major road. The decision point shown in the figure is that point at which the driver should begin to stop if another vehicle is approaching on the cross street.[3] Because of the use of Stop signs or traffic signals, approach sight triangles, as shown in Figure 3-1A, are not typically needed in urban areas.

Departure Sight Triangles. A departure sight triangle provides the driver of a stopped vehicle the sight distance necessary to either cross the intersection or merge in the traffic stream. Figure 3-1B shows typical departure sight triangles to the left and right of a vehicle at an intersection. Unlike the approach sight triangles, departure sight triangles should be provided for intersections with stop control, yield control, and some signalized intersections. The dimensions “a” and “b” shown in Figure 3-1B are based on assumptions derived from field observations of driver gap acceptance behavior. The dimension “a” is this distance from the stopped driver’s eye to the center of lane on the intersection approach. The dimension “b” provides the distance that the vehicle on the intersecting approach sees the minor-road driver.

The decision point (see Figure 3-1B) of the departure sight triangle on the minor road should be 14.4 ft [4.4 m] from the edge of the major-road traveled way. This represents the typical position of the minor-road driver’s eye when a vehicle is stopped relatively close to the major road. Field observation of vehicle stopping positions found that, where necessary, drivers will stop with the front of their vehicle 6.5 ft [2.0 m] or less from the edge of the major-road traveled way. Measurements of passenger cars indicate that the distance from the front of the vehicle to the driver’s eye for the current U.S. passenger car population is nearly always 8 ft [2.4 m] or less.[4] Where practical, it is desirable to increase the distance from the edge of the major-road traveled way to the vertex of the clear sight triangle from 14.4 ft to 17.8 ft [4.4 m to 5.4 m]. This increase allows 10 ft [3.0 m] from the edge of the major-road traveled way to the front of the stopped vehicle, providing a larger sight triangle. The length of the sight triangle along the minor road (distance “a” in Figure 3-1B) is measured from the position of the driver’s eye to the midpoint of lane of interest (either the first lane to the left or the first lane to the right, depending on the sight triangle being examined).

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 ft

[1080 mm] above the roadway. The object that is used for design approximates the height of an automobile and is assumed to be 3.5 ft [1080 mm] 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 ft [2330 mm] above the roadway surface.

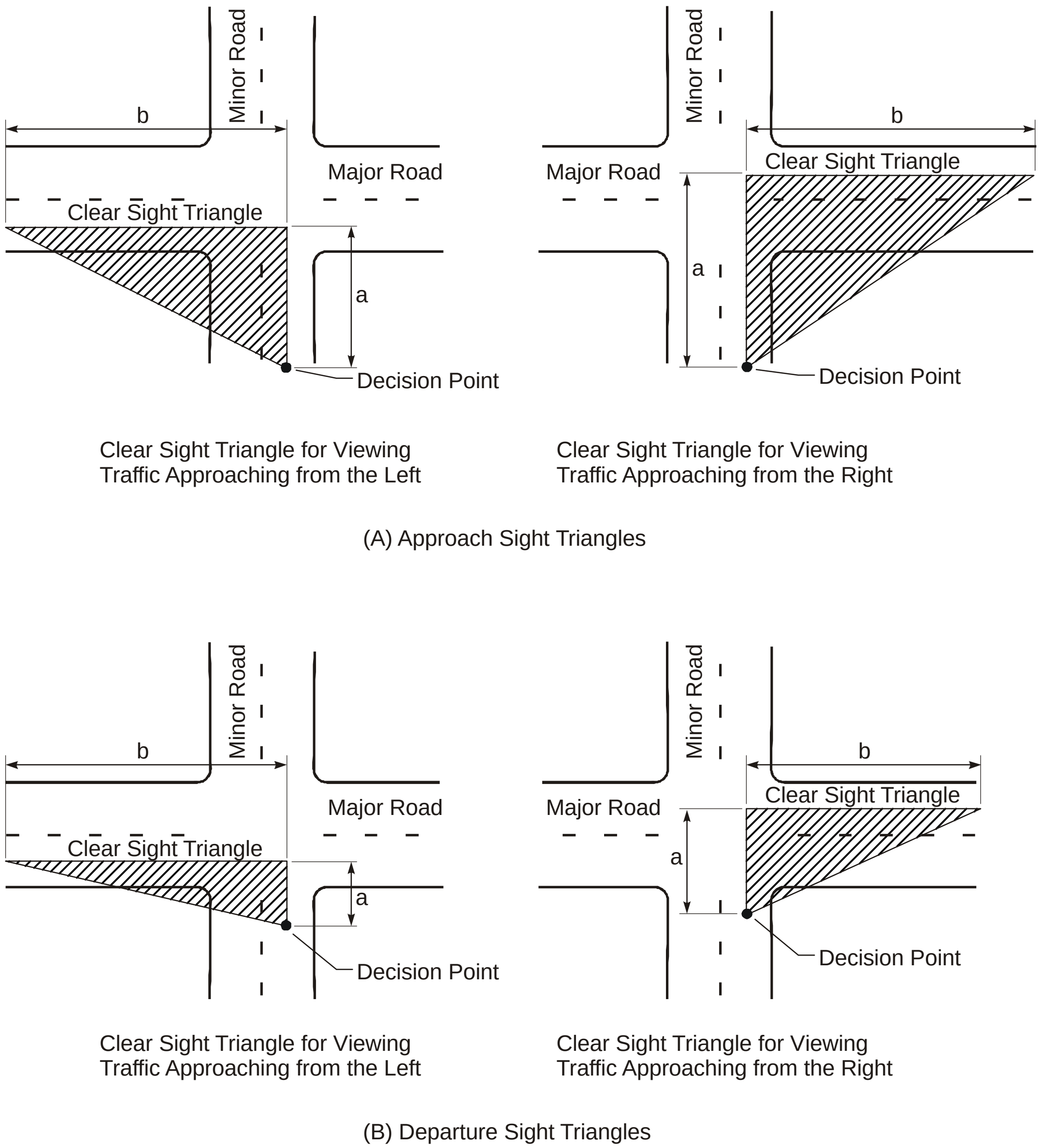


Figure 3-1. Intersection Sight Triangles.[3]

Intersection Control

The sight distance required at intersections varies depending on the type of intersection control. Sight distance criteria are discussed in AASHTO's *A Policy on Geometric Design for Highways and Streets.*[3]

Case A – Intersections with No Control. The sight triangles for an intersection with no control should allow the driver of a vehicle to see an approaching vehicle and have enough time to stop before reaching the intersection. Chapter 9 of AASHTO's *Green Book* provides tables (Exhibits 9-51 and 9-53, respectively) showing the lengths for the approach sight triangles shown in Figure 3-1A and adjustment factors for use where the approach grades are greater than 3 percent. Use of this procedure is demonstrated in ***Application 3-1*** <link>.

Case B – Intersections with Stop Control on the Minor Road. The departure sight triangles for vehicles from a minor road to a major road should allow the driver of a vehicle to see approaching vehicles and choose gaps in the traffic that allow them to accelerate and complete a crossing maneuver or a turn without unduly interfering with major-road traffic operations. The *Green Book* method to determine the required sight distance and determine dimension "b" from Figure 3-1A is shown in Table 3-1. It uses the distance traveled at the road's design speed during the time gap for the maneuvers to determine the intersection sight distance.

Table 3-1. Case B1, Left Turn from Minor Roadway, Stop Control.[3]

US Customary	**Metric**
ISD = 0.278 V_{major} t_g	**ISD = 1.47 V_{major} t_g**
where: ISD = intersection sight distance (length of the leg of sight triangle along the major road) (ft) V_{major} = design speed of major road (mph) t_g = time gap for minor road vehicle to enter the major road (s)	where: ISD = intersection sight distance (length of the leg of sight triangle along the major road) (m) V_{major} = design speed of major road (km/h) t_g = time gap for minor road vehicle to enter the major road (s)

If medians on divided roadways are wide enough to store vehicles, then departure sight triangles should be provided from the median stop position. If they are not wide enough to store vehicles then the median width's effects should be included in the determination of the required sight distance as an additional lane.

Departure sight triangle for intersections with stop control on the minor road should be considered for three situations:

- ***Case B1 – Left turn from the minor road.*** Uses *Green Book* Exhibits 9-54 to 9-56. Use of this procedure is demonstrated in ***Application 3-2*** <link>.
- ***Case B2 – Right turn from the minor road.*** The departure sight triangles for a right turn from the minor road are similar to the left-turn triangles except that the time gaps required can be reduced by one second. *Green Book* Exhibits 9-57 to 9-59 contain information on the procedure. Use of this procedure is demonstrated in ***Application 3-3*** <link>.
- ***Case B3 – Crossing maneuver from the minor road.*** When vehicles are crossing the major road, the sight triangles provided in Cases B1 and B2 should be sufficient;

however if any of the following situations exist, then the sight triangles should be checked:

- where left and/or right turns are not permitted from a particular approach and the crossing maneuver is the only legal maneuver;
- where the crossing vehicle would cross the equivalent width of six or more lanes; or
- where substantial volumes of heavy vehicles cross the roadway and steep grades that might slow the vehicle while its back portion is still in the intersection are present on the departure roadway on the far side of the intersection.

The *Green Book* provides tables and figures to determine the required sight distance for Case B3 (see *Green Book* Exhibits 9-57 to 9-59). Use of this procedure is demonstrated in ***Application 3-4*** <link>.

Case C – Intersections with Yield Control on the Minor Road. For intersections with yield control, approach sight triangles are larger than those needed for stop control. The following two situations are considered for yield control:

- ***Case C1 – Crossing maneuver from the minor road.*** *Green Book* Exhibits 9-60 to 9-62 contain the sight distance lengths for Case C1. Use of this procedure is demonstrated in ***Application 3-5*** <link>.
- ***Case C2 – Left or right turn from the minor road.*** *Green Book* Exhibits 9-63 to 9-65 contain the sight distance lengths for Case C2. Use of this procedure is demonstrated in ***Application 3-6*** <link>.

Case D – Intersections with Traffic Signal Control. There are no required sight triangles in the *Green Book* for signalized intersections, although the following sight conditions should be considered:

- The first vehicle at one approach should be visible to the first vehicles on all the other approaches.
- Left-turning vehicles should have sufficient sight distance to select gaps in oncoming traffic and complete left turns.
- Where right turn on red is permitted, as at most locations, the departure sight distance to view traffic approaching from the left should be provided, as discussed in Case B2.

If the signal will be placed on flashing mode (yellow for the major roadway and red for the minor roadway) then the appropriate sight triangles for Case B (left and right) should be provided on the minor road approaches.

Use of the Case D procedure is demonstrated in ***Application 3-7*** <link>.

Case E – Intersections with All-Way Stop Control. There are no sight triangle requirements for all-way stop control, although the first vehicles at every approach should be visible to each other.

Case F – Left Turns from the Major Road. Drivers turning left across oncoming traffic of a major roadway (see Figure 3-2) require sufficient sight distance to determine when it is safe to cross and there is time to complete the maneuver. *Green Book* Exhibits 9-66 to 9-68 provide the intersection sight distance lengths for this case. 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 for left turns from divided highways should be checked because of the possibility of sight obstructions in the median. At four-leg intersections on divided highways, opposing vehicles turning left can block a driver's view of oncoming traffic. Intersection designs using offset opposing left-turn lanes can provide drivers with a better view of oncoming traffic <insert link to Chapter 4, Section 2, Offset Left-Turn Lanes>. Use of the Case F procedure is demonstrated in ***Application 3-8*** <link>.

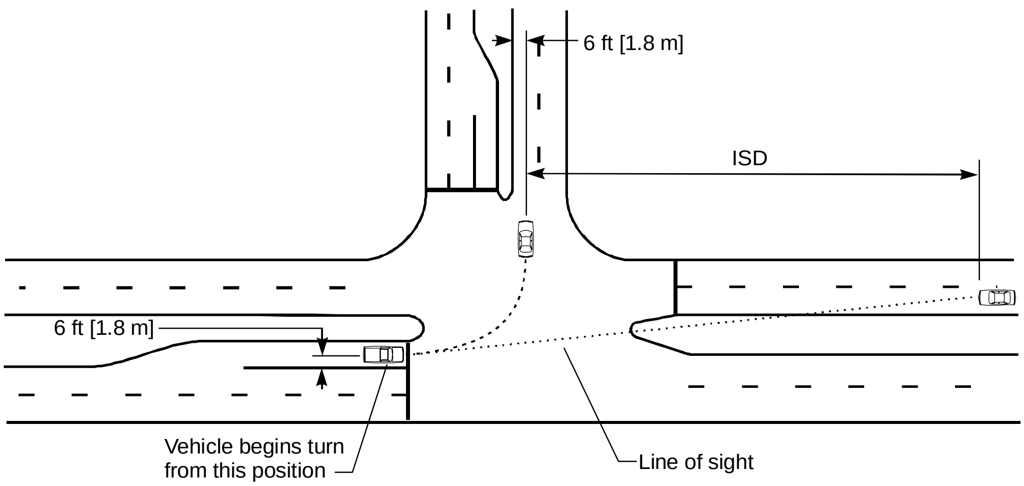


Figure 3-2. Sight Triangle for Left Turn from Major Roadway.

Table 3-2 lists the ISD cases along with a list of the relevant *Green Book* exhibits and potential conditions that would result in adjusting the base ISD value.

Table 3-2. Summary of Intersection Sight Distance Cases and Potential Adjustments.

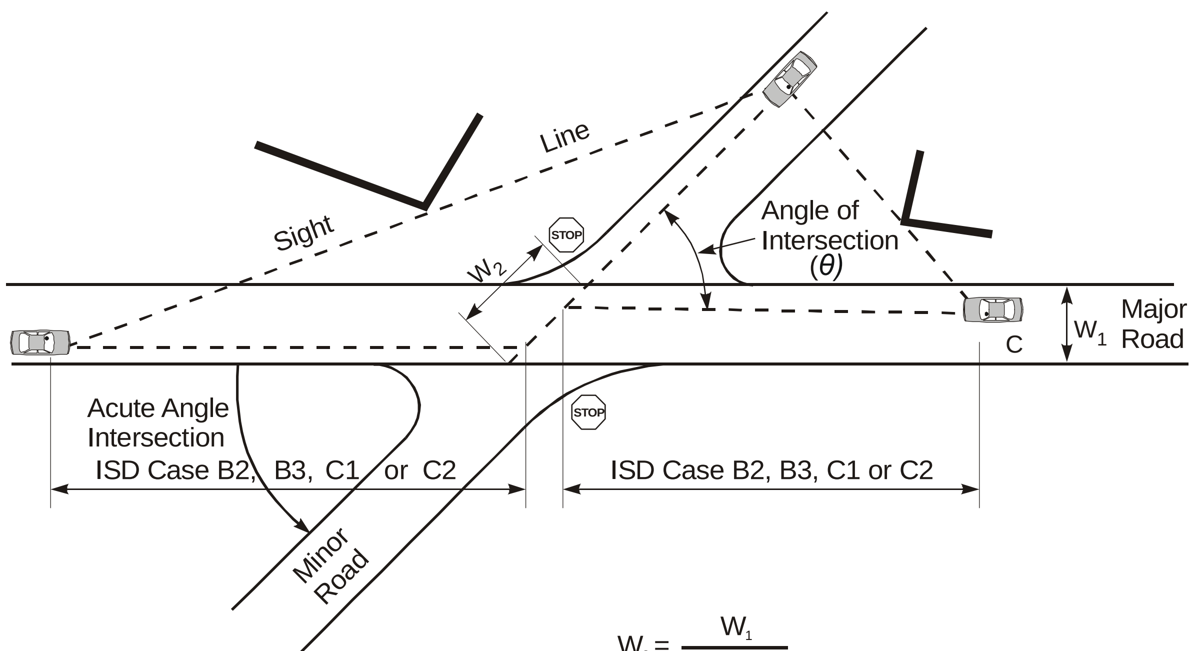
Case	Description	Potential Adjustments
Case A	Intersections with No Control	♦ Approach Grade > 3%
Case B1	Intersections with Stop Control on the Minor Road, Left Turn from the Minor Road	♦ Design Vehicle ♦ Approach Grade > 3% ♦ Number of lanes or presence of median on major road to be crossed
Case B2	Intersections with Stop Control on the Minor Road, Right Turn from the Minor Road	♦ Design Vehicle ♦ Approach Grade > 3%
Case B3	Intersection with Stop Control on the Minor Road, Crossing Maneuver from the Minor Road	♦ Design Vehicle ♦ Approach Grade > 3% ♦ Number of lanes or presence of median on major road to be crossed
Case C1	Intersections with Yield Control on the Minor Road, Crossing Maneuver from the Minor Road	♦ Design Vehicle ♦ Approach Grade > 3% ♦ Number of lanes or presence of median on major road to be crossed
Case C2	Intersections with Yield Control on the Minor Road, Left or Right Turn from the Minor Road	♦ Design Vehicle ♦ Approach Grade > 3% ♦ Number of lanes or presence of median on major road to be crossed
Case D	Intersections with Traffic Signal Control ♦ First stopped vehicle on one approach should be visible to the drivers of the first stopped vehicles on each of the other approaches. ♦ For left-turning vehicles, check Case B1 or Case F. ♦ If on two-way flash, check Case B. ♦ If right turns on red are permitted, check Case B2.	
Case E	Intersections with All-Way Stop Control ♦ First stopped vehicle on one approach should be visible to the drivers of the first stopped vehicles on each of the other approaches.	
Case F	Left Turns from the Major Road	♦ Design Vehicle ♦ Number of lanes or presence of median on major road to be crossed

Adjustment for Skewed Intersections

When two roadways intersect at an angle less than 60 deg and realignment to increase the angle of intersection is not justified, some of the factors for determination of intersection sight distance may need adjustment. Realignment may not be justified in cases involving intersections with low crossroad traffic volumes and no apparent safety concerns. However, if traffic volumes are expected to increase in the near term, or if the intersection may be signalized, realignment should be considered.

At an oblique-angle intersection, the length of the travel paths for some turning and crossing maneuvers will be increased. The actual path length for a turning or crossing maneuver can be computed by dividing the total widths of the lanes (plus the median width, where appropriate) to be crossed by the sine of the intersection angle. If the actual path length exceeds the total widths of the lanes to be crossed by 12 ft [3.7 m] or more, then an appropriate number of additional lanes should be used in applying the adjustment for the number of lanes to be crossed, as discussed in the *Green Book*[3] in its Chapter 9 section, Effect of Skew.

In the obtuse-angle quadrant of an oblique-angle intersection, the angle between the approach leg and the sight line is often so small that drivers can look across the full sight triangle with only a small head movement (see Figure 3-3). However, in the acute-angle quadrant, drivers are required to turn their heads considerably to see across the entire clear sight triangle. For this reason, it is recommended that the sight distance criteria for Case A not be applied to oblique-angle intersections and that sight distances at least equal to those for Case B be provided, whenever practical.[3]



$$W_2 = \frac{W_1}{\sin \theta}$$

Figure 3-3. Sight Triangles at Skewed Intersections.[3]

Section 2
Horizontal Alignment

Overview

There are a number of general considerations that are important in attaining safe, smooth flowing, and aesthetically pleasing facilities.

Horizontal Curvature at Intersections

Intersections on sharp horizontal curves should be avoided.[3] Superelevation and the widening of pavement on those curves complicates the design of the intersection and may affect sight distance. In addition, the curves should be evaluated with respect to the requirements imposed by the design speed on the respective roadways. The greatest benefit is obtained when the design speed used for the curve approaches that of the major roadway.

The placement of an intersection at the beginning of a horizontal curve should be avoided. Realignment as shown in Figure 3-4 typically provides better visibility and guidance onto the major roadway.[3]

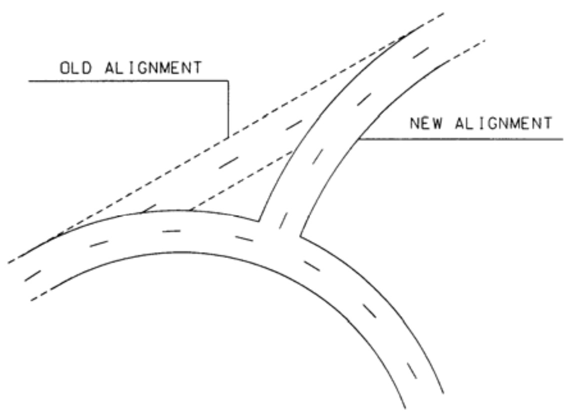


Figure 3-4. Realignment of Tangent Roadway at Intersection.[3]

The curves used for the realignment shown in Figure 3-4 should be carefully considered and be selected with regard to the design speed on the realigned roadway.

Realigning Multileg Intersections

Intersections with five or more intersection legs (multileg) should be avoided wherever practical.[3] At locations where multileg intersections are used, it may be satisfactory to have all intersection legs intersect at a common paved area, where volumes are light and stop control is used. At major intersections, traffic operational efficiency can often be improved by reconfigurations that remove some conflicting movements from the major intersection. Such reconfigurations are accomplished by realigning one or more of the intersections, as shown in Figure 3-5.

Figure 3-5A shows the simplest application of this principle on an intersection with five approach legs. The diagonal leg is realigned to join the upper road at sufficient distance from the main intersection to form two distinct intersections, each of which can be operated simply. The left-to-right highway is likely to be the more important route, and for this reason the diagonal leg is realigned to locate the new intersection on the less important road.

Figure 3-5B illustrates an intersection with six approach legs, two of which are realigned in adjacent quadrants to form a simple four-leg intersection at an appropriate distance to the right of the main intersection, which is itself converted to a simple four-leg intersection. This pattern applies where the top-to-bottom highway at the left is the more important route. If the left-to-right highway is more important, it may be preferable to realign the diagonal legs toward the other highway and thereby create three separate intersections along the minor highway. The intersection configurations in Figure 3-5 are shown in their simplest form. Turning lanes and divisional islands may be used, as appropriate, to fit the particular situation.[3]

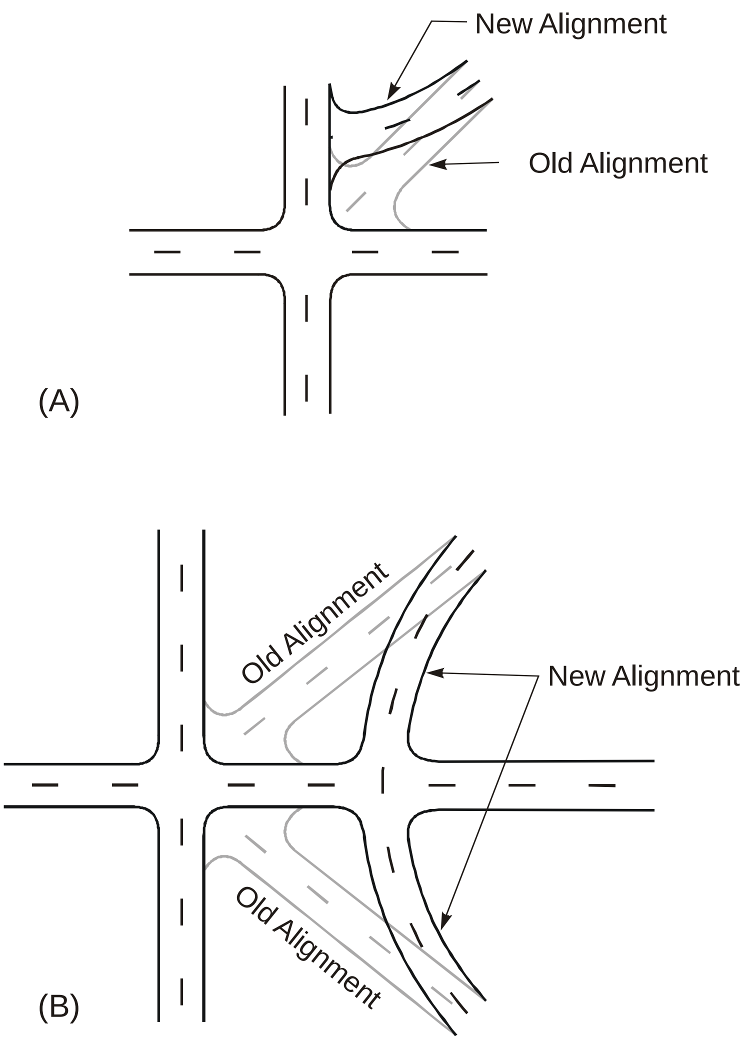


Figure 3-5. Realigning Multileg Intersections.[3]

Superelevation on Low-Speed Facilities (45 mph [72 km/h] or less)

Although superelevation is advantageous for traffic operations, various factors often combine to make its use impractical in many developed areas. These factors include the following:

- wide pavement areas,
- surface drainage considerations,
- frequency of cross streets and driveways, and
- the need to meet the grade of adjacent property.

For this reason, horizontal curves on low-speed streets in urban areas are frequently designed without superelevation, and lateral acceleration is provided solely with side friction. Figure 2.2 of the *Roadway Design Manual* <link> shows the relationship of radius, superelevation rate, and design speed for low-speed urban street design. Additional information on superelevation is provided in ***Application 3-9*** <link>.

Superelevation for Turning Roadways at Intersections

In intersection design, turning roadways frequently have curves with relatively sharp radii. When speed is not affected by the presence of other vehicles, drivers on turning roadways anticipate the sharp curves and accept higher side friction than they would accept on open highway curves of the same radii. This behavior appears to stem from their desire to maintain their speed through the curves, although some speed reduction does occur. When other traffic is present, drivers will travel more slowly on turning roadways than on open highway curves of the same radii because they must diverge from and merge with through traffic. Therefore, in designing for safe operation, periods of light traffic volumes and corresponding speeds will generally influence the design. Designs that encourage lower travel speeds will better accommodate pedestrian traffic.

Superelevation Transition

Superelevation is generally developed so that two-thirds of the transition occurs outside of the curve and one-third inside the curve, according to the *Roadway Design Manual*.[2] The AASHTO *Green Book* recommends that 70 to 90 percent of the superelevation be located on the tangent, with recognition that deviation from its recommended values by 10 percent should not result in operational concerns.[3] Chapter 2, Section 4 of the *Roadway Design Manual* should be consulted to design the superelevation transition <link>.

Superelevation Effects on Pedestrian Crossings

The provision of superelevation should be examined for its effects on pedestrian crossings. Longitudinal slopes and cross slopes in crosswalks should not exceed the maximum slopes permissible under the ADAAG and Texas Accessibility Standards. Further information on those guidelines is provided in Chapter 7, Section 2, Crosswalks <link>.

Section 3
Turning Radius

Overview

The design of the corner radius affects how drivers traverse the intersection, including the speeds chosen as well as the path the driver follows. The corner also affects other features such as the provision of islands (see Chapter 4, Section 5 <link>). Turning templates (hardcopy or CAD cells) or turning path software may be used to predict the paths of vehicles in curves. ***Application 3-10*** examines the influence of some of these factors <link>.

Design Vehicle

The choice of design vehicle greatly influences the selection of an appropriate turning radius or turning roadway width. Consideration should be given to occasional vehicles (i.e., moving vans) as well as the predominant vehicle (i.e., passenger car) in developing an intersection design. Chapter 7, Section 7 of the *Roadway Design Manual* <link> should be consulted for more information about selecting design vehicles. In addition, the vehicle classification data available through the Statewide Traffic Analysis Reporting System (STARS), administered by Transportation Planning and Programming Division (TPP), can show what types of vehicles are actually using a particular facility. Supplementing the hard infrastructure (curbs) with paint markings can be a useful technique to effectively reduce large areas of pavement to decrease the possibility of driver confusion.

Radius

The relationship between lane width, radius, and intersection angle affects the path vehicles take when turning at an intersection. The selection of the radius at an intersection affects turning-vehicle speeds and lane positioning. Consideration of the type of vehicle used in the design and acceptable lane positioning should be made based on the types of main and cross roadways. Curb radii should be selected to accommodate desired design vehicles (but not necessarily to turn into first lane on a multilane roadway). For intersections with minor roadways it is frequently judged acceptable for infrequent large trucks to occupy both lanes on the minor roadway in the course of completing the turning maneuver. This type of design would be inappropriate for a major crossroad, of course, or where trucks are frequent users of the minor roadway. Table 3-3 lists a summary of some of the effects the corner radii selection has on the operation of an intersection.

Table 3-3. Turning Radius Effects.

Benefits of Larger Radii	Benefits of Smaller Radii
♦ Accommodates larger vehicles without encroachment ♦ Permits higher turning-vehicle speeds in free-flow situations ♦ May allow the presence of islands for traffic control devices and pedestrian refuge areas <insert link to Chapter 4, Section 5>	♦ Reduced vehicle crossing time ♦ Reduced pedestrian crossing time leads to reduced vehicular delay at signalized intersections <insert link to Figure 3-7> ♦ Reduced turning speeds can benefit pedestrians <insert link to Effects on Pedestrians in this section> ♦ Reduced pavement area

Figure 3-6 illustrates various radii and swept paths for two design vehicles. The *Green Book* provides tabular values for the cross street width occupied by turning vehicles in its Exhibit 9-31.

The following curb radii are generally recommended:

- ♦ 15 ft [4.6 m] to 25 ft [7.6 m] to accommodate passenger cars and
- ♦ 40 ft [12 m] to 50 ft [15 m] to accommodate heavy volumes of trucks or buses.

If combination tractor-trailer units are anticipated in significant volume, the *Roadway Design Manual's* section on Minimum Designs for Truck and Bus Turns, Chapter 7, should be consulted <link>.

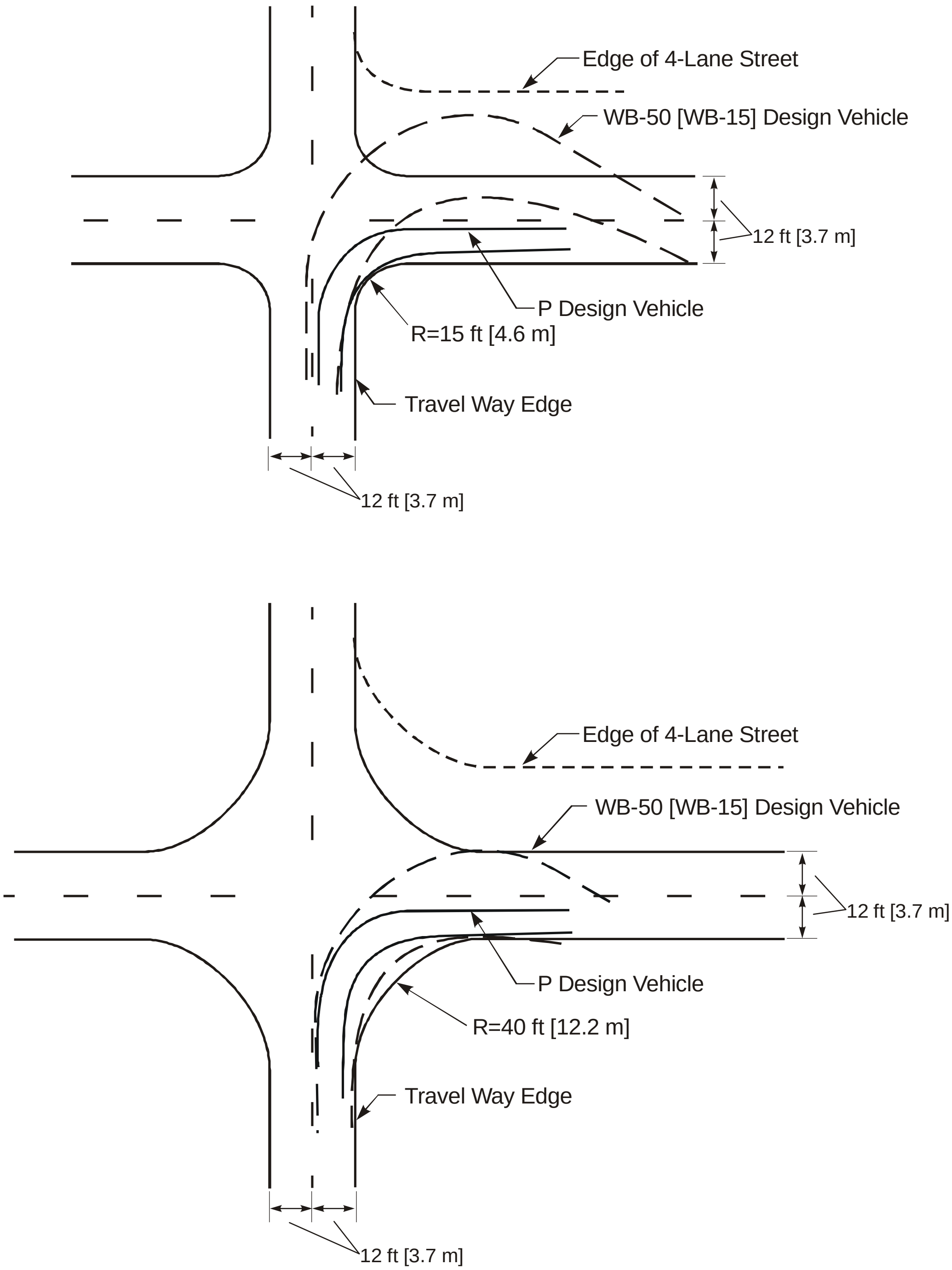


Figure 3-6. Effect of Curb Return Radius on Right Turning Paths (R=15 ft [4.6 m] and R=40 ft [12.2 m]).[3]

Effects on Pedestrians

The provision of larger radii affects the path of pedestrians at the intersection. Larger radii can increase the distance pedestrians are exposed to traffic and move crosswalks and curb ramps away from the intersection. The selection of a radius should be weighed in light of these effects, and may result in a compromise between pedestrian needs and vehicle needs.[3]

Crosswalk lengths increase with larger curb radii if the crosswalk is located inside the corner radius (see Figure 3-7), increasing pedestrian crossing time and, subsequently, traffic signal timing.

Another issue that may be problematic is the speed of the turning vehicles. The speed of turning vehicles can be estimated by the following equations:[5]

The prediction equation for the **85th percentile** speed at the **beginning** of the right turn is:

V85BT = 17.50 – 1.00 Chan + 0.10 CR – 0.006 Len + 0.13 Wid

Where:

V85BT = 85th percentile free-flow speed near the beginning of the right turn (mph)
Chan = channelization present at site, Chan = 0 for islands and 1 for lines
CR = corner radius (ft)
Len = length of right-turn lane (ft)
Wid = width of right-turn lane at start of right turn (ft)

If the length and width of the right-turn lane are not readily available and the average values of 12 ft for lane width and 193 ft for lane length are assumed, the equation becomes:

V85BT = 17.80 – 1.00 Chan + 0.10 CR

The equation for predicting the **85th percentile** speed near the **middle** of the right turn is:

V85MT = 13.03 + 0.23 Chan + 0.06 CR – 0.01 Len + 0.40 Wid

Where:

V85MT = 85th percentile free-flow speed near the middle of the right turn (mph)
Chan = channelization present at site, Chan = 0 for islands and 1 for lines
CR = corner radius (ft)
Len = length of right-turn lane (ft)
Wid = width of right-turn lane at start of right turn (ft)

If the length and width of the right-turn lane are not readily available and the average values of 12 ft for lane width and 193 ft for lane length are assumed, the equation becomes:

V85BT = 14.87 – 0.23 Chan + 0.06 CR

Slower vehicle speeds improve pedestrian safety as they cross the roadway. However, because the turning vehicles slow to complete the maneuver, large speed differentials may result in a substantial distance upstream from the crossroad or driveway. Thus, consideration for the use of deceleration lanes should be given. Further information about deceleration lanes is provided in Chapter 4, Section 3 of this manual <link>.

Right of Way

Right of way and corner setback varies with curb radii but is also affected by border width and sight distance. Right of way should be obtained that provides an acceptable border width through the curb radius and permits attaining required intersection sight distance and stopping sight distance on the turning roadways.

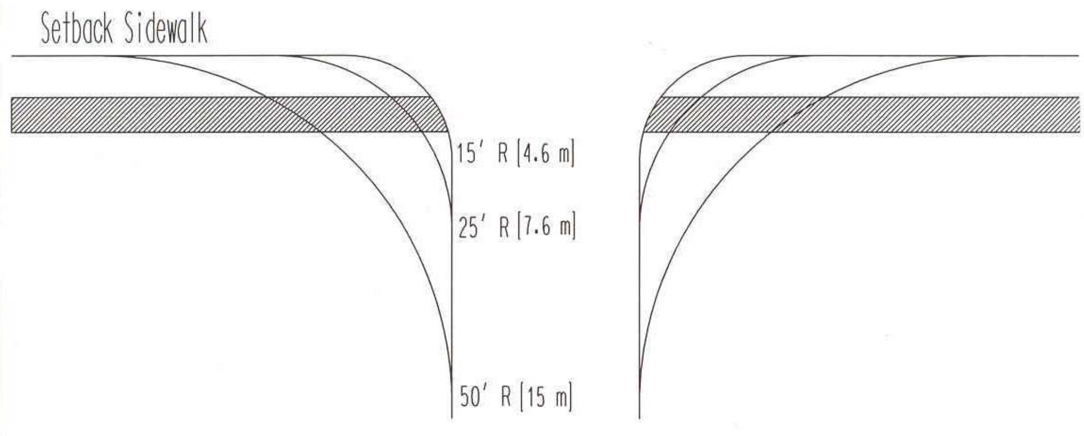
Parking Lanes

When parking lanes are provided, the effective corner radius is increased if parking is restricted near the intersection.

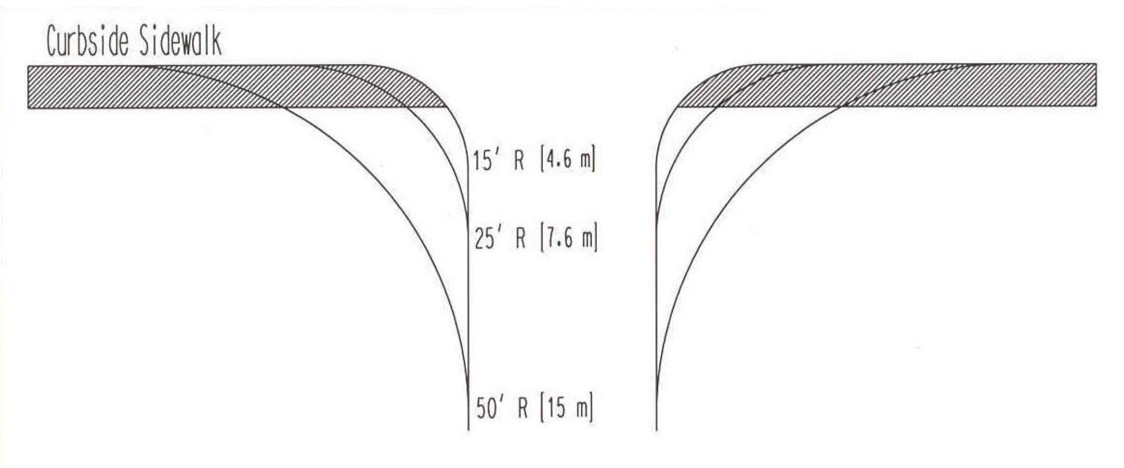
Figure 3-8 shows an example that provides accommodation for larger vehicles through encroachment into the space provided by the parking restriction. Chapter 4, Section 7 of this manual should also be reviewed for parking lane restrictions at intersections <link>.

Minimum Curb Radius

The minimum curb radius used should be 5 ft [1.5 m] to enable the effective use of street sweepers.[3]



Radius		Crossing Distance		Increase Crossing		Percent Increase
15 ft	[4.6 m]	26 ft	[7.9 m]	+0 ft	[+0 m]	0%
25 ft	[7.6 m]	36 ft	[11 m]	+10 ft	[+3 m]	38%
50 ft	[15 m]	65 ft	[20 m]	+39 ft	[+12 m]	150%



Radius		Crossing Distance		Increase Crossing		Percent Increase
15 ft	[4.6 m]	37 ft	[11 m]	+11 ft	[+3 m]	42%
25 ft	[7.6 m]	50 ft	[15 m]	+24 ft	[+7 m]	92%
50 ft	[15 m]	89 ft	[27 m]	+53 ft	[+16 m]	203%

Figure 3-7. Added Crosswalk Distance with Increased Radius (Illustrated Using a 26-ft [7.9 m] Roadway, 5-ft [1.5 m] Sidewalk, and 6-ft [1.8 m] Planting Strip for the Setback Sidewalk).[6]

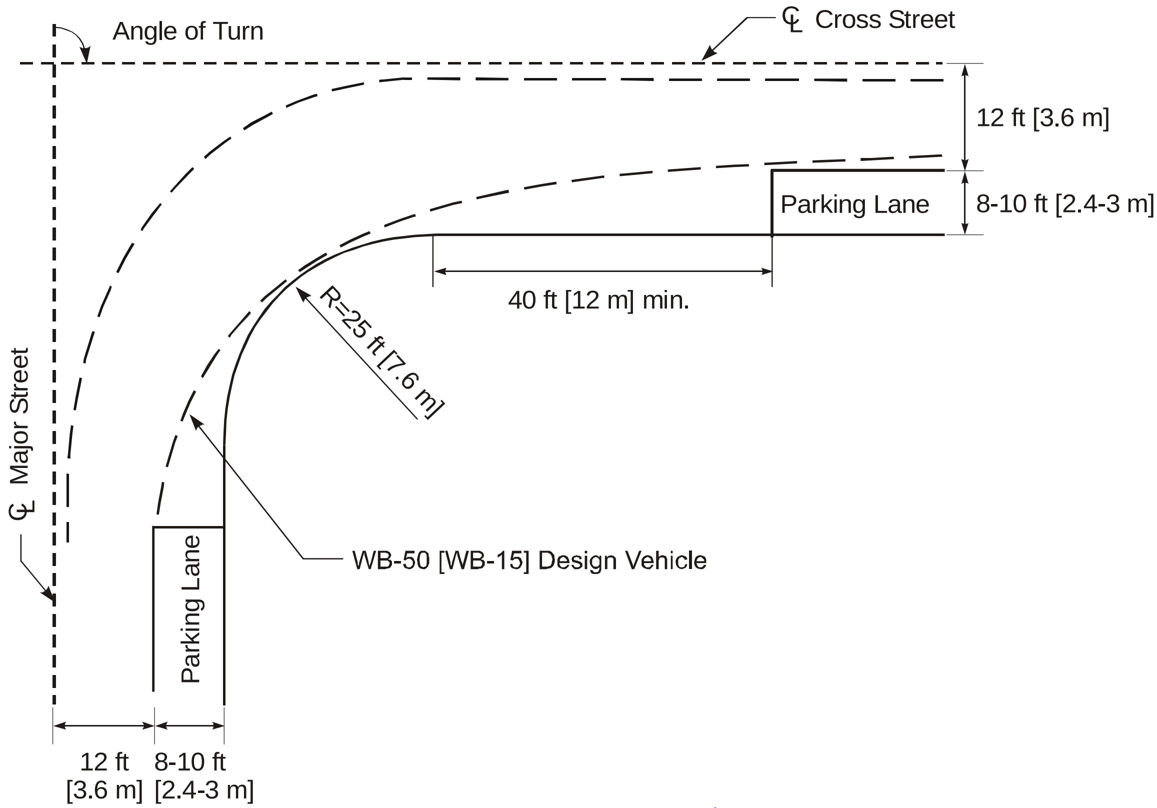


Figure 3-8. Effective Radius with Parking Restriction.[4]

Section 4
Angle of Intersection

Overview

For safety and economy, intersecting roads should generally meet at or nearly at right angles.

General Considerations

The ideal angle of intersection is 90 deg between two roadways. If a 90-deg angle cannot be obtained, the AASHTO *Green Book*[3] recommends an angle of intersection of no less than 60 deg (see Figure 3-9). Skewed intersections of less than 60 deg should be evaluated for intersection sight distance using adjusted turning paths and criteria (see Chapter 3, Section 1, Adjustment for Skewed Intersections) <link>.

Older drivers have significantly more problems at skewed intersections than average drivers. Therefore, the *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians* Handbook[7] recommends an angle of intersection of no less than 75 deg. If the angle must be less than 75 deg, it recommends that right turn on red be prohibited.

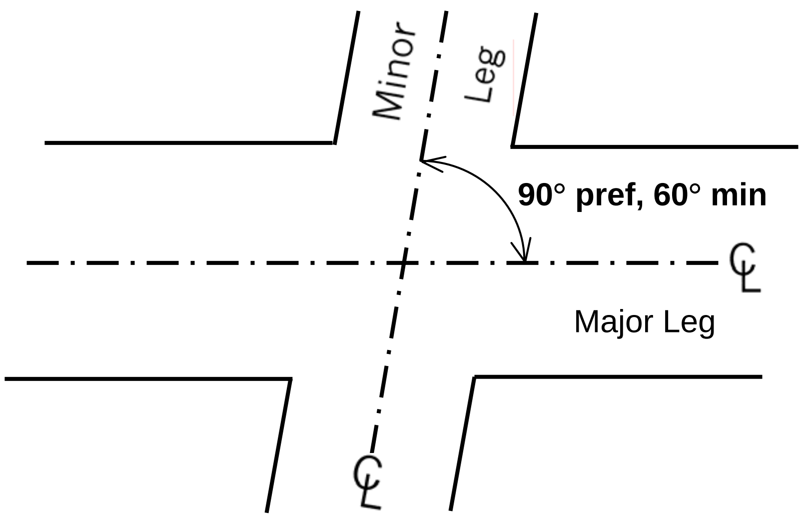


Figure 3-9. Example of Angle of Intersection (Minor Leg Skewed to the Right).

Realigning Intersections

When existing intersecting roadways do not meet the desired specifications, redesigning the intersection is recommended. Roads intersecting at acute angles need extensive turning roadway areas and tend to limit visibility, particularly for drivers of trucks. When a truck is on an obtuse angle, the driver has blind areas on the right side of the vehicle. Acute angle intersections increase exposure time for the vehicles crossing the main traffic flow. Realigning roadways as shown in Figure 3-10 has been shown to be beneficial. The greatest benefit is obtained when the curves used to realign the roads allow operating speeds nearly equivalent to the roadway approach speeds.[3] A design exception may be required if curvature and sight distance requirements are not met (see *Roadway Design Manual* Chapter 1, Section 2 <link>). It should be noted that options A and B may require a considerable amount of new ROW, option C may present problems if there is a significant through movement on the realigned roadway due to the potential for large left-turn queues on the major roadway, and the separation distance between the intersections in options C and D needs to be sufficient to allow for adequate storage. The design of the profile and alignment should be carefully considered if there is a potential for the signalization of the intersection (or a change in which roadway has a stop condition), since vehicles would enter the intersection at speed rather than from a stop condition.

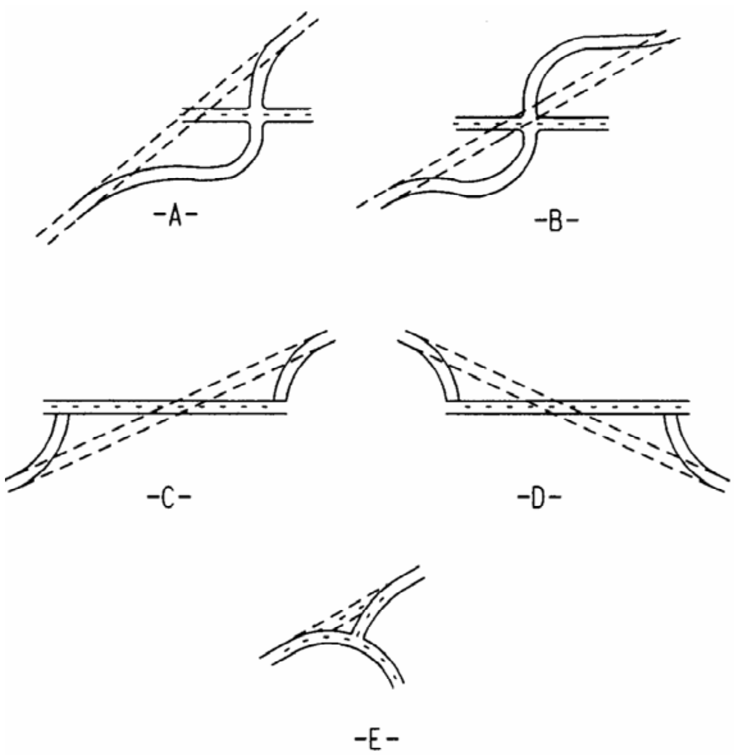


Figure 3-10. Realignment Options at Intersections.[3]

Section 5
Vertical Alignment

Overview

At an intersection, the combination of grade lines of the intersecting roadways should provide as seamless a transition as possible. Chapter 6, Section 3 Profile <link> should also be reviewed to address drainage concerns regarding the vertical alignment of intersections.

Vertical Alignment

Substantial grade changes should be avoided at intersections, but that is not always possible. Adequate sight distance along all intersecting roads should be provided. Those sections of roads that are used for storage of stopped vehicles, otherwise known as storage platforms, should have a gradient that is as flat as possible. Where pedestrians are expected, intersections should be "tabled" as much as possible to ensure the cross slope in crosswalks is less than 2 percent <insert link to Chapter 7, Section 2, Crosswalks>.

The alignment and grades are subject to greater constraints at or near intersections than on the open road. At or near intersections, the combination of horizontal and vertical alignment should provide traffic lanes that are clearly visible to drivers at all times, clearly understandable for any desired direction of travel, free from the potential for conflicts to appear suddenly, and consistent in design with the portions of the highway just traveled.[3]

The combination of vertical and horizontal curvature should allow adequate sight distance at an intersection. As discussed in Chapter 3 of the AASHTO *Green Book*, a sharp horizontal curve following a crest vertical curve is undesirable, particularly on intersection approaches.[3]

Grades

When the intersecting gradients are 3 percent or less, stopping and accelerating distance do not differ substantially from those for level grades. However, if grades are greater than 3 percent, changes in several design elements may have to be made because of the effects of the grades on vehicle performance. Because of these effects and the complexities of intersecting two roadways when one or both are on substantial grades, grades of 3 percent or more should generally be avoided at intersections. If existing conditions require grades above 3 percent, grades up to 6 percent may be retained, although adjustments for the effects of the grades should be made in the geometric design elements (primarily sight distance) of the roadways. The use of grades greater than 2 percent will not allow compliance for cross slopes in the crosswalk as required by ADAAG[8] and TAS.[9] Chapter 3, Section 1 of this manual should be consulted regarding intersection sight distance and the *Roadway Design Manual* regarding stopping sight distance <insert link to ISD chapter of this manual and SSD section of the *Roadway Design Manual*>.

Coordination of Vertical Profiles

The vertical profiles of the main and cross roadways should be coordinated to provide acceptable ride quality for drivers.[10] Simply matching the crossroad vertical profile to the main road vertical profile and cross section (see Figure 3-11A) may be acceptable in situations where the roadways are relatively flat. A considerable transition length is generally required when significant grades are involved because of the length of the vertical curves needed to meet design speed requirements. In locations where traffic does not always stop on the crossroad (i.e., a traffic signal is present) the minor road will have an undesirable vertical profile unless adequate vertical curves are provided.

The profile gradelines and cross sections on the legs of an intersection should be adjusted for a distance back from the intersection proper to provide a smooth junction and proper drainage. Normally, the gradelines of the major road should be carried through the intersection and that of the minor road should be adjusted to it. This design involves a transition in the crown of the minor road to an inclined cross section at its junction with the major road. For simple unchannelized intersections involving low design speeds and stop or signal control, it may be desirable to warp the crowns of both roads into a plane at the intersection; the appropriate plane depends on the direction of drainage and other conditions. Changes from one cross slope to another should be gradual. Intersections at which a minor road crosses a multilane divided highway with a narrow median on a superelevated curve should be avoided whenever practical because of the difficulty in adjusting grades to provide a suitable crossing. Gradelines of separate turning roadways should be designed to fit the cross slopes and longitudinal grades of the intersection legs.[3] It is generally helpful to plot contours of the entire intersection to evaluate the impacts of the proposed warping on drainage and ADAAG/TAS compliance. Further guidance regarding warping the pavement surfaces can be found in Chapter 6, Section 3, Profile <link>.

Figure 3-11B provides an example of coordinating the cross section of the main roadway and the vertical alignment on the crossroad to achieve a better design. By changing the crown on the main road, the passage across it is much smoother. Because the resulting grade changes will be reduced and result in shorter vertical curves, this alignment will require less distance to meet design speed than that shown in Figure 3-10A while meeting design speed requirements. The design will require that a sufficient transition length on the major roadway be provided, however.

Minor changes in vertical profiles may be required on either the main or cross roadway. Changes in grade should generally be affected by using a vertical curve with a K-value that meets the design speed of the roadway. As provided in the *Roadway Design Manual*,[2] however, minor grade changes may be accomplished without the use of a vertical curve under the following circumstances:

- 1 percent or less for design speeds equal to or less than 45 mph [72 km/h], or
- 0.5 percent or less for design speeds greater than 45 mph [72 km/h].

Even when the above criteria are met, conditions where grade changes without vertical curves are not recommended include:

- bridges (including bridge ends),
- direct-traffic culverts, and
- other locations requiring carefully detailed grades.

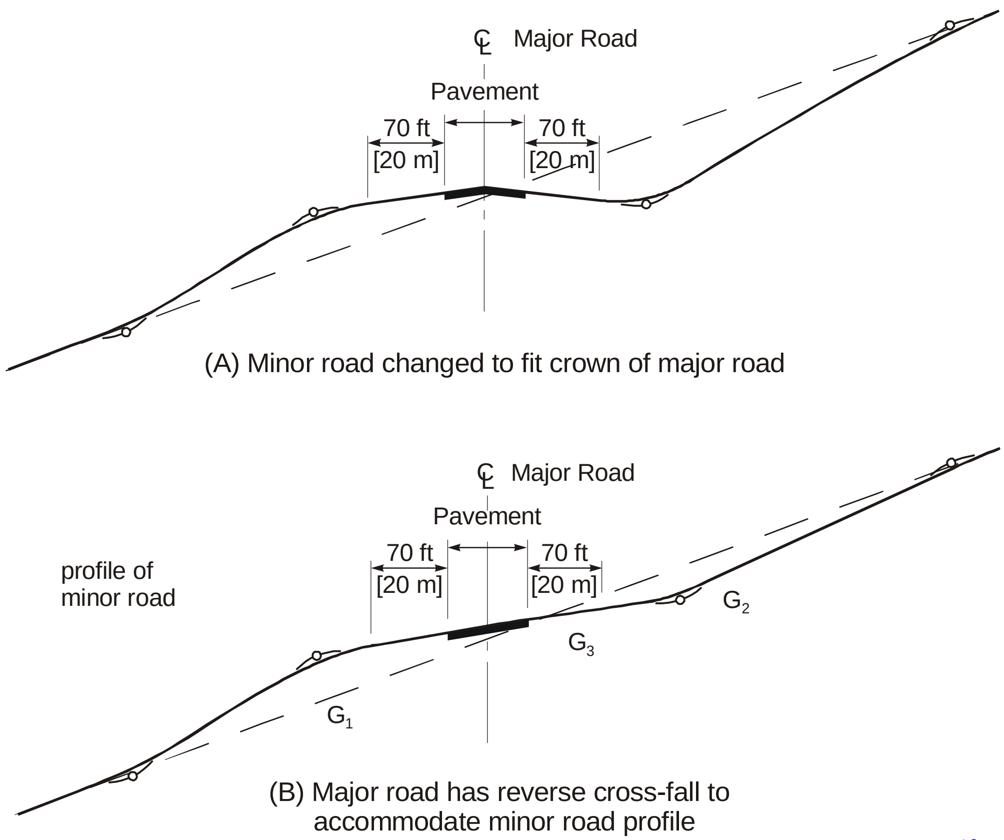


Figure 3-11. Coordination of Vertical Alignments on Horizontal Tangent.[10]

Figure 3-12 provides other examples of coordinating alignments where roadways are on curves. If the vertical alignment of the crossroad and the horizontal curve on the main roadway are complementary as in Figure 3-12A, then the alignment can be relatively smooth. The case illustrated in Figure 3-12B is more difficult to accomplish because of the introduction of the required vertical curves on the minor road. The vertical curve lengths and the intersection sight distance requirements will necessitate careful consideration of the alignment on the minor road.

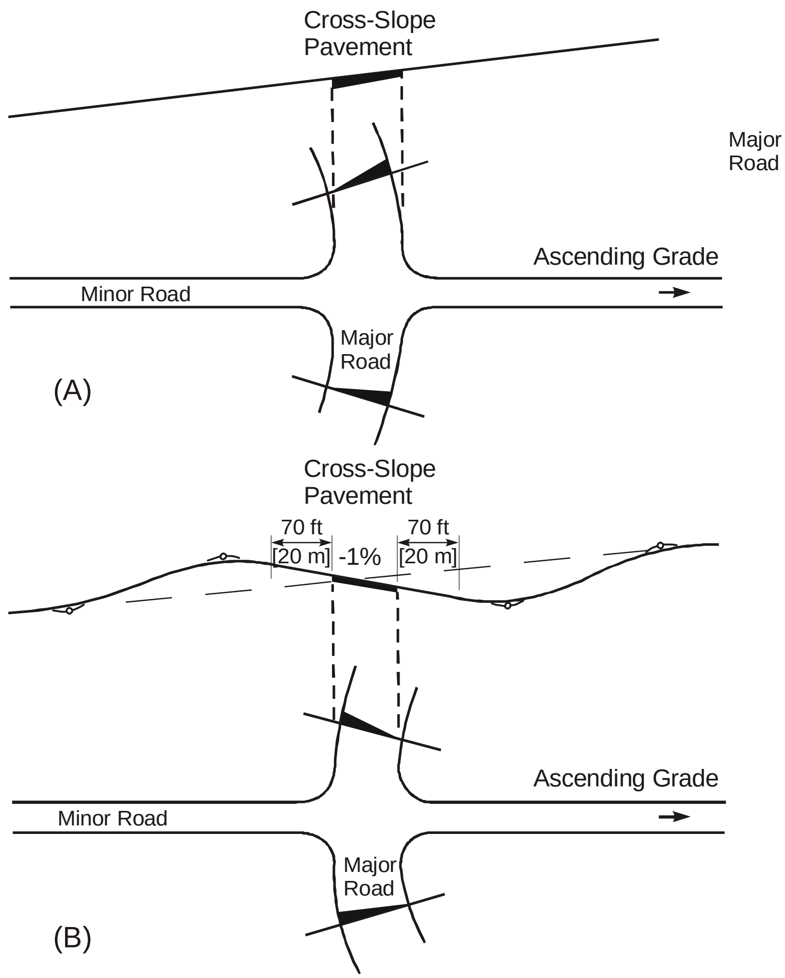


Figure 3-12. Coordination of Vertical Alignments on Horizontal Curves.[10]

Section 6
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[2] Texas Department of Transportation. *Roadway Design Manual.* Revised April 2002. http://manuals.dot.state.tx.us:80/docs/coldesig/forms/rdw.pdf. Accessed August 30, 2002.

[3] American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets.* AASHTO, Washington, D.C., 2001.

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[6] *Design Standards and Guidelines for Eugene Streets, Sidewalks, Bikeways, and Accessway.* City of Eugene, Oregon. November 1999.

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[10] Walker, R.J. "Coordination of Basic Intersection Design Elements: An Overview." *Transportation Research Record 1385,* Transportation Research Board, Washington, D.C, 1991.

Chapter 4
Cross Section

Contents:

Section 1
Through Lanes

Overview

Through lanes in the intersection should normally match the lanes upstream of the intersection in both number and width, although lanes can be added (i.e., downstream of an intersection or in the immediate area of the intersection) or removed if necessary for capacity purposes (i.e., for a lane drop).

Width

Lane widths vary for different functional classifications and depend on the scope of work. Design criteria are provided in the *Roadway Design Manual*:[1]

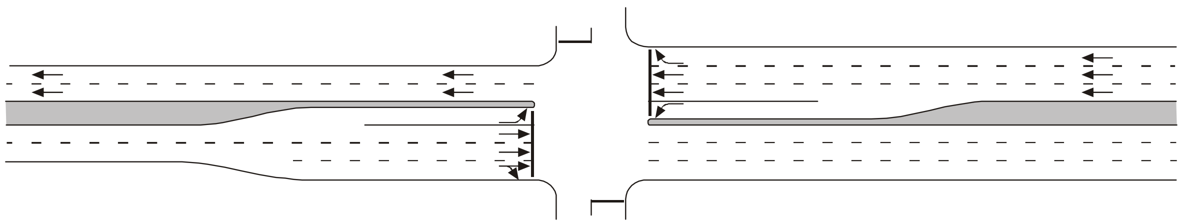
- ♦ Reconstruction (4R) work:
  - Urban streets and frontage roads: *Roadway Design Manual* Table 3-1, Geometric Design Criteria for Urban Streets <link>
  - Suburban roadways: *Roadway Design Manual* Table 3-5, Geometric Design Criteria for Suburban Roadways <link>
- ♦ Rehabilitation (3R) work:
  - *Roadway Design Manual* Table 4-3, 3R Design Guidelines for Urban Streets All Functional Classes <link>
  - *Roadway Design Manual* Table 4-5, 3R Design Guidelines for Urban Frontage Roads <link>

Adding a Lane

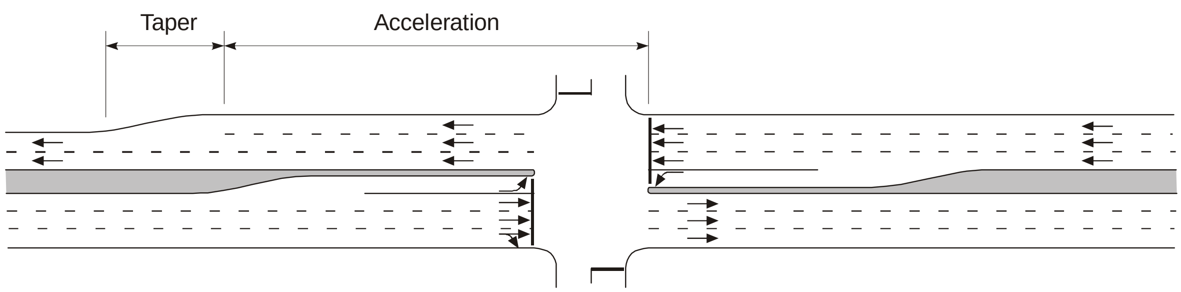
The capacity of urban roadways near at-grade signalized intersections is generally limited by the capacity at those intersections rather than on the links between the intersections. Signalization restricts the movement of vehicles through an intersection (thus limiting conflicts between opposing travel directions) but restricts capacity on the through roadways. Additional through lanes may be required at an intersection to meet capacity needs. Taper lengths and deceleration lengths for a new through lane are similar to those needed when introducing a left-turn lane (see Table 3-3 in the *Roadway Design Manual* <link>).[1]

Lane Drop

Lane drops are used to reduce the total number of lanes. The lane drop can occur at an intersection in the form of a mandatory right (or left) turn or after the intersection (see Figure 4-1). When the lane drop occurs after the intersection, the taper and acceleration lengths shown in the *Roadway Design Manual,* Figure 3-10 <link> can be utilized. ***Application 4-1*** <link> provides an example of a situation when a lane drop occurs after an intersection due to the end of a widening project.



(A) Lane Drop at Intersection



(B) Lane Drop after Intersection

Figure 4-1. Lane Drops.

Reallocation of Cross Section

Undivided multilane roadways without turn lanes may sometimes function as if the centermost through lanes were left-turn lanes, as vehicles wait for openings in the opposing traffic. If large numbers of turning vehicles are present, then these "through" lanes may actually operate as turn lanes. An improvement alternative to the four-lane urban cross section is to redesign it to a three-lane cross section with the middle lane becoming a continuous left-turn lane since this is similar to how the cross section is working. The redesign can result in additional width available for bicycle lanes, wider sidewalks, or roadside amenities. The improvement is generally called a "road diet." ***Application 4-2*** <link> provides examples of the road diet concept.

Section 2
Left-Turn Lanes

Overview

Left-turn lanes are used to provide space for the deceleration and storage of turning vehicles (see Figure 4-2). They may be used to improve safety and/or operations at intersections. Multiple left-turn lanes may be used to accommodate high peak hour left-turn volumes.

Provision of Left-Turn Lanes

Strong consideration should be given to the provision of left-turn bays at all signalized intersections, intersections that may be signalized in the future, and intersections of higher-class roadways.

Left-turn lanes can also improve safety at all types of intersections. The TxDOT *Roadway Design Manual* includes recommendations for when left-turn lanes should be considered based on traffic volumes <link to RDM Table 3-11>. ***Application 4-3*** <link> illustrates the use of the guidelines on when to consider a left-turn lane on a two-lane highway.

Length

The length of the turn lanes depends on three elements:

- deceleration length,
- storage length, and
- entering taper.

If insufficient room is available for each of these elements, allowing a moderate amount of deceleration length to be included in the taper section is acceptable. Table 3-3 of the *Roadway Design Manual* <link> provides recommended lengths for the dimensions shown in the *Roadway Design Manual* figure <link to *Roadway Design Manual* Figure 3-1>. Deceleration length assumes that moderate deceleration will occur in the through traffic lane and the vehicle entering the left-turn lane will clear the through traffic lane at a speed of 10 mph [16 km/h] slower than through traffic. Where providing this deceleration length is impractical, it may be acceptable to allow turning vehicles to decelerate more than 10 mph [16 km/h] before clearing the through traffic lane. See the *Roadway Design Manual* Table 3-3 <link>.

When determining storage lengths, the length of the queue in the adjacent through lane should be reviewed to ensure that queued traffic will not block the entrance to the dedicated turn lane. ***Application 4-4*** <link> demonstrates this concept.

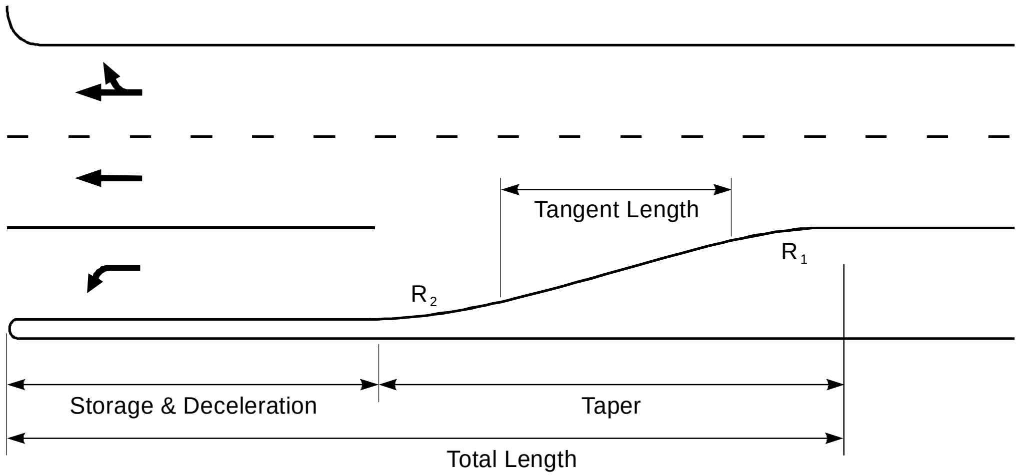


Figure 4-2. Left-Turn Lanes on Urban Streets.

A dual left-turn lane is shown in Figure 4-3. The length of dual left-turn lanes may be found in the *Roadway Design Manual*[1] <link to *Roadway Design Manual* Table 3-4>. If dual left-turn lanes are used, the length required for storage is approximately half that required for single left-turn lanes.[2] Flexibility in signalization is provided if the left-turn movements are separated as shown in Figure 4-3 (dimension m, note at *). This separation, if sufficient, can allow concurrent dual left-turn phases. Separate dual left-turn phases eliminate the potential problem of overlapping vehicle paths in the intersection.

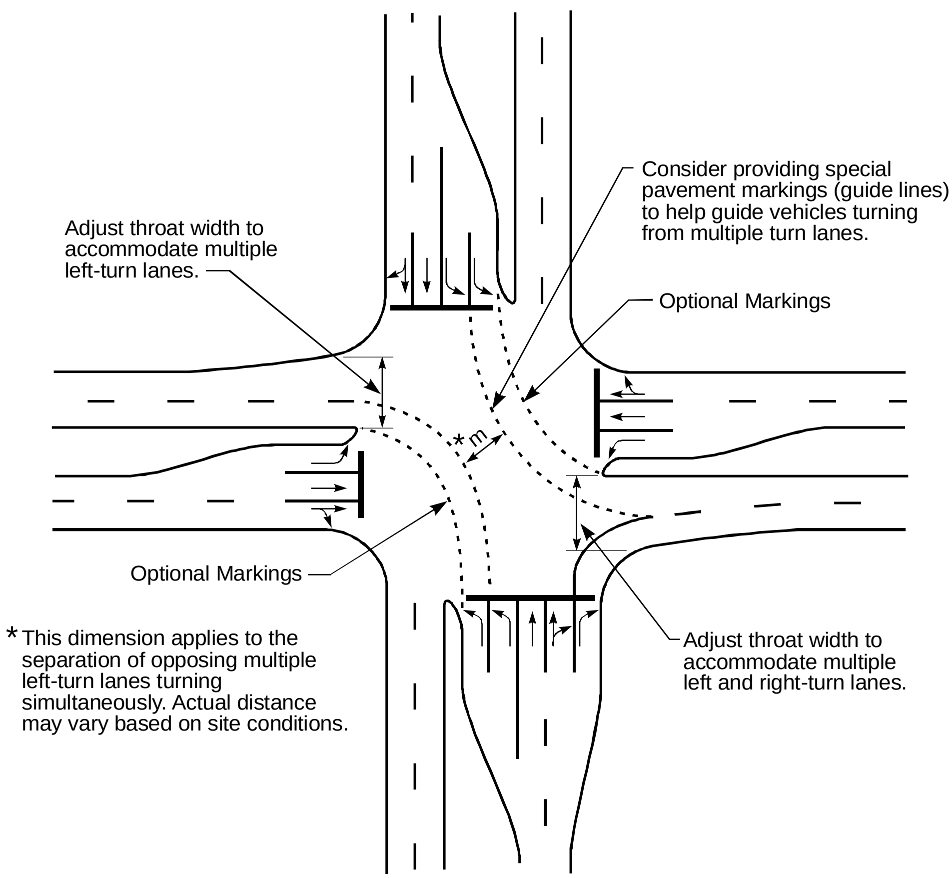


Figure 4-3. Dual Left-Turn Lane.[3]

Width

The width of auxiliary lanes should preferably match the width of the through lanes, although they should be at least 10-ft wide [3 m].[2] If curbs are present, a curb offset of 1 to 2 ft [0.3 to 0.6 m] from the edge of the travel lane to the face of the curb should be used.

To accommodate a single left-turn lane, a median width of 18 ft [5.5 m] (12-ft-lane width [3.7 m] plus a 6-ft divider [1.8 m]) is recommended. The 6-ft divider [1.8 m] may provide a refuge for pedestrians, depending on its design (see Chapter 4, Section 5, Island and Median Design <link>); however, it is not sufficient to fully offset the turn lane (discussed below). If dual left-turn lanes are used, a median width of 28 to 30 ft [8.5 to 9.1 m] (11 to 12 ft [3.4 to 3.7 m] lanes plus a 6-ft divider [1.8 m]) is recommended.

If dual left-turn lanes are used, the median opening and crossroad should be sufficiently wide to accommodate both incoming lanes.

Offset Left-Turn Lanes

Vehicles in opposing left-turn lanes can limit each other's views of approaching traffic. The restriction on the sight distance is dependent on the amount and direction of the offset between the opposing left-turn lanes. The offset is measured between the left edge of a left-turn lane and the right edge of the opposing left-turn lane as shown in Figure 4-4.

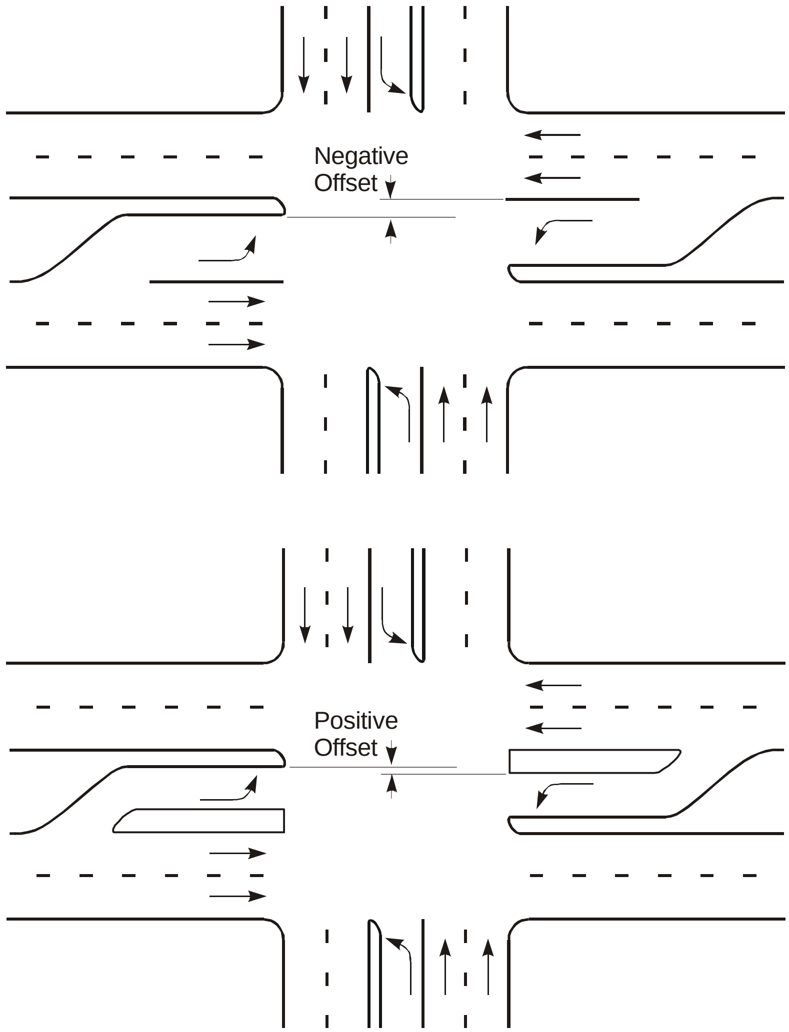


Figure 4-4. Negative and Positive Offsets of Left-Turn Lanes.[4]

Benefits of positive offset left-turn lanes include:

- better visibility of opposing through traffic,
- improved unprotected left-turn phase,
- decreased possibility of conflict between opposing left-turn movements within the intersection, and
- service for more left-turn vehicles in a given period of time (particularly at signalized intersections).

The impact on pedestrian crossings of all roadways should be considered in the design of offset left-turn lanes.

Figure 4-5 shows an example of an offset left-turn lane.

Application 4-5 <link> presents an example where offset left-turn lanes were used to improve the view of oncoming vehicles.

Figure 4-5. Example of an Offset Left-Turn Lane.

Guidelines for Offset Left-Turn Lanes

Greater ROW width is required to offset left-turn lanes, but research has shown that they can provide significantly greater sight distance for left-turn maneuvers, a particularly critical maneuver for older drivers.[5] Guidelines were developed for offsetting opposing left-turn lanes at 90-degree intersections on level, tangent sections of divided roadways with 12 ft [3.7 m] lanes (see Table 4-1).[6] The minimum offsets in the table are those required to provide opposing left-turning vehicles with adequate sight distances. They are applicable to left-turning passenger cars opposed by either another passenger car or a truck. The desirable offsets are those that provide opposing left-turning vehicles with unrestricted sight distances, and therefore, they are independent of design speed. The guidelines include minimum and desirable offsets when (a) both vehicles are unpositioned and (b) the left-turning vehicle is unpositioned and the opposing left-turning vehicle is positioned. Positioned vehicles entered the intersection to obtain a better view of oncoming traffic while unpositioned vehicles were defined as those that remained behind the stop line while waiting to turn left. A previous study found that 60 percent of older drivers did not position their vehicle. Therefore, in areas with high percentages of older drivers, the guidelines based on both vehicles being unpositioned should be used. Likewise, in areas where there are high percentages of trucks, the guidelines based on the opposing left-turning vehicle being a truck should be used.

Table 4-1. Guidelines for Offsetting Opposing Left-Turn Lanes. [6]

Metric									
Opposing Left-Turn Vehicle		**Minimum Offset (m)**							
		Design Speed (km/h)							
Type	**Location**	50	60	70	80	90	100	110	**Desirable Offset**
Passenger Car	Unpositioned	1.0	1.0	1.1	1.1	1.1	1.2	1.2	1.3
	Positioned	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.6
Truck	Unpositioned	1.5	1.5	1.5	1.6	1.6	1.6	1.6	1.7
	Positioned	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.1
U.S. Customary									
Opposing Left-Turn Vehicle		**Minimum Offset (ft)**							
		Design Speed (mph)							
Type	**Location**	80.5	96.6	112.7	128.8	144.9	161.0	177.1	**Desirable Offset**
Passenger Car	Unpositioned	3.3	3.3	3.6	3.6	3.6	3.9	3.9	4.3
	Positioned	0.7	1.0	1.0	1.3	1.3	1.3	1.3	2.0
Truck	Unpositioned	4.9	4.9	4.9	5.2	5.2	5.2	5.2	5.6
	Positioned	2.6	2.6	2.9	2.9	2.9	3.3	3.3	3.6

The guidelines presented in Table 4-1 would typically involve reconstructing the left-turn lanes. Increasing the width of the lane line between the left-turn lane and the adjacent through lanes can also improve the sight distance by encouraging the driver to position the vehicle closer to the median. McCoy et al.[7] developed a methodology for determining the width of the left-turn lane line.

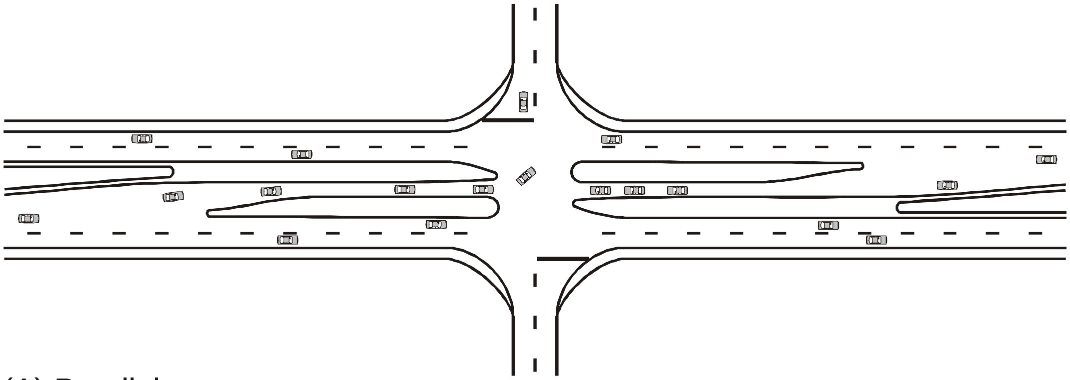
Types of Offset Left-Turn Lanes

Two types of offset left-turn lanes are typically used: parallel and tapered. Parallel lanes may be used at both signalized and unsignalized intersections, while tapered lanes are usually used only at signalized intersections. An illustration of both types is provided in Figure 4-6.

Tapered offset left-turn lanes are normally constructed with a 4-ft [1.2 m] nose between the left-turn and the opposing through lanes. This median nose can be offset from the opposing through-traffic by 2 ft [0.6 m] or more with a gradual taper, making it less vulnerable to contact by the through traffic (see part B of Figure 4-6).

This type offset is especially effective for turning radii allowance where trucks with long rear overhangs, such as logging trucks, are turning from the mainline roadway. This same type of offset geometry may also be used for trucks turning right with long rear overhangs.[2]

Parallel and tapered offset left-turn lanes should be separated from the adjacent through traffic lanes by painted or raised channelization. Adequate advance signing is essential so that drivers recognize the need to enter the turn lane well in advance of the intersection.


(A) Parallel

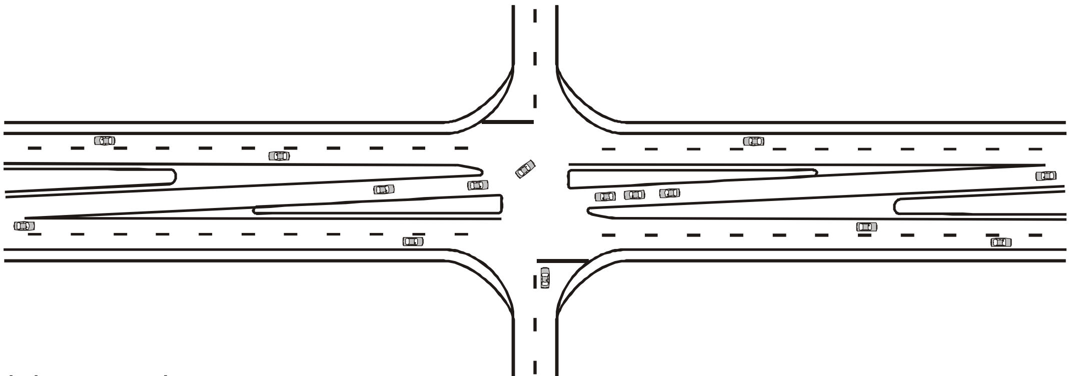

(B) Tapered

Figure 4-6. Parallel and Tapered Offset Left-Turn Lane.[2]

Performance

Results of a 1996 study[6] indicated that driver performance can be adversely affected by offsets that are much less (i.e., more negative) than -2.95 ft [-0.9 m]. Such large negative offsets significantly increased the size of the critical gaps of drivers turning left and also seemed to increase the likelihood of conflicts between left turns and opposing through traffic. Large negative offsets may be particularly troublesome for older drivers and women drivers, who are less likely to position their vehicles within the intersection to see beyond vehicles in the opposing left-turn lane.

The same 1996 study had a somewhat counter-intuitive finding. Driver perceptions of the level of comfort were not found to improve with greatly increased offsets. An offset of 5.9 ft [1.8 m] was associated with a lower level of comfort and a higher degree of difficulty perceived by drivers than an offset of -2.95 ft [-0.9 m], even though the latter provides less sight distance. The study's authors speculated that this reaction might be because the -2.95-ft offset [-0.9 m] is more common than the 5.9-ft-offset [1.8 m].

Section 3
Right-Turn Lanes

Overview

Right-turn lanes are used to provide space for the deceleration and storage of turning vehicles. They may be used to improve safety and/or operations at intersections. If a parking lane is present, it may provide the space necessary for a right-turn lane.[2]

In built-up areas, channelized right-turn lanes should be used only where significant capacity and safety problems may occur without them and adequate pedestrian crossings can be provided <insert link to Chapter 7, Section 2>.[2]

Figure 4-7 illustrates examples of right-turn lanes.

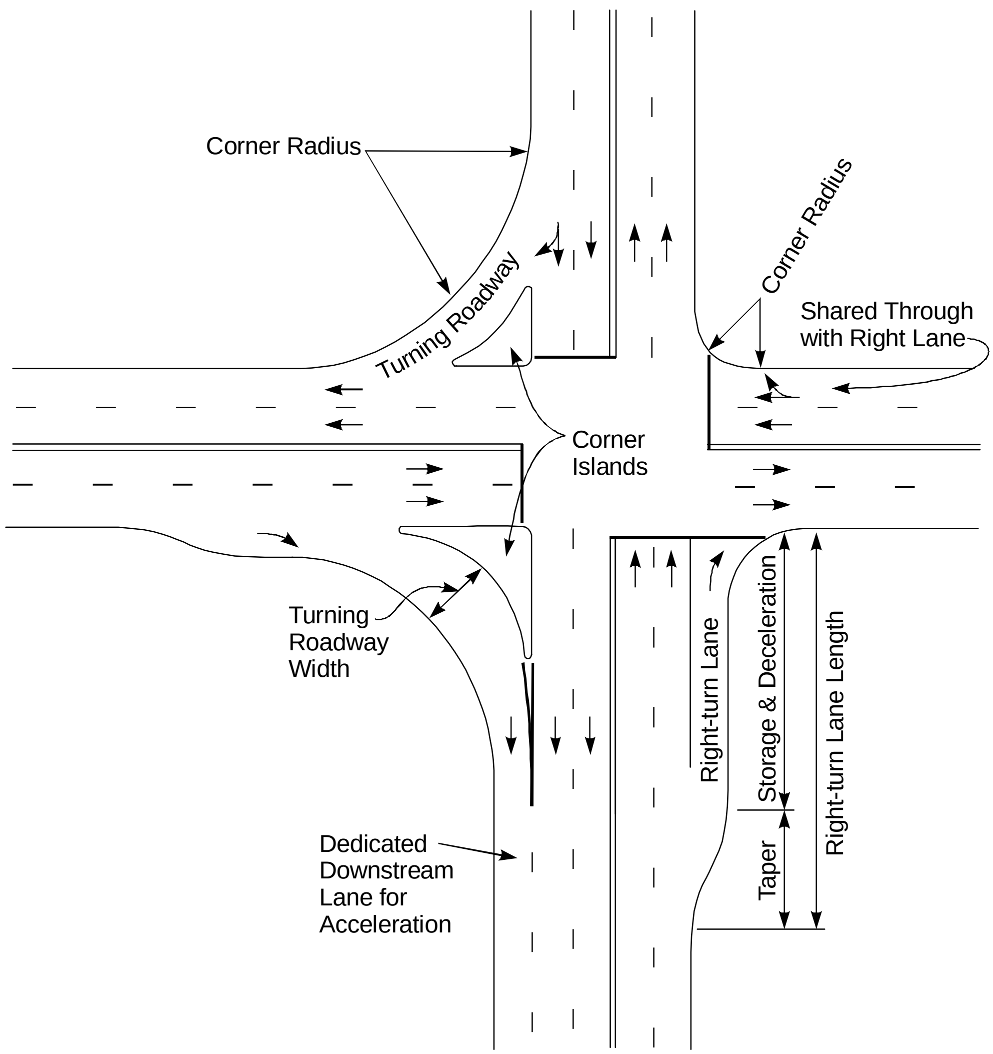


Figure 4-7. Right-Turn Lane Examples.

Location

A number of factors enter into the decision regarding whether right-turn lanes should be used: speeds, traffic volumes, percentage of trucks, capacity, type of highway, service provided, and the arrangement and frequency of intersections.[2] Deceleration lanes that include storage lanes for turning traffic are particularly advantageous, providing improved intersection performance and safety.

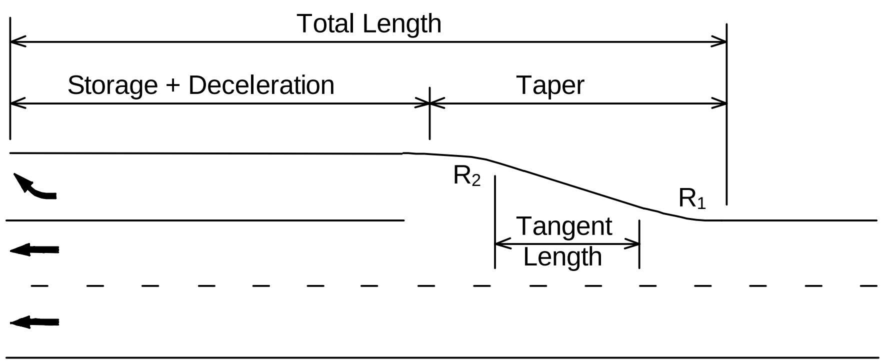
Length

The length of turn lanes depends upon three elements:

- entering taper,
- deceleration length, and
- storage length.

If insufficient room is available for each of these elements, including a moderate amount of deceleration length in the taper section is acceptable. Figure 4-8 provides an illustration of a basic right-turn lane, while Table 3-3 <link> of the TxDOT *Roadway Design Manual* provides recommended lengths. Storage length calculations should consider that the queue from the through movement may block the entry to the right-turn lane, so both the right-turn and through-movement queues should be reviewed when establishing the length of the right-turn lane. ***Application 4-6*** <link> demonstrates this concept.

Application 4-7 <link> provides an example of a design where length requirements overlapped in an area needing successive right-turn lanes.



$R_1 = 2R_2$ (Approximate)
Tangent Length = (1/3 to 1/2)(Taper Length)

Figure 4-8. Example of Right-Turn Lane.

Width

The width of right-turn lanes should preferably match the width of the through lanes, although they should be at least 10 ft wide [3 m].[2] If curbs are present, a curb offset of 1 to 2 ft [0.3 to 0.6 m] from the edge of the travel lane to the face of the curb should be used.

The width of the turning roadway present with a corner island is discussed in Chapter 4, Section 5 <link>.

Radius

Corner radii are designed to accommodate the expected vehicle classes for each location. Chapter 3, Section 3 provides more information regarding corner radius selection <link>.

Corner Island

When a turning radius is designed for semitrailer combinations or when the design allows passenger vehicles to turn at 10 mph [16 km/h] or more, the pavement area becomes very large. In order to reduce the pavement area and prevent vehicles from wandering from their natural paths, a corner triangular island is usually used. In urban areas, the island in all instances should be located about 2 ft [0.6 m] outside the traveled way edge extended, as shown in Figure 4-9.

An important part of the design for some intersections is the design of a free-flow alignment for right turns. Information on corner islands is included in Chapter 4, Section 5 <link> and turning radius in Chapter 3, Section 3 <link>.

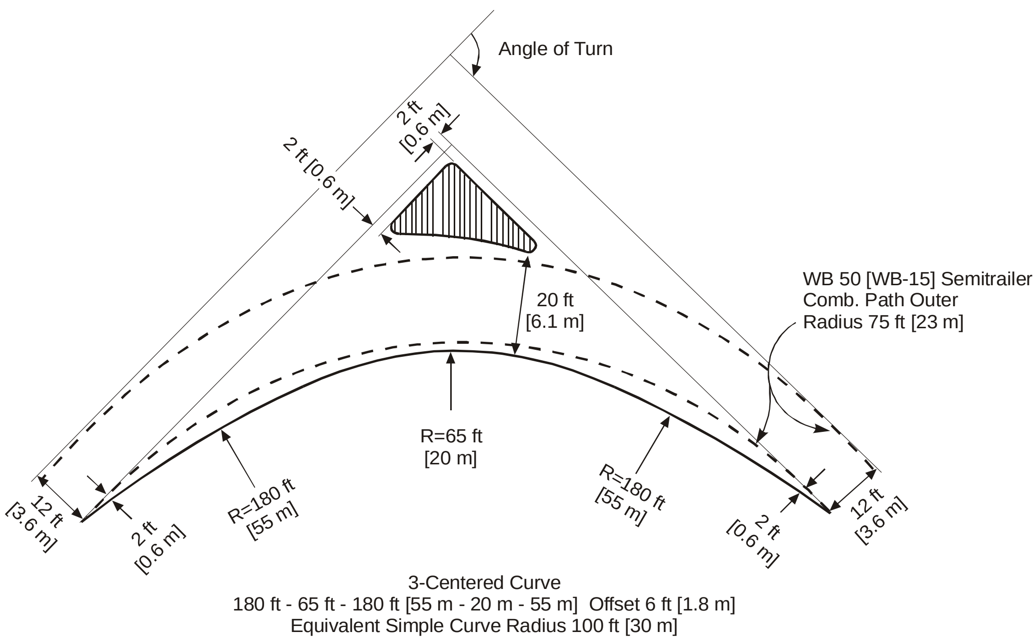


Figure 4-9. Minimum Turning Roadway Design to Accommodate WB-50 [WB-15] with Corner Island at Urban Locations.[2]

Configuration and Control of Right-Turn Lanes

The type of control established by traffic control devices and geometry of an intersection affects the operation of the turning lane. Right-turn lanes can have many forms, based on the design elements used and method of control on the right turn. At the intersection of two high-speed or high-volume roadways, a free-flow design has been used with some frequency. At intersections where one or both of the intersecting roadways has low speeds and low pedestrian activity, a turn lane with island design has emerged as a cost-effective design. In other locations with low volumes or strong pedestrian activity, turn lanes without an island may be appropriate. Vehicles turning right must stop at a red signal or Stop sign before proceeding, resulting in some right-turn queues but improving the location for pedestrians. Common configurations for right turns along with their pluses and minuses are shown in Table 4-2.

Table 4-2. Right-Turn Lane Designs.

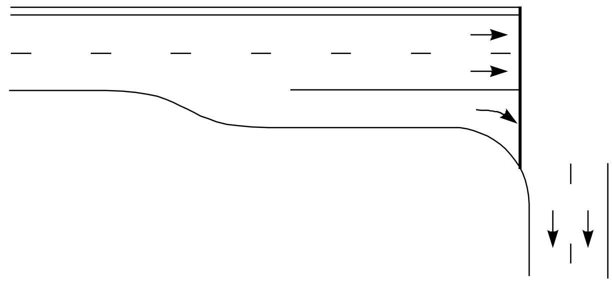
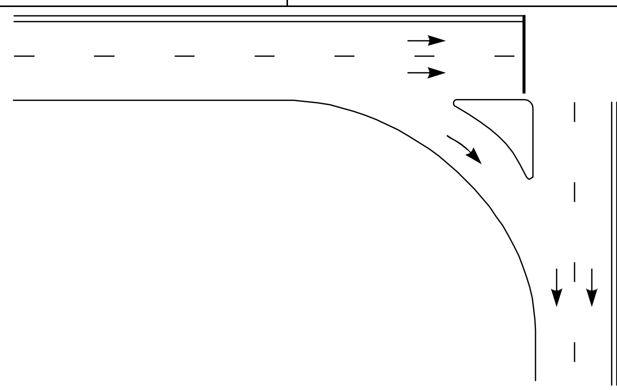
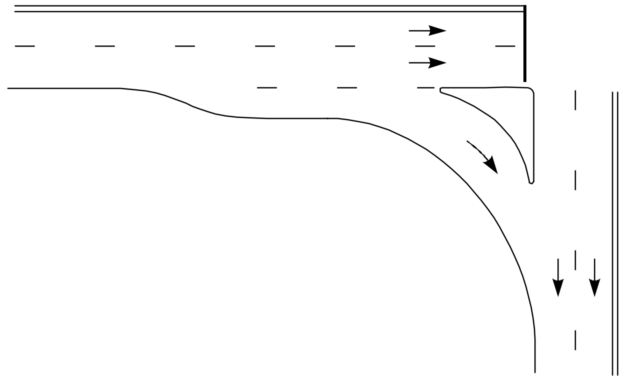
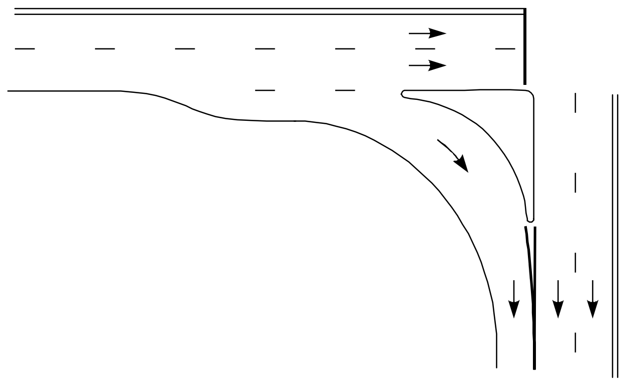
 **Right-Turn Lane**	
Plus	**Minus**
♦ Allows right turn on red (unless prohibited), reducing right-turn queues. ♦ Removes turning vehicles from through-vehicle lane for improved intersection operations. ♦ Lower turning speeds provide a safer pedestrian environment.	♦ All vehicles must stop on red, potentially increasing the right-turn queue. ♦ The absence of an island eliminates its use for: • placement of traffic control devices, and • a pedestrian refuge.
 **Shared Lane with Island**	
Plus	**Minus**
♦ Provision of islands permits its use for placement of traffic control devices or as a pedestrian refuge. ♦ Removes turning vehicle from head of queue.	♦ May encourage higher speeds. ♦ If signal support is located on island, pedestrians will need to cross uncontrolled lane to reach pedestrian push button. ♦ Design may result in small island size. ♦ The through movement queue may obstruct the throat of the right-turn lane, reducing capacity of the intersection.

Table 4-2. Right-Turn Lane Designs (Cont).



Right-Turn Lane with Island

Plus	Minus
♦ Provides relatively free movement for vehicles after yielding to pedestrians and opposing traffic, reducing right-turn queues. ♦ Removes turning vehicles from through-vehicle lane for improved intersection operations.	♦ Higher turning speeds may present a hazard to pedestrians. ♦ Driver attention is split between looking back to merging traffic and looking forward to pedestrian crossing points that may be present in front of the vehicle.



Right-Turn Lane with Island and Dedicated Downstream Lane

Plus	Minus
♦ Benefits motorized vehicles by lowering emissions and increasing capacity. ♦ Provides free flow of turning vehicles, reducing right-turn queues. ♦ Eliminates need to look for merging vehicles (attention may be focused ahead of vehicle because driver is entering dedicated lane). ♦ Removes turning vehicles from through-vehicle lane for improved intersection operations.	♦ High-turning speeds are detrimental to pedestrian safety, so this design is not generally recommended in the urban environment. ♦ Vehicles are observed to frequently stop prior to entering the cross street even with an available dedicated lane because drivers do not know they have a dedicated lane or how long it lasts. ♦ Dedicated downstream lane must be sufficient length for vehicles to merge. ♦ Access needs to be managed along dedicated downstream lane to ensure proper operation.

Section 4
Channelization

Overview

Channelization is used to control, direct, or divide vehicle paths. Where the use of large radii for turning movements results in areas of pavement too large for the proper control of traffic, channelization in the form of raised islands or pavement markings may be used to enhance the guidance of vehicles.[1] Information on raised islands is included in Chapter 4, Section 5 <link>.

Definition

According to AASHTO,[2] channelization is defined as “the separation or regulation of conflicting traffic movements into definite paths of travel by traffic islands or pavement marking to facilitate the orderly movements of both vehicles and pedestrians.” Properly done, channelization can improve traffic operations, improve convenience, and enhance driver confidence. Improperly done, channelization can accomplish exactly the opposite effects. Over-channelization can result in confusion and poor operations.

Principles of Channelization Design

A number of principles have been identified that typically govern the design of channelized intersections, although their application will depend on the specific circumstances of specific intersections:

- Pedestrian traffic and crossings should be considered.
- Motorists should not be confronted with more than one decision at a time.
- Unnatural paths that require turns greater than 90 degrees or sudden and sharp reverse curves should be avoided.
- Areas of vehicle conflict should be reduced as much as possible. Channelization should be used to keep vehicles within well-defined paths that minimize the area of conflict.
- Traffic streams that cross without merging and weaving should intersect desirably at right angles with a range of 60 to 120 degrees acceptable.
- The points of crossing or conflict should be studied carefully to determine if such conditions would be better separated or consolidated to simplify design with appropriate control devices added to ensure safe and efficient operation.
- Refuge areas for turning vehicles should be provided clear of through traffic.
- Islands used for channelization should not interfere with or obstruct bicycle lanes at intersections.
- Prohibited turns should be blocked wherever possible.

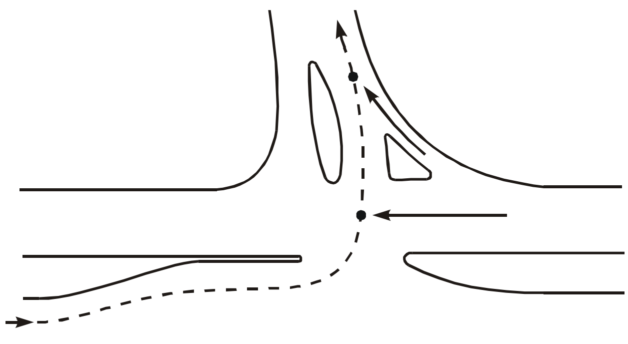
- Location of essential control devices should be established as a part of the design of a channelized intersection.
- Channelization may be desirable to separate the various traffic movements where multiple-phase signals are used.

Additional information on island design and usage is provided in Chapter 4, Section 5 <link>.

Usage

The use of channelization usually provides improved path guidance, narrowed conflict areas, controlled vehicle movements, areas for the placement of traffic signals and signs, or refuge areas. Channelizing islands must be raised if intended for pedestrian refuge, but this may not be possible due to truck turning radius requirements. Examples of the use of channelization are provided below.

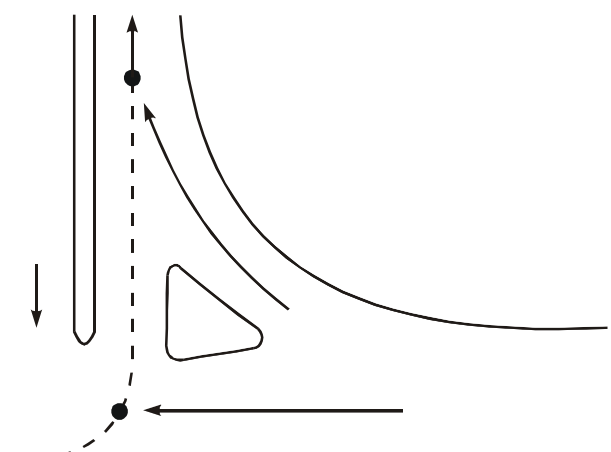
- The paths of vehicles are confined by channelization so that not more than two paths cross at any one point (see Figure 4-10).



Channelized left-turn lanes and exit legs separate points of conflict and define vehicle paths, thereby greatly simplifying the left-turn movement.

Figure 4-10. Channelized Left-Turn Lanes and Exit Legs.[8]

- The angle and location at which vehicles merge, diverge, or cross are controlled (see Figure 4-11).



Highly channelized right turns separate merge-related, right-turn conflicts from other turning and crossing conflicts within the intersection. Median dividers separate head-on conflicts.

Figure 4-11. Channelized Right Turns.[8]

- The amount of paved area is reduced and thereby decreases vehicle wander and narrows the area of conflict between vehicles (see Figure 4-12).

Unchannelized right turns with large turning radii greatly increase open pavement area and pedestrian exposure to conflicts. Raised traffic islands serve as locations of pedestrian refuge, reducing maximum time of exposure to conflicting vehicular flows for easier crossing.

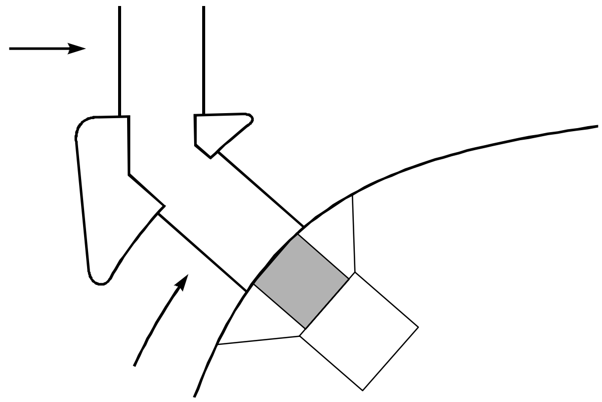


Figure 4-12. Reduction of Pedestrian Exposure with Raised Islands.[8]

- Areas are provided for pedestrian refuge (see Figure 4-13).

Raised median channelization of sufficient width provides midway refuge for pedestrians crossing wide arterial streets. This reduces total time of exposure to conflict and also greatly eases the crossing task. With median refuge, pedestrians can concentrate on one direction of traffic at a time. This is particularly important to the elderly and disabled, whose travel times crossing the intersection may be much greater than the general population.

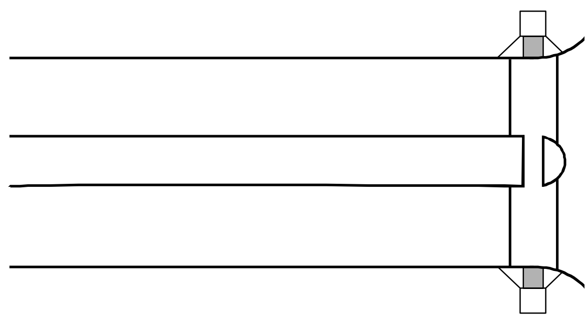


Figure 4-13. Raised Median Channelization.[8]

- ♦ Space is provided for traffic control devices so that they can be more readily perceived (see Figure 4-14). Pedestrian crossing visibility should not be impaired, however. The use of a smaller radius and eliminating the island could provide lower vehicle speeds and place pedestrians in the driver's cone of vision <link to Chapter 4, Section 5>.

Traffic islands, in addition to serving other functions, are appropriate locations for Stop and Yield signs. Use of islands in this manner results in the sign being placed at the stop line and within the driver's cone of vision. Also note the use of separate turning lanes at this stop-controlled intersection. Provision for a right-turn lane eliminates unnecessary delays to right-turning vehicles from drivers waiting to make the more difficult left turn.

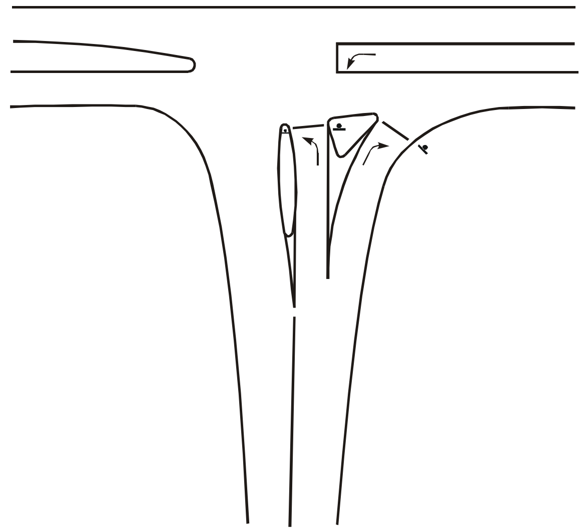
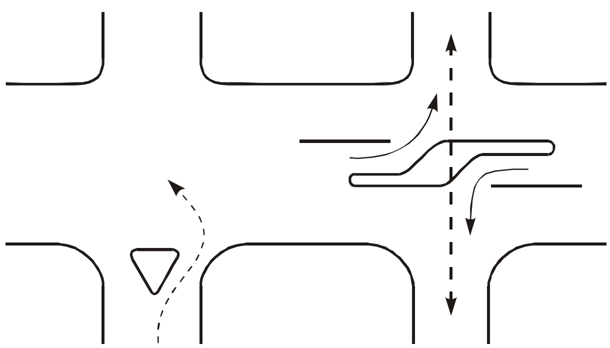


Figure 4-14. Traffic Islands.[8]

- ♦ Prohibited turns are controlled (see Figure 4-15). The solid lines in the figure represent permitted movements while the dashed lines represent prohibited movements blocked by the traffic islands.



Raised traffic islands can block through movements or undesirable turning movements without hindering other intersection movements.

Figure 4-15. Raised Traffic Islands.[8]

Section 5

Island and Median Design

Overview

Three primary purposes that islands and medians provide are:

- channelization—to control and direct traffic movement, usually turning (principles of channelization can be found in Chapter 4, Section 4 <link>);
- division—to divide opposing or same direction traffic streams, usually through movements; and
- refuge—to provide refuge for pedestrians.[2]

Islands are defined areas between traffic lanes used for the control of vehicle movements.[2] Medians are considered to be a type of island, but they separate opposing directions of the roadway.

The design of islands and medians varies, depending on the purpose for their inclusion and the site characteristics present. Examples of islands used in roadway design are shown in Figure 4-16. This section presents overall guidelines for the design of islands and medians, as well as guidance for specific circumstances (i.e., requirements if pedestrian refuge or accommodation for large vehicles is to be provided).

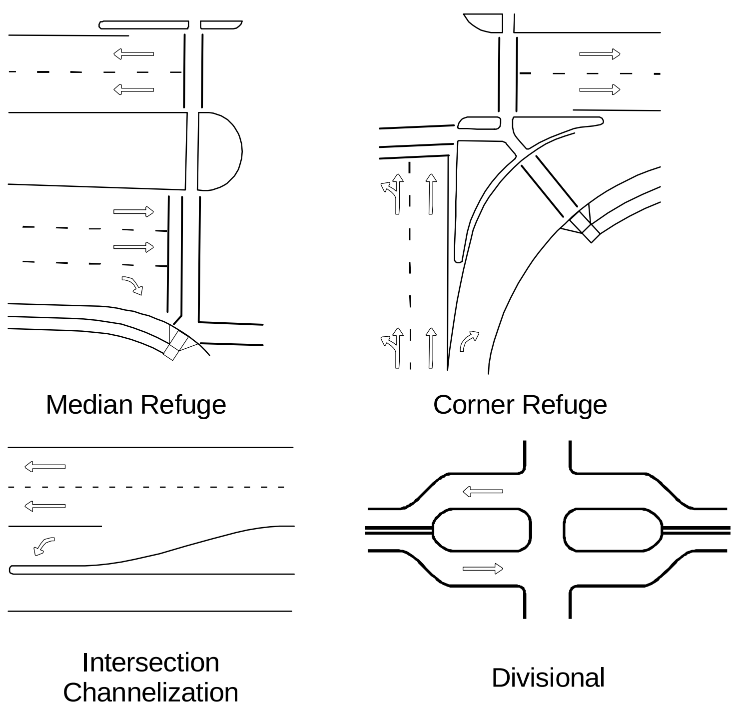


Figure 4-16. Examples of Island Types.

Corner Islands

Corner islands may be used effectively to reduce conflicts where large corner radii or oblique crossings lead to large areas of pavement. Used to delineate the path of through and turning vehicles, corner islands also provide refuge areas and space for sign placement.

Island Size. Channelization in the form of raised islands should be designed so that it commands the driver's attention. Because small islands may be overlooked, curbed corner islands should be at least 50 ft^2 [5 m^2] for urban intersections, although 100 ft^2 [9 m^2] is preferred. To afford refuge to pedestrians, islands should be at least 6 ft [1.8 m] in width.[1] If pedestrians are intended to use cuts through islands for passage, the cuts must have a minimum 5-ft width [1.5 m]. If curb ramps are used, there must be a minimum 5 ft × 5 ft [1.5 m × 1.5 m] landing provided in the island. This landing area, combined with a maximum curb ramp slope of 1:12, means that ramped islands are only feasible where the median or island width is at least 17 ft [5.2 m]. Because bicyclists may traverse intersections in the crosswalk as pedestrians, this use should be considered. To provide refuge for bicyclists, islands must be at least 6 ft wide [1.8 m].[9]

Turning Roadway Widths. Corner islands should accommodate turning roadway widths of 14 ft [4.2 m] and allow turning vehicles to keep their wheel tracks within the traveled way by about 2 ft [0.6 m] on both sides. If large trucks are used as design vehicles this may result in undesirably wide lanes that may encourage passenger cars to use the facility as if it had two lanes; to discourage this behavior, paint or other flush markings may be used to delineate the desired path. For a right turn at a 90-degree intersection with a minimum-size island, a 60-ft-radius [18.2 m] on the outer edge provides a 14-ft turn lane [4.3 m]. Other designs using three-centered curves are shown in AASHTO's Exhibit 9-41.

Oblique-Angle Turns with Corner Islands. The characteristics of islands and turn lane width for intersections with oblique angles may be found in AASHTO's Exhibit 9-42.

Delineation and Approach Treatments. Small islands are usually delineated by curbs and retroreflective materials, while large islands may be delineated by vegetation, mounded earth, shrubs, reflector posts, signs, or any combination of these. Section 3G of the *TMUTCD* provides guidance on the use of delineation treatments for islands.[10]

Island outlines are dictated by the through or turning roadways that surround them. An offset should be provided to the face of the curb on through lanes, although offsets may also be used to turning roadways if necessary to provide clearance for turning trucks. The AASHTO *Green Book* provides details for corner island designs. Figure 4-17 depicts details regarding curb offsets on urban streets. Offsets to islands are desirable but not essential if large uncurbed islands are used.[2]

Nose Offset. The offset from the travel lane to the approach nose should be greater than that to the face of the curbed island, normally about 2 ft [0.6 m]. For curbed median islands, the face of curb at the approach island nose should be offset at least 2 ft [0.6 m] and preferably 3 ft [1.0 m] from the normal median edge. The island should then be gradually widened to its full width. For other curbed islands, the total nose offset should be 3 to 6 ft [1 to 2 m] from the normal edge of through lanes and 2 to 3 ft [0.6 to 1 m] from the edge of the traveled way of a turning roadway. Large offsets should be provided where the curbed corner island is preceded by a right-turn deceleration lane. ***Application 4-8***, Island Offsets, <link> provides an example of the design of curbed corner island offsets.

If the approach roadway has shoulders, the face of the curb on the corner island should be offset by an amount equal to the width of the shoulder.[2] If a right-turn deceleration lane precedes the corner island, the shoulder offset should be at least 8 ft [2.4 m].

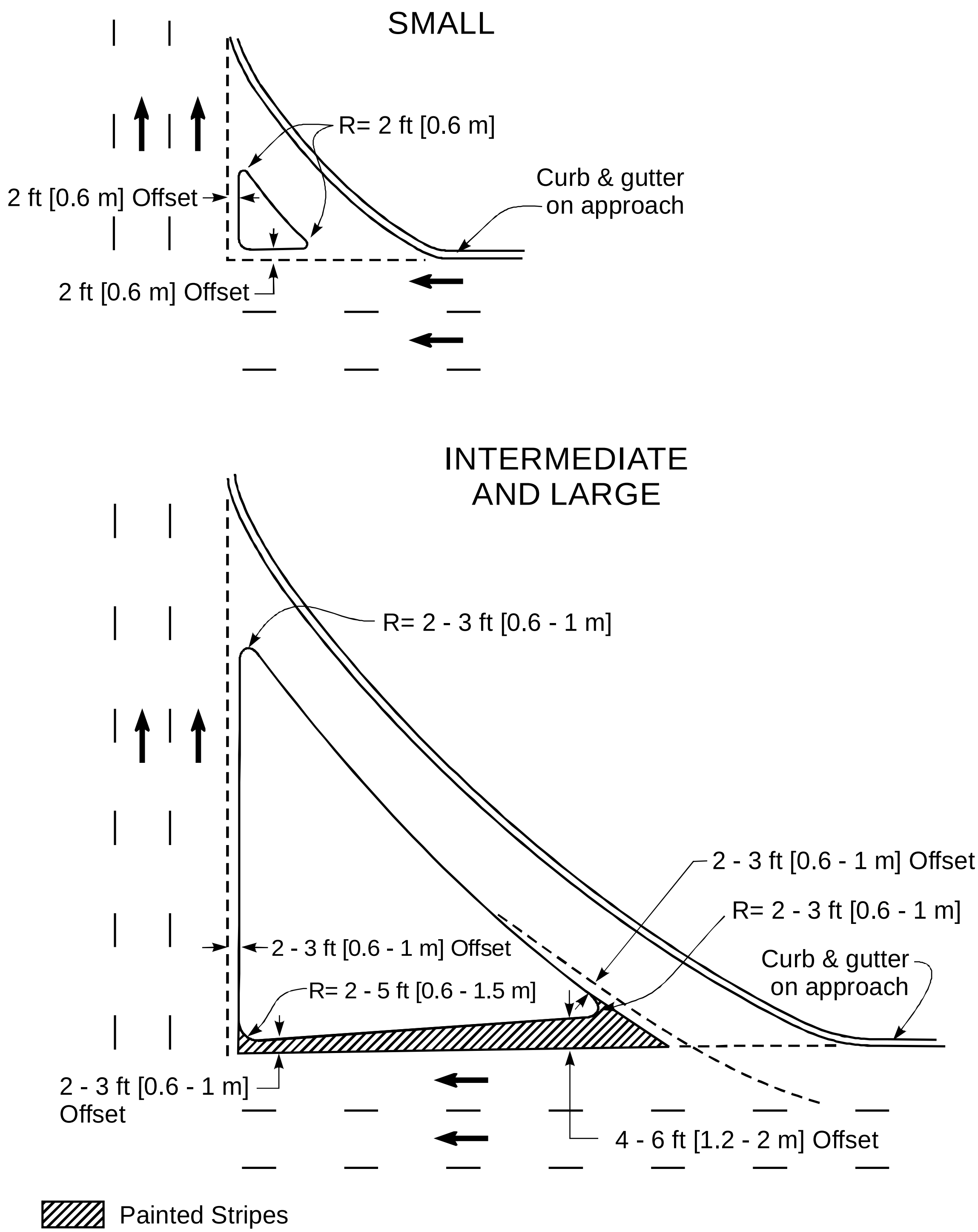


Figure 4-17. Details of Corner Island Designs for Turning Roadways (Urban Locations).

Visibility of Islands. Islands may be curbed or painted.[1] The use of painted islands can be effective and may be more readily modified if layouts are unsatisfactory. Their effectiveness may be reduced in inclement weather; they may require more frequent maintenance, and they do not provide pedestrians with the height advantage that a curbed island provides. Although curbed islands are common in urban areas, painted islands are frequently used where speeds are low and available space is limited. Curbs 6 inches [152 mm] in height are usually used for urban curbed islands.

Because of the difficulty of seeing curbed islands at night, they can be illuminated with fixed-source lighting or delineated appropriately with retroreflective devices, although large curbed islands may be sufficiently delineated by color and texture contrast of vegetative cover, mounded earth, shrubs, reflector posts, or any combination of these.[2]

Large channelizing islands frequently have turf or other vegetation to enhance their appearance and delineation characteristics. Care should be taken to select low plants that do not obstruct sight distance. Large islands should be depressed to prevent drainage from crossing the intersection.

Pedestrians. Pedestrian accommodation is especially challenging at right-turn lanes with islands. Turning drivers have a tendency to be focused more on negotiating the curve or seeking gaps in the cross street than looking for pedestrians. In addition to marked crosswalks, innovative pedestrian treatments may be appropriate at right-turn lanes with islands; however, the literature in this area is limited and tends to focus more on crossings at midblock locations and intersection corners (see Chapter 7 <link>). Figure 4-18 provides an example of an island design intended to improve the performance for pedestrians of a right-turn lane with islands.

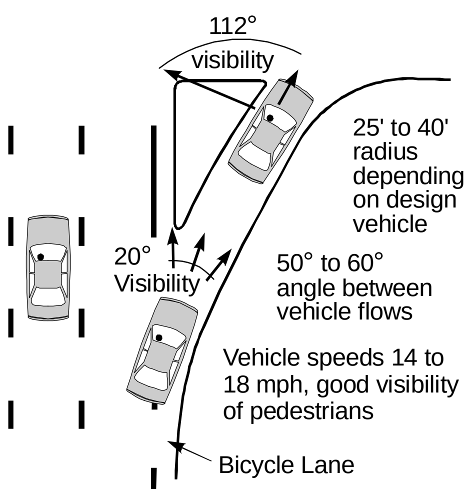


Figure 4-18. Suggested Design for Right-Turn Lane with Island.[11]

Observations on this design include:

- Compound curvature decreases the effective radius of the turn and thus reduces speed and increases entry angle.
- It is believed to be a better solution for accommodating pedestrians due to lower speeds.

- The smaller angle (112 degrees) between the right-turning vehicle and the cross traffic when searching for an acceptable gap requires less head turning that is especially beneficial for older drivers.
- The location of the pedestrian crosswalk is sometimes moved upstream, providing a better driver view of pedestrians in an area where the driver is not yet searching for a gap. However, pedestrians frequently cross downstream, parallel to the flow of traffic on the cross street since it is the shortest route.
- It is believed to be safer, although definitive studies have not been conducted.

Also, directional barriers or devices (such as fences, bollards, or signs) may be used to encourage pedestrians to not step off the curb in areas other than the crosswalk.

Two NCHRP projects are addressing pedestrian concerns at right-turn lanes with islands. NCHRP Project 3-72's[12] objective is to develop design guidance or criteria addressing the safety and operational trade-offs for motorists, pedestrians, and bicyclists for channelizing right turns, along with lane width and right-turn deceleration lanes at driveways and unsignalized intersections. NCHRP Project 3-72[12] began in 2003. NCHRP Project 3-78[13] is anticipated to begin in 2004 and will address crossing treatments at roundabouts and channelized turn lanes for pedestrians with vision disabilities. With any free-flowing design, pedestrians with vision disabilities do not have cues available to enable them to determine where to cross nor when a sufficient gap is available to make a safe crossing.

Median Design

Divisional islands (also called medians) may be introduced on undivided highways at intersections (if they are not already present).[2] Divisional islands can serve to alert drivers to the presence of the intersection, help to channel traffic through the intersection, and provide pedestrian refuge. The islands may be used to help control left turns (particularly at skewed intersections) or where right-turning traffic has separate channels.

Alignments. Alignments used to introduce the islands should be done so that driver paths are clear and unmistakable. Reverse curves or tapers should be used, but their characteristics should be selected so their designs are appropriate for the facility's design speed. If reverse curves are used, roadways with speeds up to 45 mph [72 km/h] should use radii of 2035 ft [620 m] or more; radii of 3825 ft [1166 m] or greater should be used on high-speed roadways.[2] Figure 4-19 shows some typical layouts used for the introduction of divisional islands at intersections.

If located near a crest or the beginning of a horizontal curve, the approach end of an island should be extended to be clearly visible to approaching drivers.

Pedestrians. The presence of a median presents both challenges and opportunities for pedestrians:

- Raised medians may allow pedestrians to cross the intersection in stages.
- If used as a refuge area, pedestrians must be able to traverse the median without leaving the line of the crosswalk and have sufficient room for refuge.

Additional information on the use of a median for refuge is included in Chapter 4, Section 5, Island and Median Refuge <link>.

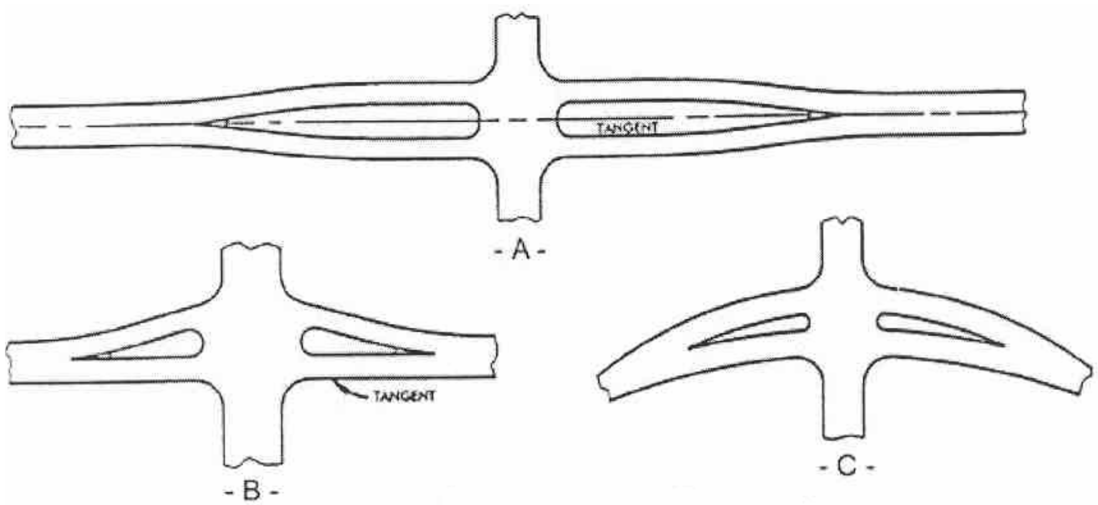


Figure 4-19. Layouts for Addition of Divisional Islands at Intersections.[2]

Median Size. Elongated or divisional islands should be a minimum of 4 ft wide [1.2 m] and 20 to 25 ft long [6 to 8 m], although in special cases with limited space they may be reduced to 2 ft wide [0.6 m].[1] Divisional islands used as pedestrian refuges should be at least 6 ft wide [1.8 m]. Other restrictions on island size and design related to their use as a refuge area for pedestrians are provided later in Chapter 4, Section 5, Island and Median Refuge <link>.

Median End Treatment Design

The design of the median end treatment for a raised or depressed median has to address a number of considerations. An example of a raised median end is shown in Figure 4-20. The median end treatment:

- should not infringe on the expected path of turning vehicles and should delineate the beginning of traffic separation provided by the median;
- should be located as close as practical to the intersecting curb lines to minimize crossing times;
- should not impede pedestrian crossings; and
- may provide a pedestrian refuge area.

Application 4-9 <link> provides an example of the impacts of using a large design vehicle in the design of the median.

Figure 4-20. Example of Median Nose.

Shape. The shape of the median end treatment is usually dictated by the design vehicle, the width of the median, the vehicle turning path, and the length of the median opening. The two basic shapes are:

- semicircular and
- bullet ends.

Bullet-nose shapes share a number of characteristics. In general they:

- more closely follow the path of turning vehicles,
- minimize the median opening,
- reduce the amount of time required for vehicles to clear the intersection (allowing a more efficient signal timing plan),
- provide better guidance for the turning driver because they position the left-turning vehicles to turn to or from the crossroad centerline (semicircular ends tend to direct vehicles onto the opposing traffic lane of the crossroad), and
- are better positioned to provide refuge areas for pedestrians (see Section 5, Island and Median Refuge <link>).

Median widths below 4 ft [1.2 m] will generally function similarly regardless of the selected end shape. For medians greater than about 14 ft wide [4.3 m] and with a 40-ft control radius [12.2 m], the left-turn path controls the median opening length.

Squared bullet noses (see Figure 4-21) should be used for medians greater than 14 ft [4.3 m] (the flat end parallel to the crossroad centerline). This accommodates left-turning vehicles and directs them into appropriate lanes on the crossroad because it allows the median nose to match the turning path of the vehicle.

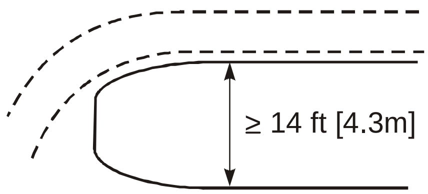


Figure 4-21. Example of Squared Bullet Nose Median End.

Profile. Curbed median noses should be ramped down (see Figure 4-22) and provided with delineation devices to provide advance warning of their presence.[2] For details, the AASHTO *Green Book* should be reviewed. Special care should be used to delineate divisional island approach noses. If practical, raised texturized surfaces or jiggle bars may be used to provide a transition section.

Figure 4-22. Ramped Down Median Nose.

Median Opening Design

Median opening designs for a variety of vehicle types are provided in the AASHTO *Green Book*. Figure 4-23 shows a minimum design median opening designed using a passenger car as a design vehicle. The turning path of a WB-50 [WB-15] is overlaid on the design, showing that the truck would infringe on other lanes and possibly strike the curb on the turn from the major roadway onto the minor roadway.

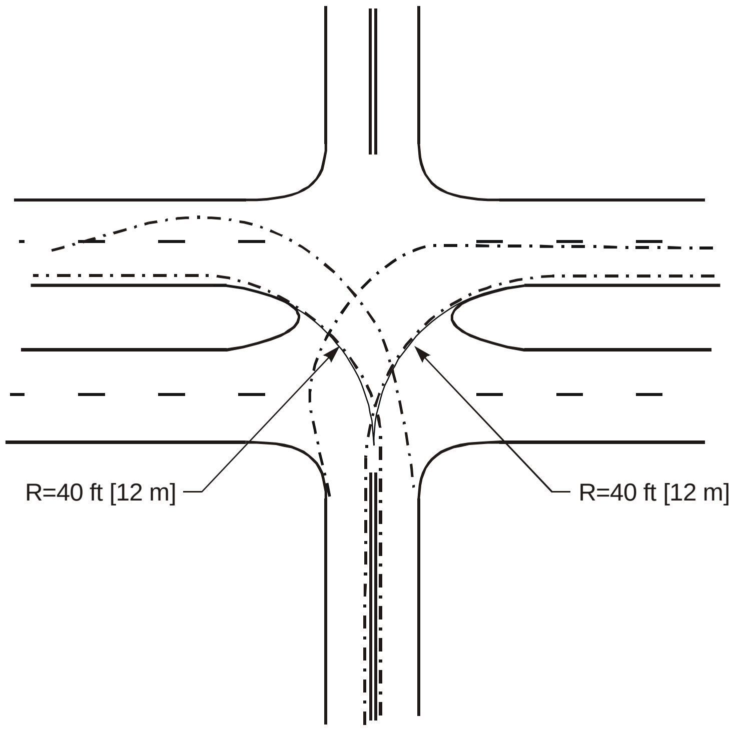


Figure 4-23. Minimum Design of Median Openings (WB-50 [WB-15], Control Radius of 40 ft [12 m]).[2]

If permitted, U-turning vehicles may also be considered in the selection of the median nose shape. The U-turning vehicle is usually expected to proceed from a turning lane to the outermost lane on the opposite side of the roadway. It may not be practical to accommodate greater than passenger car or single-unit truck traffic.

Asymmetrical shapes may be used when vehicle turning paths warrant this type of design, such as at intersections with one-way roadways or at skewed intersections.[2]

Median Opening Length. Minor roadway intersections may be accommodated by median opening lengths as small as the width of the crossroad including shoulders; if the crossroad is a divided highway, that length should include the width of the median. In most other circumstances, however, the median opening length should be determined after consideration of vehicle turning paths.

Median openings longer than 80 ft [24.4 m] should be avoided. The provision of channelization, turning lanes, or reducing skew angles should be considered to reduce the required median opening.

Island and Median Refuge

Medians and islands help pedestrians cross streets by providing refuge areas that are physically separated from the vehicle path of travel. A *median* separates opposing lanes of traffic, and an *island* is a defined area between traffic lanes used for the control of vehicle movements. They both can provide a protected area within a crosswalk for pedestrians to wait to continue crossing the street. Medians and islands allow pedestrians to cross during smaller gaps in traffic.

Pedestrian refuge islands (shown in Figure 4-24, Figure 4-25, and Figure 4-26) are commonly installed on wide streets where adequate crossing time cannot be provided or when the characteristics of the pedestrians indicate that some pedestrians might need more time, or when space is available. Pedestrian refuge should be considered in all reconstruction projects. Raised-curb corner islands and center channelizing or divisional islands can be used as refuge areas.[2] Pedestrian refuge islands should include the following characteristics:[14]

- If landscaping is present, it should not obstruct:
  - the pedestrian pathway,
  - the visibility of the pedestrian and drivers to each other, or
  - the sight distance at the intersection.
- It should be equipped with pedestrian actuation detectors at signalized crossings to allow the pedestrian to recall the WALK phase if adequate time is not provided for a full pedestrian crossing.

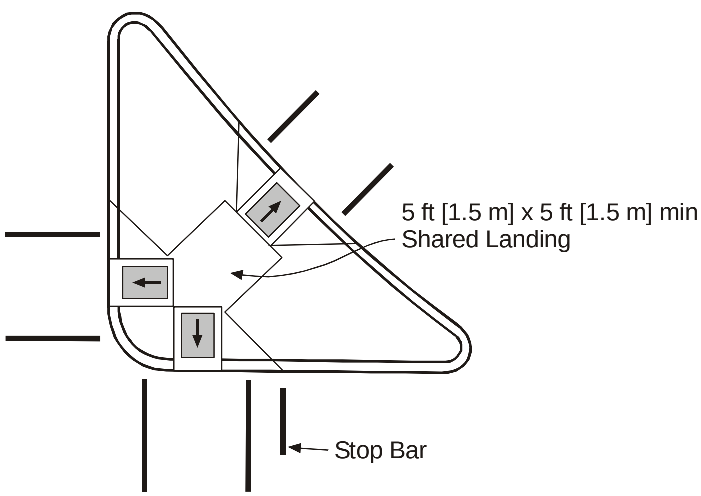


Figure 4-24. Typical Layout of Curb Ramps at a Channelizing Island.[15]

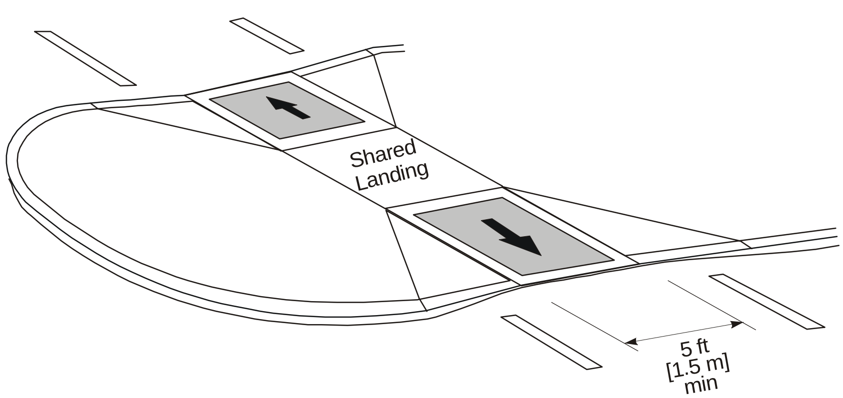


Figure 4-25. Curb Ramp at Median Islands.[15]

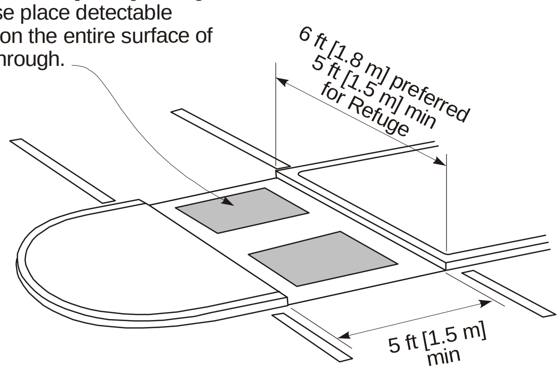


Figure 4-26. Cut through at Raised Median.[15]

Whether the median is raised or depressed, access to the crossing island and median is to be functional and safe for all pedestrians. The island or median should be large enough to enable a wheelchair to wait on a level landing, or a cut-through design should be provided. The cut-through width should be the same as the complete width of the crosswalk. Cut-through designs should be graded to drain quickly and may also require additional maintenance such as sweeping, etc. An example of a cut through is shown in Figure 4-26. Where the cut through connects to the street, the edges of the cut through should be aligned with the direction of the crosswalk for a minimum length of 2 ft [0.6 m].

Application 4-10 <link> provides a review of some of the issues related to median design in a design that considers the staged development of a roadway and its median. Consideration of the impacts of the median width on pedestrians and vehicles is provided in the application.

Section 6
Bicycle Facilities

Overview

Bicycle facilities are defined as improvements made to accommodate or encourage bicycling,[9] and include (but are not limited to) improvements such as:

- Bicycle lane: a portion of a roadway which has been designated by striping, signing, and/or pavement markings for the preferential or exclusive use of bicyclists.[1]
- Shared roadway: a roadway which is open to both bicycle and motor vehicle travel. This may be an existing roadway with wide curb lanes or a roadway with paved shoulders.[15]

The most complete source of bicycle facility design information is contained in AASHTO's *Guide for the Development of Bicycle Facilities.*[9] The AASHTO guide provides information on the planning, design, construction, maintenance, and operation of bicycle facilities.

Bicycle Lane

Bicycle lanes are located at the right side of the roadway, and they carry bicycle traffic in the same direction as the adjacent motor vehicle traffic; even on one-way roadways bicycle lanes are still generally located on the right side of the roadway to avoid violating driver expectancy.[9]

Minimum widths for bicycle lanes are 4 ft [1.2 m] if parking is not allowed, although 5 ft [1.5 m] is recommended from the face of a curb or guardrail.[9] If parking is permitted the bicycle lane should be 5 ft [1.5 m]. The recommended width of a bicycle lane from the face of a curb or bridge rail is 5 ft [1.5 m]. The 5 ft width [1.5 m] should be sufficient in cases where a 1 to 2 ft [0.3 to 0.6 m] gutter pan exists if the longitudinal joint between the bicycle lane and the gutter pan is smooth. If the joint is not smooth then 4 ft [1.2 m] of ridable surface should be provided. The width of the gutter pan should not be included in the measurement of the ridable or usable surface, with the possible exception of those communities that use an extra-wide, smoothly paved gutter pan that is 4 ft [1.2 m] wide as a bicycle lane. In areas that allow parking, bicycle lanes should be 5 ft [1.5 m] in width and located between the parking area and the motor vehicle lanes. Bicycle lanes should never be placed between the parking lane and the curb. If parking is permitted but no parking stripes or stalls are provided, the shared area should be 11 ft [3.4 m]. However, 13 ft [4.0 m] is recommended where there is substantial parking or turnover of parked cars is high (e.g., commercial areas).

Bicycle lane markings should not extend across intersections in most cases, although in some exceptionally complex intersections dotted guidelines may be used. Bicycle lane markings should never cross crosswalks.[9] If no crosswalks are present the bicycle lane markings should stop at the near side street property line extension and resume at the far side street property line extension. Figure 4-27 shows typical markings for signalized or stop-controlled intersections and for a minor intersection with crosswalks, while Figure 4-28 shows typical markings at T-intersections.

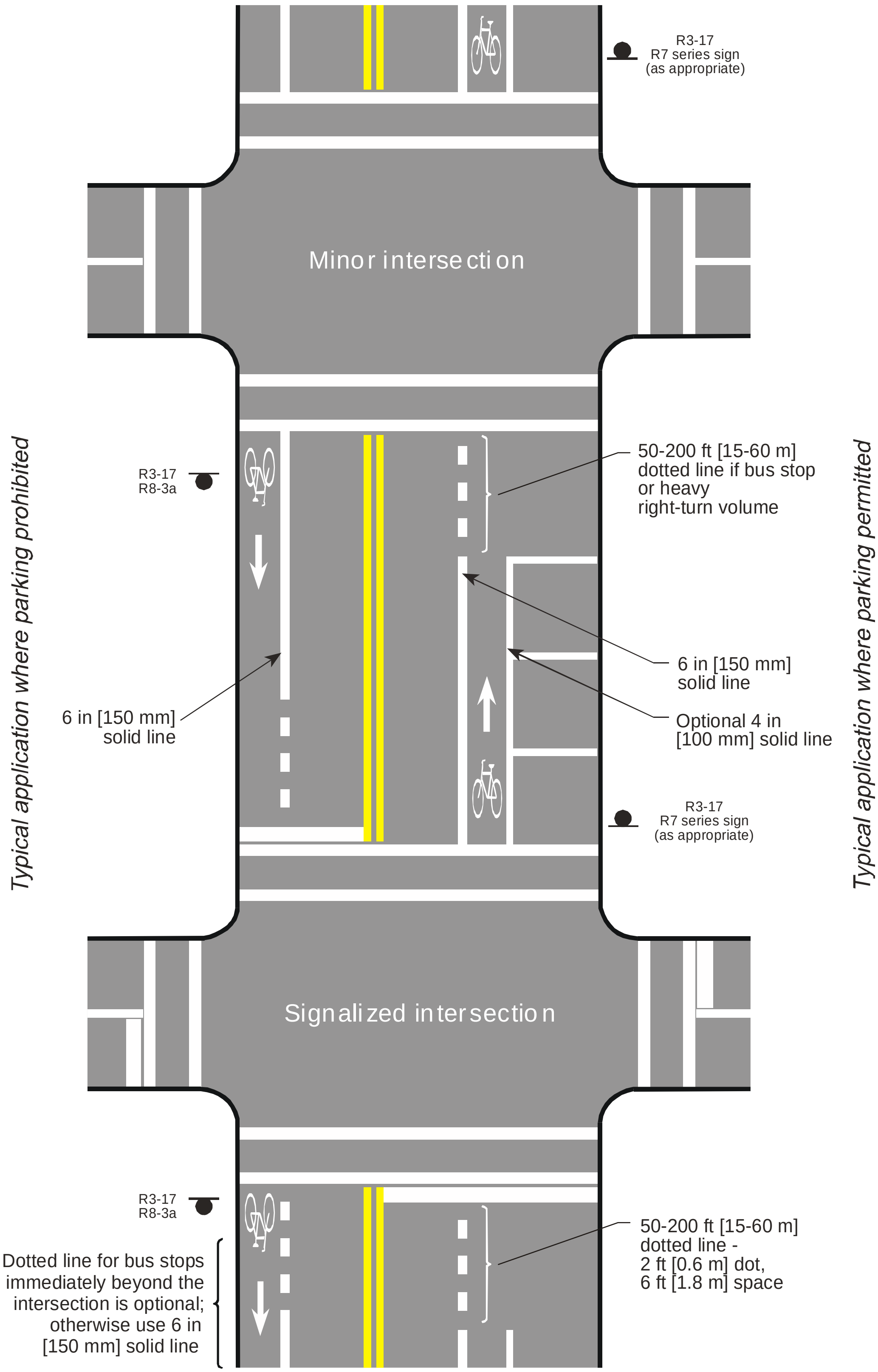


Figure 4-27. Bicycle Lane Marking Examples.[9]

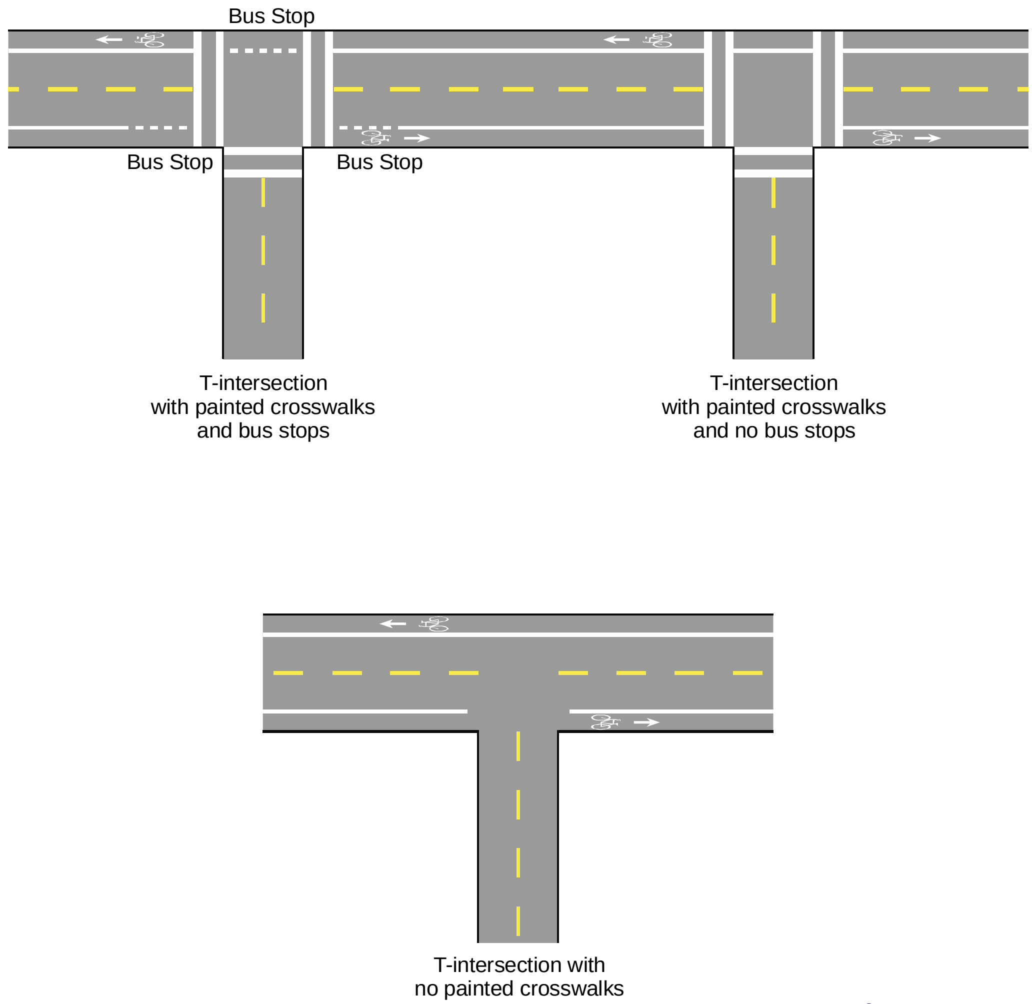


Figure 4-28. Example of Bicycle Lane Marking at T-Intersections.[9]

The introduction of right-turn lanes at intersections complicates the design of bicycle lanes. As Figure 4-29 shows, a number of paths may be used by motorists and bicyclists at intersections with bicycle lanes. Figure 4-30 provides four potential alternatives for the bicycle lane and turn lane layout. Locations with sufficient room should provide the marked bicycle lane between the through traffic and the right-turning traffic, as shown in Figure 4-30.

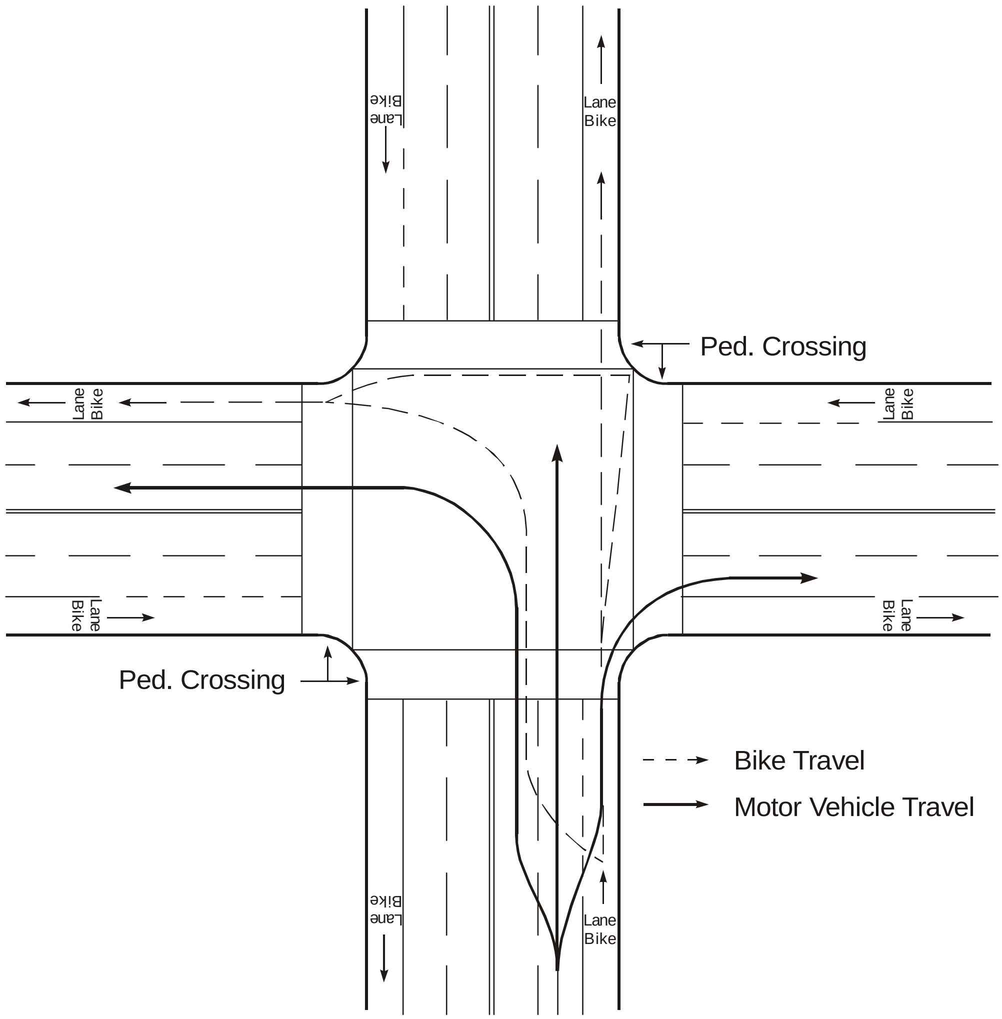


Figure 4-29. Typical Bicycle and Motor Vehicle Paths at Major Intersections.[9]

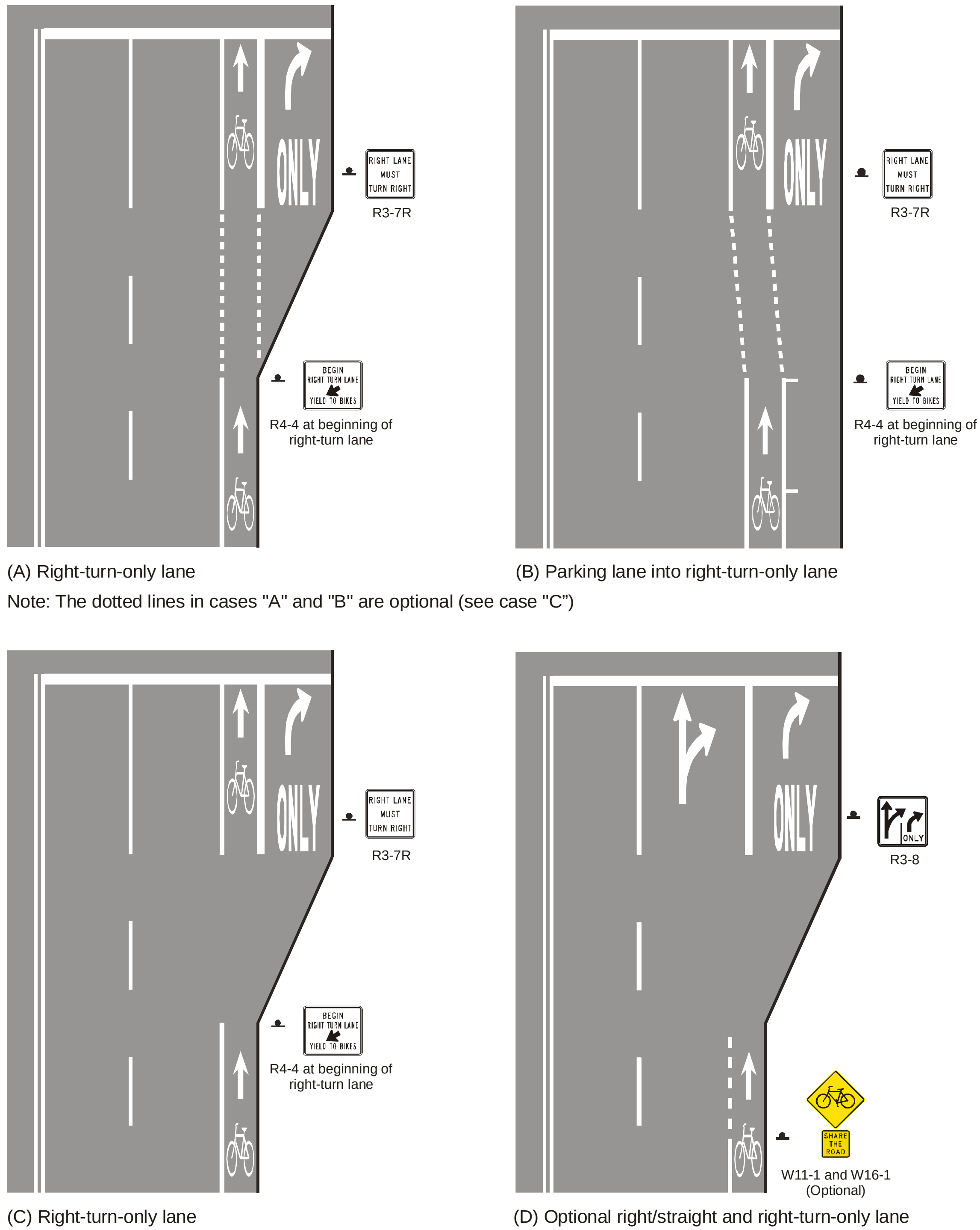


Figure 4-30. Illustration of Bicycle Lane Treatments at Location with Right-Turn Lane.[9]

Shared Roadways

Bicycles will be used to varying extent on all roadways where they are legally permitted. Design features that can make roadways more compatible to bicycle travel include:

- bicycle-safe drainage grates and bridge expansion joints,
- improved railroad crossings,
- smooth pavements,
- adequate sight distances,
- signal timing and detector systems that respond to bicycles, and
- shoulder improvements and wide curb lanes.

Signed shared roadways are those that have been identified by signing as preferred bicycle routes. The addition of destination information, as shown in Figure 4-31, enhances the functionality of the bicycle route signing.[9] Paved shoulder widths should be at least 4 ft [1.2 m] (not including any gutter pan, if present, unless the pan width is 4 ft [1.2 m] or greater) to accommodate bicycles. A 5-ft wide [1.5 m] shoulder is recommended in areas with guardrail or roadside barrier. Wide curb lanes are preferred if shoulders are not present. Curb lane widths exclusive of the gutter pan of 14 ft [4.3 m] are recommended, although 15 ft [4.6 m] may be used where drainage grates, raised pavement markers, or on-street parking effectively reduce the usable width.[1]

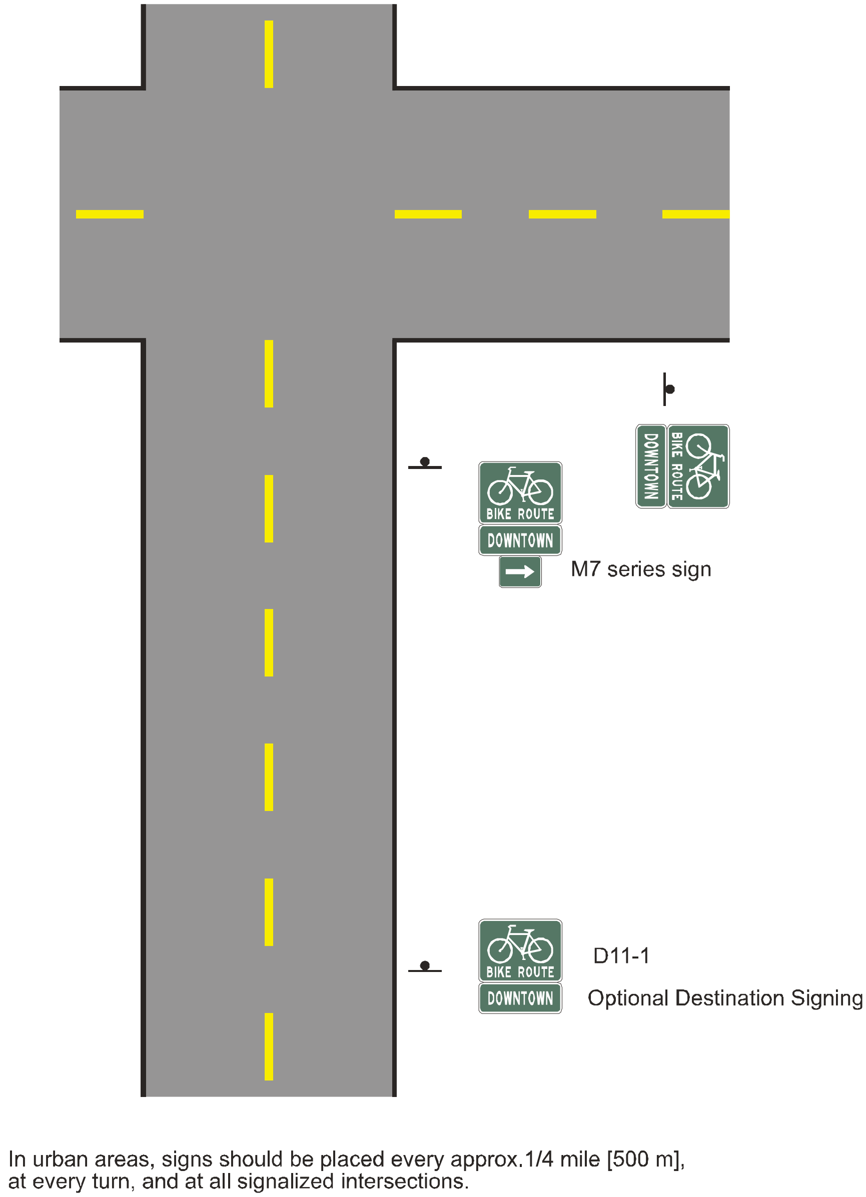


Figure 4-31. Bicycle Route Signing.[9]

Section 7
Shoulders and Parking

Overview

Although not frequently provided on urban streets, shoulders provide a number of important functions:[1,2]

- Wide, surfaced shoulders provide a suitable, all-weather area for stopped vehicles to be clear of the travel lanes.
- Shoulders lend lateral support to travel lane pavement structure.
- Shoulders provide a maneuvering area.
- Shoulders provide space for postal and other delivery vehicles to stop.
- Shoulders can be used by bicyclists.

Width

Design shoulder widths are provided in the *Roadway Design Manual*:[1]

- Reconstruction (4R) work:
  - Urban streets and frontage roads: *Roadway Design Manual* Table 3-1, Geometric Design Criteria for Urban Streets <link>
  - Suburban roadways: *Roadway Design Manual* Table 3-5, Geometric Design Criteria for Suburban Roadways <link>
- Rehabilitation (3R) work:
  - *Roadway Design Manual* Table 4-3, 3R Design Guidelines for Urban Streets All Functional Classes <link>
  - *Roadway Design Manual* Table 4-5, 3R Design Guidelines for Urban Frontage Roads <insert>

Shoulder width consideration may also include the shoulder's use as a *de facto* right-turn lane. If shoulders are widened to explicitly permit the inclusion of a right-turn lane then it eliminates the possibility of conflicts between vehicles turning right from the main lanes and vehicles turning right from the shoulder.

Parking Lanes

As noted in the *Roadway Design Manual*[1], parking lanes may be provided rather than shoulders on urban collector and local streets, although they are discouraged on arterial streets because of the effect that vehicles entering and exiting parking spaces have on capacity in the adjacent through lanes. Parking should be restricted (or replaced with a curb extension) in locations where it interferes with sight distance (particularly intersection or stopping sight distance) or operations. Parking is not permitted within 20 ft [6 m] of a crosswalk or within 30 ft [9 m] of the approach to Stop signs, Yield signs, or traffic control signals.[16] The *Roadway Design Manual* states that parking should be restricted 20 ft [6 m] prior to the curb radius to meet these needs and to even provide a short right-turn lane if desired.

Because erratic maneuvers may result if parking lanes are carried up to the intersection, the designer can consider the following:

- prohibiting parking and creating a short turn lane, or
- providing a transition (also referred to as curb extensions or bulb) such as shown in Figure 4-32.[2]

The use of a parking lane transition or curb extension may provide enhanced visibility to pedestrians approaching the curb or awaiting a crossing opportunity, and shortens the time required for them to cross the roadway. For further information, see Chapter 5, Section 5 <link>.

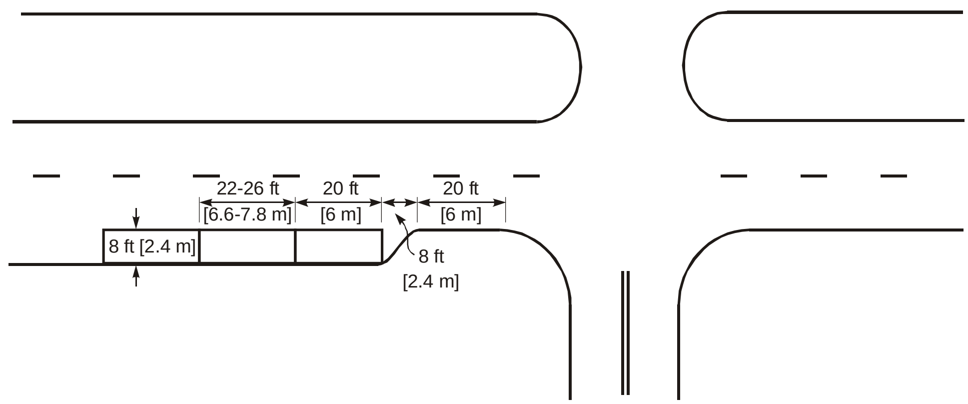


Figure 4-32. Parking Lane Transition.[2]

Curb Offset

Although not defined as a "shoulder," an offset of 1 to 2 ft [0.3 to 0.6 m] from the edge of the travel lane to the face of the curb should be provided for curb-and-gutter sections.[1]

Section 8

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Chapter 5
Roadside

Contents:

Section 1
Sidewalks

Overview

Sidewalks provide distinct separation of pedestrians and vehicles, serving to increase pedestrian safety as well as to enhance vehicular capacity. A sidewalk is a paved area (typically concrete) that normally runs parallel to vehicular traffic and is separated from the road surface by at least a curb and gutter.[1] Properly planned, designed, and constructed sidewalks are essential for increasing pedestrian mobility, accessibility, and safety, especially for persons with disabilities, older pedestrians, and children. A recent Federal Highway Administration study[2] cited the presence of sidewalks in residential areas as the one physical factor in the roadway environment having the greatest effect on pedestrian safety.

Application 5-1 <link> discusses sidewalk considerations during a redevelopment of an area.

Planning for Sidewalks

Sidewalks are typically an integral part of the transportation system in central business districts. In rural and suburban areas, sidewalks are most justified at points of community development such as at schools, recreation areas, and local businesses when these developments result in pedestrian concentrations near or along the highways. In typical suburban development, there are initially few pedestrian trips because there are only a few closely located pedestrian destinations. However, when pedestrian demand increases with additional development, it may be more difficult and more costly to install pedestrian facilities if they were not considered in the initial design. Early consideration of pedestrian facility design during the project development process may also greatly simplify compliance with accessibility requirements established by the *Americans with Disabilities Act Accessibility Guidelines*[3]and the *Texas Accessibility Standards*.[4]

In some cases the inclusion of sidewalks is left to the discretion of the engineer or planner on a site-by-site or project-by-project basis. Some cities and communities have requirements for the use and the design of the sidewalk that are based on functional classification of the roadway. The ITE publication on *Design and Safety of Pedestrian Facilities*[5] includes general sidewalk installation guidelines that are based on land use, roadway functional classification, and, in the case of residential areas, dwelling unit density.

When to Include Sidewalks on TxDOT Projects

Early in the project development process, several factors should be considered when determining whether to include new sidewalks on a TxDOT project. When any of the following factors are present, sidewalks should be included on the project:

- The facility is part of a locally adopted sidewalk planning document.

- There is evidence of pedestrian traffic (either pedestrians are observed, there is a beaten down path, or significant potential exists for pedestrians to walk in the roadway).
- Facility is located on a route to a school or a transit route.

In addition, where pedestrian generators/attractors exist, new sidewalk construction may also be considered.

It is important that walking be incorporated into the TxDOT system and that the facilities constructed are usable by those with disabilities. Therefore, planning for these facilities must occur early and continuously throughout project development.

Even when sidewalks are not incorporated into a project, they will likely be added in the future. The designer can make the future addition of sidewalks much simpler by providing preliminary grading that includes space for a future sidewalk and by designing driveways to include an accessible path across them (see TxDOT *Roadway Design Manual*, Chapter 2, Section 6, Sidewalks and Pedestrian Elements <link>).

Sidewalk Location

It is desirable to provide a buffer space between the traveled way and the sidewalk for pedestrian comfort, especially adjacent to high-speed traffic. Figure 5-1 illustrates a buffer zone. For curb and gutter sections, a buffer space of 3 ft [915 mm] or greater between the back of the curb and the sidewalk is desirable. For rural sections without curb and gutter, sidewalks should be placed between the ditch and the right-of-way line if practical.

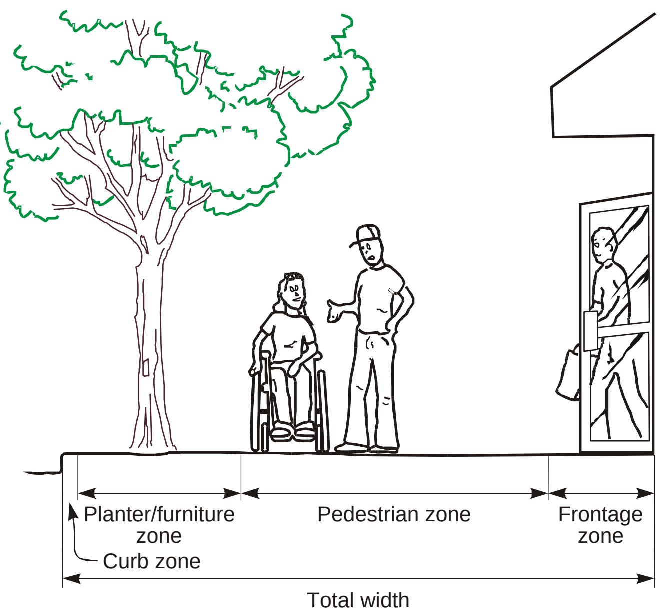


Figure 5-1. Sidewalks Zones.[6]

ADAAG/TAS

Specific design minimum requirements to accommodate the needs of persons with disabilities are established by the ADAAG[3] and TAS.[4] More generous values should be utilized when possible. A request for a design variance for any deviations from TAS requirements must be submitted to the Design Division for forwarding to the Texas Department of Licensing and Regulation for approval.

Sidewalk Width

Sidewalks should be wide enough to accommodate the volume and type of pedestrian traffic expected in the area. Following are suggested sidewalk widths:

- The minimum clear sidewalk width is 5 ft [1525 mm]. Any exception to this minimum dimension must satisfy ADAAG/TAS requirements.
- Where a sidewalk is placed immediately adjacent to the curb, a sidewalk width of at least 6 ft [1830 mm] (measured from back of curb) is desirable to allow additional space for street and highway hardware and to allow for the proximity of moving traffic.
- Sidewalk widths of 8 ft [2.4 m] or more may be appropriate in commercial areas, along school routes, and other areas with concentrated pedestrian traffic.
- The sidewalk width may be reduced to 4 ft [1.2 m] where necessary to cross a driveway while maintaining the maximum 2 percent cross slope.
- The width may be reduced to 4 ft [1.2 m] for a length of 2 ft [0.6 m] maximum if insufficient space is available to locate street fixtures (elements such as sign supports, signal poles, fire hydrants, manhole covers, and controller cabinets), provided that reduced width segments are separated by at least 5 ft [1.5 m] in length.

Cross Slope

Sidewalk cross slope is not to exceed 1:50 (2 percent). Due to construction tolerances, it is recommended that sidewalk cross slopes be shown in the plans at 1.5 percent to avoid exceeding the 2 percent limit when complete. Cross slope requirements also apply to the continuation of the pedestrian route through the crosswalk. Sidewalks immediately adjacent to the curb or roadway may be offset to avoid a non-conforming cross slope at driveway aprons by diverting the sidewalk around the apron. Chapter 7, Section 1 <link> discusses and shows examples of sidewalk treatments at driveways.

Grades

Steep grades create problems for pedestrians with mobility impairments. Wheelchair users may travel quickly on downhill pathways but will travel much more slowly on uphill segments and at greater expense of energy or battery reserves. Sidewalks should be designed with the flattest grade possible to maximize accessibility. Wherever possible, sidewalks and walkways should be designed with maximum grades of 5 percent (1:20).

When the topography of an area has a steeper grade, the sidewalk may follow the grade of the roadway.

Surfaces

The sidewalk surface treatment can have a significant impact on the overall accessibility and comfort level of the facility. The ADAAG[3] requirement is that the surface be stable, firm, and slip resistant. The preferred materials are Portland cement concrete (PCC) and asphaltic concrete pavement (ACP). PCC (typically found in urban areas) provides a smooth, long-lasting, and durable finish that is easy to grade and repair. ACP has a shorter life expectancy but may be appropriate in less urban areas and park settings. Crushed limestone may be used as an all-weather walkway surface in park settings or rural areas, but such paths generally require a higher level of maintenance to maintain accessibility.

Sidewalks, walkways, and crosswalks can be constructed with bricks and pavers if they are constructed to avoid settling or removal of bricks, which can create a tripping condition. Stamping molds have also been used to create the visual appearance of bricks and pavers. The technique has the advantages of using traditional concrete without some of the maintenance issues associated with bricks and pavers. There are commercially available products that produce a variety of aesthetically pleasing surfaces that are almost impossible to distinguish from real bricks and pavers. Stamped surface treatments are not completely without maintenance issues: the color has been known to fade, and there is usually little or no attempt made to replicate the original pattern and color when utility cuts or sidewalk repairs are made. In addition, stamped products should be selected carefully to ensure a smooth ride for persons using wheelchairs.

A disadvantage of either real or stamped brick sidewalks is the problem that seemingly small surface irregularities pose for wheelchair users with spinal injuries. However, it is possible to enhance sidewalk aesthetics while still providing a smooth walking surface by combining a concrete main walking area with brick edging where street furniture (lights, trees, poles, etc.) can be placed.

Street Furniture

Street furniture includes items intended for use by the public such as benches, public telephones, bicycle racks, and parking meters. Special consideration should be given to the location of street furniture. A clear ground space at least 2.5 ft × 4 ft [760 mm × 1220 mm] with a maximum slope of 2 percent must be provided and positioned to allow for either forward or parallel approach to the element in compliance with ADAAG[3] or TAS.[4] The clear ground space must have an accessible connection to the sidewalk. The draft guidelines for ADAAG[7] state that the clear ground space can overlap the pedestrian route a maximum of 12 inches [305 mm]. Additional information on street furniture is provided in Chapter 5, Section 4 <link>.

Street Crossings

Intersections can present formidable barriers to pedestrian travel. Intersection designs that incorporate properly placed curb ramps, sidewalks, crosswalks, pedestrian signal heads, and pedestrian refuge islands can provide a pedestrian-friendly environment. Desirably, drainage inlets should be located on the upstream side of crosswalks and sidewalk ramps. Refuge islands enhance pedestrian comfort by reducing effective walking distances and pedestrian exposure to traffic. Islands should be a minimum of 5 ft wide [1525 mm] to afford refuge to wheelchair users. A minimum 5 ft width [1525 mm] should be cut through the island for pedestrian passage, or curb ramps with a minimum 5 ft × 5 ft [1525 mm × 1525 mm] landing should be provided in the island. Additional information on street crossing issues is included in Chapter 7 <link>.

Curb Ramps and Landings

Curb ramps must be provided in conjunction with each project where the following types of work will be performed:

- resurfacing projects, including overlays and seal coats, where a barrier exists to a sidewalk or path;
- construction of curbs, curb and gutter, and/or sidewalks;
- installation of traffic signals with pedestrian signals; and
- installation of pavement markings for pedestrian crosswalks.

Discussion on design criteria for curb ramps and landings is presented in Chapter 7, Section 1 <link>.

Sidewalk Considerations

Sidewalks should be continuous and installed to the recommended widths, exclusive of street furniture and other appurtenances. Discontinuous sidewalks and street appurtenances located within the sidewalk can create problems for pedestrian access or safety (see Figure 5-2 through Figure 5-4).

Figure 5-2. Discontinuous Sidewalk to Bus Stop.

Figure 5-3. Discontinuous Sidewalk to Mailbox.

Figure 5-4. Examples of Street Appurtenances Located within the Sidewalk.

Section 2
Horizontal Clearance

Overview

A clear recovery area, or horizontal clearance, should be provided along roadways as practical. Ideally this area would be free of obstacles such as unyielding sign and luminaire supports, non-traversable drainage structures, utility poles, and steep slopes. Note that horizontal clearance involves a series of compromises between "absolute" safety and engineering, environmental, and economic constraints.

Horizontal Clearance

The TxDOT *Roadway Design Manual*[8] and the AASHTO *Roadside Design Guide*[9] provide discussion on principles and criteria for horizontal clearances. Table 5-1 is a reproduction of the *Roadway Design Manual* Table 2-11 <link>. The horizontal clearance values shown in Table 5-1 are measured from the edge of the travel lane unless otherwise indicated.

Protruding Objects

Obstacles on the roadside can encroach into the pedestrian's path of travel and be difficult for visually impaired pedestrians to detect with a cane. The typical cane techniques do not locate objects extending into the travel path above 15 to 27 inches [38 to 69 cm] before contact with the body (see Figure 5-5). Figure 5-6 provides examples of objects in the roadside and the recommended protrusion limits. Generally objects with leading edges more than 27 inches [685 mm] and not more than 80 inches [2030 mm] above the finish floor or ground may protrude 4 inches [100 mm] maximum horizontally into the circulation path. Guardrails or other barriers shall be provided where the vertical clearance is less than 80 inches [2030 mm]. An example of this situation might be under a stairway. The leading edge of such guardrail or barrier shall be located 27 inches [685 mm] maximum above the finish floor or ground. An exception is that door closers and door stops shall be permitted to be 78 inches [1980 mm] minimum above the finish floor or ground.

Figure 5-5. Protruding Controller Equipment.

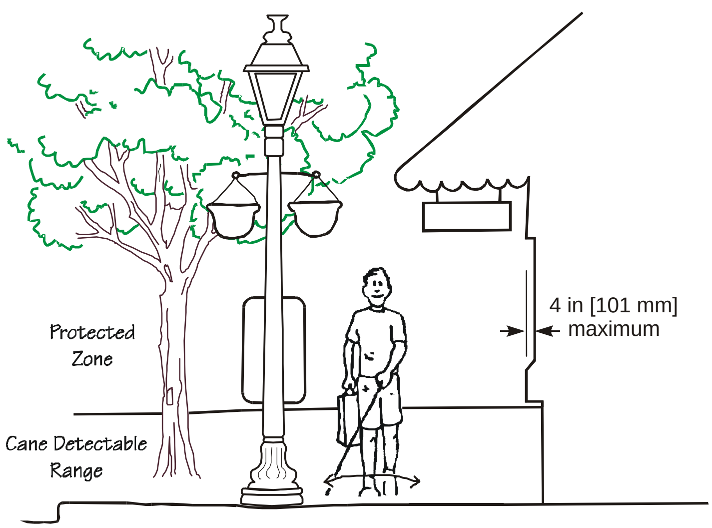


Figure 5-6. Post-Mounted Objects (Post-Mounted Objects Seen in Elevation, Dimensioned to Indicate 4 inch [101 mm] Maximum Protrusion).[10]

Placement of Poles

TRB State of the Art Report 9[11] (*Utilities and Roadside Safety*) provides the following guidance on locating poles.

Lane Drops and Roadway Narrowing. Placement of poles downstream of a lane drop or the area where the roadway narrows should be discouraged. This is especially important when it can be reasonably foreseen that an inattentive or physically impaired driver might not be able to accurately perceive the lane drop or lane narrowing. These situations are presented in Figure 5-7 and Figure 5-8. Another cause of this problem is a traffic conflict, where a driver is prevented by another vehicle from changing lanes or moving laterally. If it is impractical to span the critical zone without a pole, consideration should be given to the use of a guardrail or crash cushion.

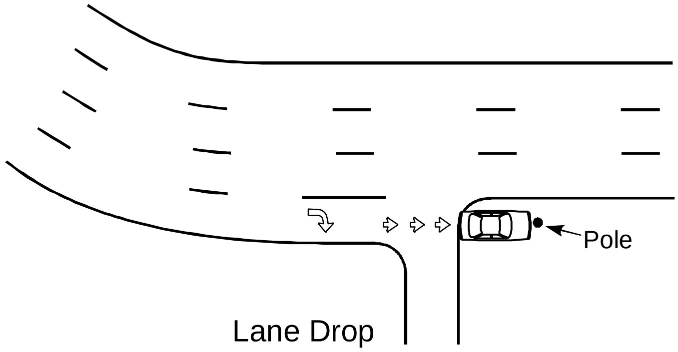


Figure 5-7. Exposure of Vehicle to Utility Pole Downstream of Lane Drop.[11]

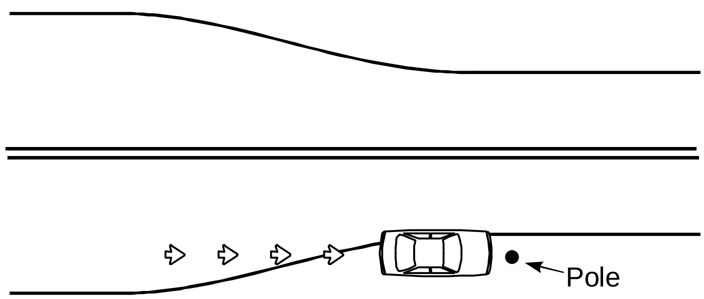


Figure 5-8. Placement of Pole Downstream of Roadway Narrowing.[11]

Traffic Island. Placement of poles on a traffic island should be strongly discouraged. Islands are an element of traffic control at an intersection and are usually located within the boundaries of the traveled way. As such, they are likely to be occasionally traversed by errant vehicles. This traversal should not be prevented by a utility pole placed as indicated in Figure 5-9. If placement of a utility pole on an island is a practical necessity, consideration should be given to protecting errant vehicles with a crash cushion.

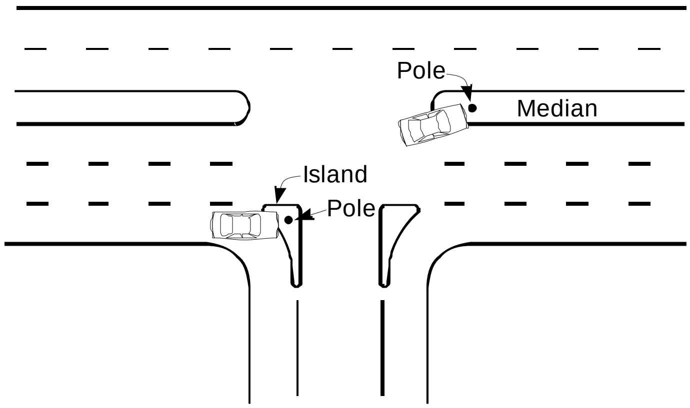


Figure 5-9. Inappropriate Location of Poles within a Traffic Island or Median.[11]

Medians. Placement of poles in medians, as indicted in Figure 5-9, should be strongly discouraged. Medians are safeguards against head-on collisions and, as such, provide space for errant vehicles to regain control or space for installation of median barriers. A pole or pole line in a median should be considered only if vehicles can be completely shielded from the poles by median barriers. Luminaires are often placed in protected positions on top of median barriers.

Traffic Conflicts. Where critical traffic conflicts can be foreseen, especially at intersections of high-speed roadways, pole placement may be designed to avoid the most critical secondary collisions. For example, if the major roadway is in a north-south direction and the minor roadway is east-west, the most critical quadrants for a secondary collision (collision of a vehicle with a pole after an initial two-vehicle collision) are the northeast and southwest quadrants. Thus, the preferred placement for poles at this intersection would be in the northwest and/or southeast quadrants, as indicated in Figure 5-10.

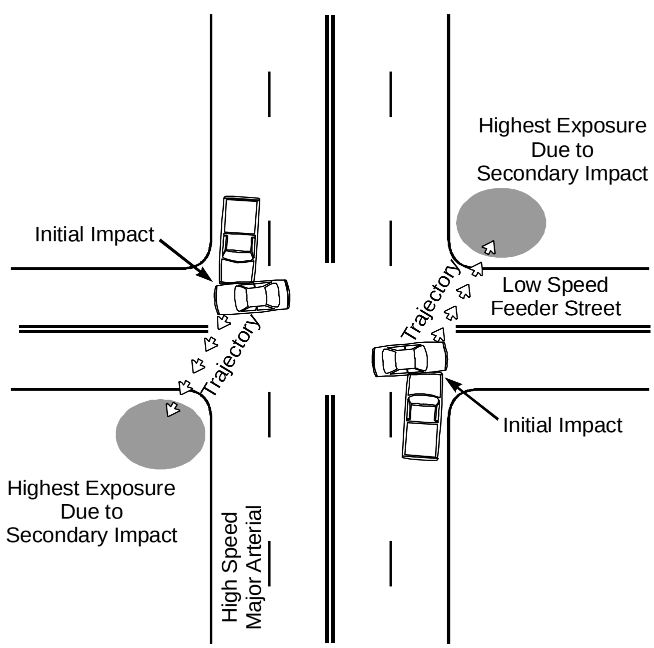


Figure 5-10. Intersection Zones Having Highest Exposure to Secondary Collisions.[11]

Table 5-1. Horizontal Clearances.[8]

			U.S. Customary				Metric	
Location	**Functional Classification**	**Average Daily Traffic**[B]	**Design Speed (mph)**	**Horizontal Clearance Width (ft)** [A,C,D,E]		**Design Speed (km/h)**	**Horizontal Clearance Width [m]** [A,C,D,E]	
				Minimum	**Desirable**		**Minimum**	**Desirable**
Suburban	All	<8000	All	10[F]	10[F]	All	3.0[F]	3.0[F]
Suburban	All	8000-12,000	All	10[F]	20[F]	All	3.0[F]	6.0[F]
Suburban	All	12,000-16,000	All	10[F]	25[F]	All	3.0[F]	7.6[F]
Suburban	All	>16,000	All	20[F]	30[F]	All	6.0[F]	9.0[F]
Suburban	Freeways	All	All	30 (16 for ramps)		All	9.0 (4.9 for ramps)	
Urban	All (Curbed)	All	≥50	Use above suburban criteria insofar as available border width permits.		≥80	Use above suburban criteria insofar as available border width permits.	
Urban	All (Curbed)	All	≤45	1.5 from curb face	3.0	≤70	0.5 from curb face	1.0
Urban	All (Uncurbed)	All	≥50	Use above suburban criteria.		≥80	Use above suburban criteria.	
Urban	All (Uncurbed)	All	≤45	10	--	≤70	3.0	--

[A]Because of the need for specific placement to assist traffic operations, devices such as traffic signal supports, railroad signal/warning device supports, and controller cabinets are excluded from horizontal clearance requirements. However, these devices should be located as far from the travel lanes as practical. Other non-breakaway devices should be located outside the prescribed horizontal clearances or these devices should be protected with a barrier.

[B]Average Daily Traffic (ADT) over project life, i.e., 0.5 (present ADT plus future ADT). Use total ADT on two-way roadways and directional ADT on one-way roadways.

[C]Without barrier or other safety treatment of appurtenances.

[D]Measured from edge of travel lane for all cut sections and for all fill sections where side slopes are 1V:6H or flatter. Where fill slopes are steeper than 1V:6H it is desirable to provide an area free of obstacles beyond the toe of slope.

[E]Desirable, rather than minimum, values should be used where feasible.

[F]Purchase of 5 ft [1.5 m] or less of additional right of way strictly for satisfying horizontal clearance provisions is not required.

Section 3
Landscaping

Overview

Landscaping is used to enhance the appearance of roadways and highways. It can help to define the character of the corridor or region or illustrate a community's value. Figure 5-11 shows an example of landscaping added in the median of a major thoroughfare to help define the importance of the roadway and the neighboring developments. Landscaping is also being considered for slowing or "calming" of traffic to enhance safety. It can consist of continuous plantings along a street (see Figure 5-12) or as a treatment to define the entrance of a community, development, or roadway (see Figure 5-13). Trees are also used to provide shade for pedestrians waiting at a bus stop or walking along a street (see Figure 5-14).

Many of the landscaping features, however, are considered fixed objects and should not be located within the design horizontal clearance. Reducing existing, wider horizontal clearance area by introducing fixed objects, reduces the recovery distance available for errant vehicles.

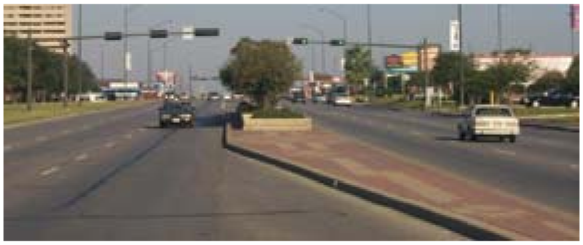


Figure 5-11. Example of Landscaping along a Major Street.

Figure 5-12. Example of Continuous Landscaping to Encourage Lower Operating Speeds.

Figure 5-13. Example of an Entrance Treatment to a Development.

Figure 5-14. Example of Landscaping at a Bus Stop That Provides Shade.

Sight Distance and Landscaping

When making landscaping decisions, designers should consider several criteria including aesthetics, erosion-control needs, maintenance requirements, future sidewalks, utilities, etc. Sight distance and clearance to obstructions also need to be considered, especially at intersections (see Figure 5-15). Information on determining the sight triangle is included in Chapter 3, Section 1 <link>.

Plants with the potential of blocking a sign should not be placed in front of the face of any sign (see Figure 5-16). The landscape designs should be arranged to permit a sufficiently wide, clear, and safe pedestrian walkway. Tree limbs will not be evident to visually impaired pedestrians and should be kept trimmed to provide 80 inches [2030 mm] minimum vertical clearance above the sidewalk. Vegetation should not be permitted to create a protrusion into the pedestrian area (see Chapter 5, Section 2 <link>). The check on landscaping height and width should occur both for the initial installation and for the anticipated growth of the vegetation.

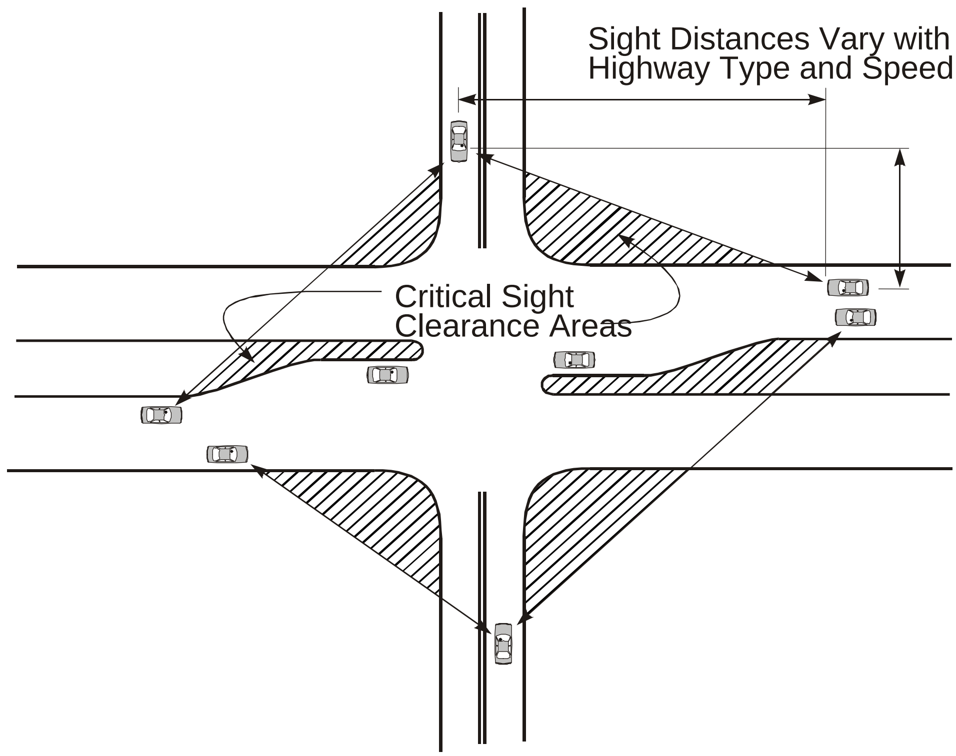


Figure 5-15. Plant Use in Intersection Areas Must Be Limited to Low-Growing Varieties to Provide for a Clear Sight Triangle.[12]

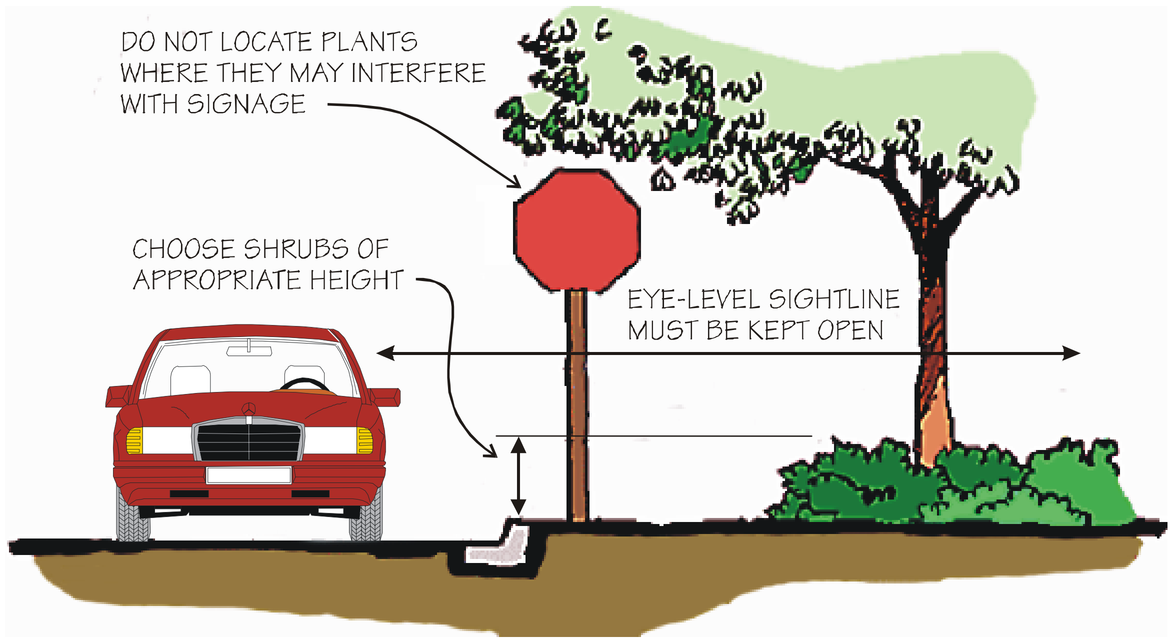


Figure 5-16. Example of Landscaping Near Sign.[12]

References Available

Two AASHTO publications that discuss landscaping issues are *A Guide for Transportation Landscape and Environmental Design*[13] and the *Roadside Design Guide*.[9] The *Guide for Transportation Landscape and Environmental Design*[13] report was revised in 1991 and was expanded to include all modes of transportation and interaction of landscape considerations with transportation improvements. It is a basic reference to improve landscape and environmental design. The Third Edition of the *Roadside Design Guide*[9] was published in 2002 and is a synthesis of current information and operating practices related to roadside safety. It focuses on safety treatments that can minimize the likelihood of serious injuries when a motorist leaves the roadway. TxDOT also has the *Landscape and Aesthetics Design Manual* available online.[12]

National Cooperative Highway Research Program (NCHRP) Project 16-04

There are needs to (1) identify landscape designs that have performed acceptably and (2) develop new design guidelines that enhance the roadside environment while being forgiving to errant vehicles. The objectives of an NCHRP project that began in October 2003 are to develop (1) design guidelines for safe and aesthetic roadside treatments in urban areas and (2) a toolbox of effective roadside treatments that (a) balance pedestrian, bicyclist, and motorist safety and mobility and (b) accommodate community values.[14] The guidelines are to be based on an evaluation of the effects of treatments such as trees, landscaping, and other roadside features on vehicle speed and overall safety. The guidelines will generally focus on arterial and collector-type facilities in urban areas with speed limits between 25 and 50 mph [40 and 81 km/h].

Section 4
Street Furniture and Fixtures

Overview

Street furniture can provide comfort and convenience along a roadway or at an intersection. Street furniture includes features used by pedestrians such as benches and bus shelters along with bicycle racks, drinking fountains, and telephones. Street fixtures include those devices that are not generally used by pedestrians, such as utility poles, fire hydrants, drainage grates, and signal controller cabinets.

Placement

When determining the placement of both street furniture and street fixtures, the designer needs to consider both pedestrian and vehicular needs. Poorly placed objects can affect:

- pedestrians' movement or become an obstacle for pedestrians (see Figure 5-17),
- sight distance between drivers,
- sight distance between drivers and pedestrians, and
- the safety of the roadside by becoming a roadside object.

Figure 5-18 is an example of artwork located on a sidewalk. Art in downtowns and neighborhoods can improve the aesthetics of an area; however, it needs to be placed so that it does not become an obstacle to pedestrian movement. In Figure 5-18 the artwork was aligned with the urban landscaping and appears to have a minimal impact on the pedestrians moving alongside it.

Figure 5-17. Example of Street Furniture.

Figure 5-18. Example of Artwork in Downtown Area (Seattle, WA).

Planters can also improve the aesthetics of an area. Figure 5-19 shows the use of planters alongside a roadway and along the curb return. There is a wide gap in the planters at the crosswalks so that the pedestrians can access the street to cross it. Even though a gap is provided at the crosswalk, pedestrians are still moving between the planters to cross the streets, and the planters appear to have a significant impact on pedestrian movement.

Figure 5-20 shows another example of planters at an intersection. In this situation fewer but larger planters are used resulting in more open sidewalk area.

Figure 5-19. Example of Several Planters at an Intersection.

Figure 5-20. Example of a Planter at an Intersection.

Accessibility Requirements for Street Furniture and Fixtures

Street furniture shall have clear floor or ground space of 30 inches [0.8 m] by 48 inches [1.2 m] minimum.[3] The street furniture is to be connected to the pedestrian route, and the draft accessibility guidelines[7] propose to allow the clear floor or ground space to overlap the pedestrian route by 12 inches [305 mm] maximum. Street furniture and fixtures should not encroach into the minimum 5 ft [1.5 m] sidewalk width.

Placement of Street Furniture with Respect to On-Street Parking

Placement of street furniture near on-street parking can make exiting a lift-equipped vehicle difficult. One remedy is to have street furniture or fixtures, such as benches, telephone poles, or streetlights, placed at the ends of parking spaces rather than in the middle of parking spaces.

Drainage Grates

Drainage grates, particularly those with parallel bars, can cause problems for wheelchair, bicycle, stroller, walker, and crutch or cane users. Whenever possible, drainage grates should be placed outside of the pedestrian travel way. However, if unavoidable, the openings on the grates should not exceed 0.5 inches [13 mm] in width, should be mounted flush and level with the surrounding sidewalk surface, and should be placed so that the long dimension is perpendicular to the dominant direction of travel. This dimension also applies to manhole covers, hatches, vaults, and other utility coverings. Additional information on drainage issues is provided in Chapter 6 <link>.

Section 5
Curb Extensions

Overview

Curb extensions exist when the sidewalk extends across the parking lanes to the edge of the travel lanes (see Figure 5-21). They are used in areas with high pedestrian activity (downtowns, neighborhoods, etc.) where there is a need to shorten crossing distances and to improve the visibility of pedestrians. Curb extensions also are called pedestrian bulbs, bulbouts, knuckles, and intersection narrowing.

This treatment also minimizes the impact of parked vehicles on pedestrian visibility. Pedestrians' height is increased by the height of the curb when standing at the end of the bulb (which is typically at or near the edge of the travel lane). When space limitations prevent the inclusion of amenities, curb extensions create additional sidewalk space that could be used for street furniture, a bus stop, seating for a café, or additional room for general pedestrian traffic (see Figure 5-22). Curb extensions self-enforce parking restrictions near the intersection and provide additional space in which to construct curb ramps.

Figure 5-21. Example of a Curb Extension.

Figure 5-22. Example of a Curb Extension with Landscaping and a Bench.

Advantages and Disadvantages

Advantages of curb extensions include the following:

- Reduce the distance that pedestrians travel in the street and the potential for being struck by a vehicle.
- Make streets more pedestrian friendly.
- Add sidewalk space for the installation of a curb ramp in a narrow sidewalk.
- Slow the speed of turning vehicles by tightening the corner radius.
- Improve the visibility of pedestrians by placing them where drivers can see them and where parked vehicles do not obscure their presence.

- Make it difficult for drivers to park illegally at the corners of intersections.

Disadvantages of curb extensions include the following:

- Impact turning ability of trucks and other heavy vehicles.
- Increase chance that pedestrians may be hit by drivers at night and in inclement weather conditions (e.g., snow) when parked vehicles are not present.
- Result in no buffer existing between the pedestrian waiting at the curb and the passing vehicles.
- Pose obstacles to street sweepers and snowplows.
- May result in merchant objections to loss of on-street parking.
- May result in drainage problems or trash accumulation.
- Increase potential for conflicts between bicyclists and motorists.

Bus Bulbs

Placing a bus stop at a curb extension (also called a bulb) can provide several advantages to both the bus patrons and pedestrians. In these cases the treatment has been called a bus bulb or a bus nub.

- The bus bulb creates additional area for pedestrians to walk and for patrons to wait for a bus (see Figure 5-23).
- The bulb can also provide space for bus patron amenities, such as shelters and benches, and for additional landscaping to improve the visual environment.
- The replacement of a bus bay in a parking lane with a bus bulb can result in additional parking spaces because the bulb does not require the inclusion of weaving space for a bus to enter the bay.
- The bulb can be the length of the bus or the minimum length required for boarding and alighting activities.

Figure 5-23. Example of Bus Bulb.

A late 1990s research project found the replacement of a bus bay with a bus bulb improved vehicle and bus speeds on a corridor in San Francisco.[15] Buses experienced approximately a

7 percent increase (about 0.5 mph [0.8 km/h]) in both the northbound and southbound directions. Vehicle speeds also improved by as much as 7 mph [11.3 km/h]. Reductions in travel speeds are assumed to be the consequence of installing bus bulbs because buses are stopping in the travel lane rather than moving into a bus bay. In the before period when the bus bay configuration was present, the majority of the buses stopped partially or fully in the travel lane rather than pulling into the bay. In addition, buses pulling away from the bay sometimes used both travel lanes to complete the maneuver. The number of buses affecting vehicles in the outside travel lane may not have greatly changed after the bulb's installation. The number of buses affecting vehicles in both travel lanes did decrease because bus drivers no longer needed to use both travel lanes to leave the bus stop.

Additional information on bus bulb performance and recommendations on their use is contained in *Evaluation of Bus Bulbs.*[15] Figure 5-24 is a schematic of typical bus bulb dimensions determined as part of that study.

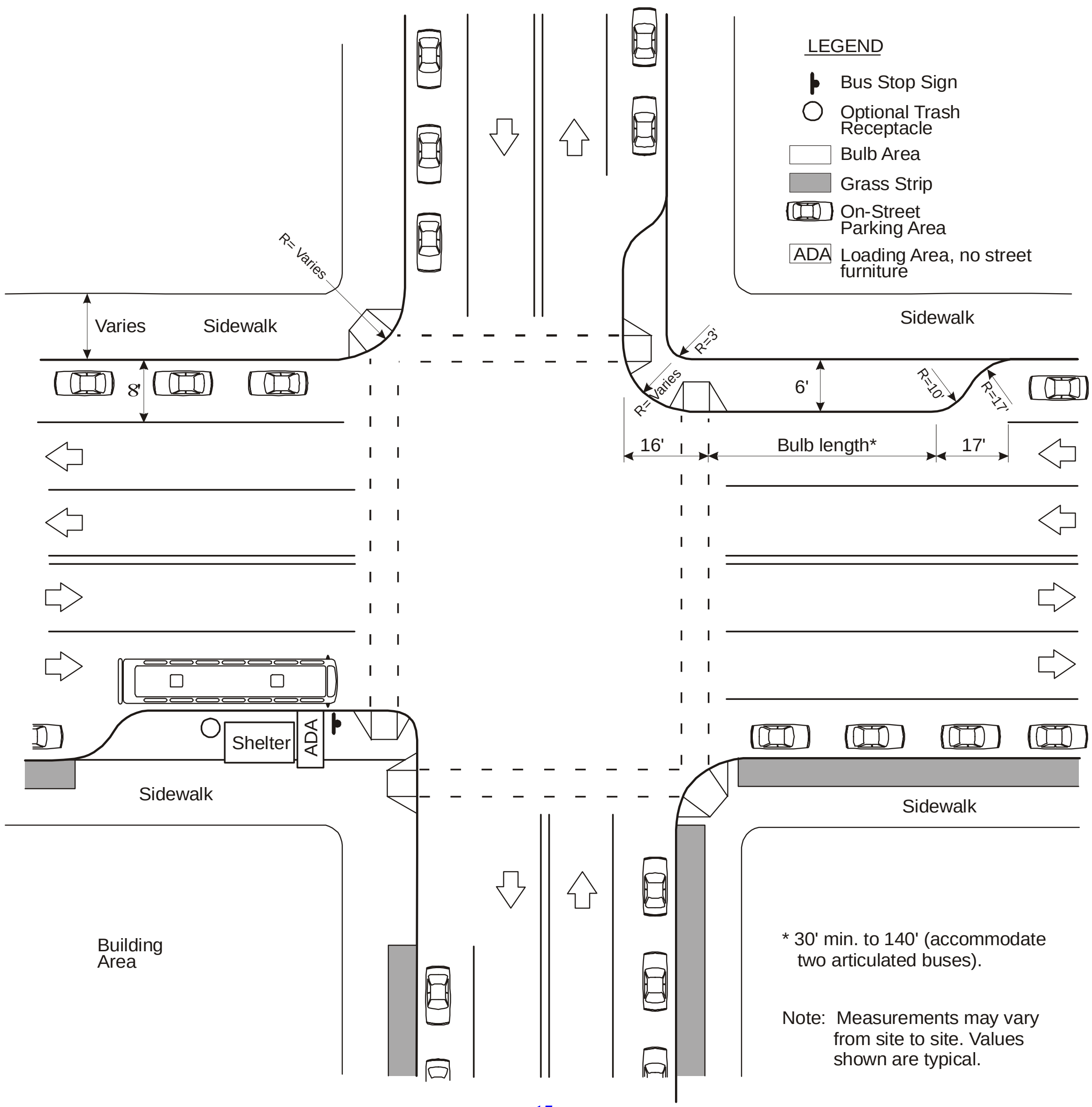


Figure 5-24. Typical Bus Bulb Dimensions.[15]

Section 6
Bus Stops

Overview

Transit needs to be an integral part of a transportation system for the system to efficiently serve the state's transportation needs. As a result of this expanded multi-modal approach to transportation planning, there is a need to incorporate provisions for transit vehicles and services into the department's roadway planning, design, and operation guidelines.

Following is a summary of bus stop design issues as related to intersections.

Application 5-2 <link> presents an example where a bus stop is moved.

Placement of Bus Stop

Bus stops can be located far-side, near-side, or at midblock in relationship to an intersection (see Table 5-2). Some communities have a strong preference for the use of farside or nearside bus stops and attempt to use only one or the other to achieve a consistent type of location for all bus stops. Other communities are not as strict and will select different locations based on the characteristics present at the proposed bus stop location.

Table 5-2. Bus Stop Placements. [16]

Placement	Definitions	Advantages	Disadvantages
Farside Bus Stop	The bus stops immediately after passing through an intersection.	This type of stop minimizes conflicts between buses and vehicles turning right from the roadway with the transit route. It also encourages pedestrians to cross behind the bus.	Disadvantages include that an increase in the number of rear-end crashes may occur since drivers do not expect buses to stop again after stopping at a red signal indication or that the traffic stopped behind the bus could queue into the intersection.
Nearside Bus Stop	The bus stops immediately prior to an intersection.	Patrons can board and alight while the bus is stopped at a red signal indication, and the bus driver has the width of the intersection available for pulling away from the curb.	Stopping at the near-side of an intersection can increase conflicts with right-turning vehicles and could limit sight distance to curbside traffic control devices and crossing pedestrians.
Midblock Bus Stop	The bus stops within the block.	It can minimize intersection sight distance restrictions for vehicles and pedestrians.	It encourages patrons to cross the street at midblock or it could increase walking distance.

Types of Stops

Various roadway configurations are available to accommodate bus service at a stop, including:

- Curbside stop — buses stop in the travel lane alongside the curb.
- Bus bay (with or without acceleration and deceleration lanes) — buses move from the travel lane into a bay that is separated from the main lanes. The bay allows through

traffic to flow freely without being impeded by the stopped buses. They can be advantageous at locations where the bus operator is scheduled for a break or at timed stops where the bus must wait until a specific time even if running ahead of schedule.

- Open bus bay — similar to a far-side bus bay; however, the bay is open to the intersection (no deceleration length is needed as the bus can decelerate while moving through the intersection).
- Queue jumper bus bay — an open bus bay with an upstream right-turn lane. The bus can enter the right-turn lane and bypass the queue of through vehicles stopped at the upstream traffic signal.
- Bulb — the sidewalk is extended through a parking lane and the bus stops in the travel lane while servicing the bus stop. Bus bulbs have several qualities similar to curb extensions or pedestrian bulbs (see Chapter 5, Section 5) <link>.

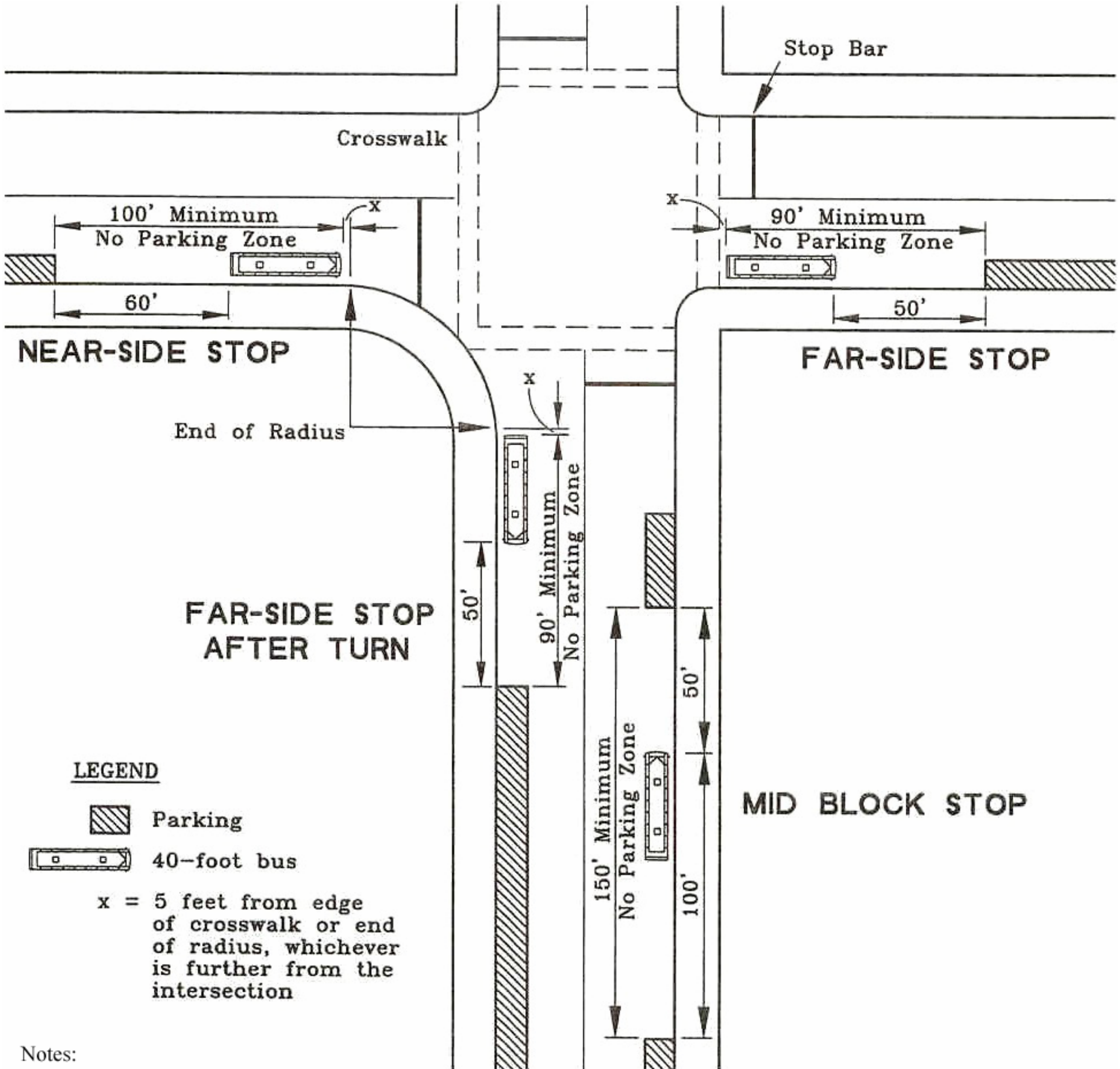
Table 5-3 lists advantages and disadvantages of the various bus stop configurations.

Table 5-3. Advantages and Disadvantages of Bus Stop Configurations.[16]

Type of Stop	Advantages	Disadvantages
Curbside	♦ Provides easy access for bus drivers and results in minimal delay to bus ♦ Is simple in design and easy and inexpensive for a transit agency to install ♦ Is easy to relocate	♦ Can cause traffic to queue behind stopped bus, thus causing traffic congestion ♦ May cause drivers to make unsafe maneuvers when changing lanes in order to avoid a stopped bus
Bus Bay	♦ Allows patrons to board and alight out of the travel lane ♦ Provides a protected area away from moving vehicles for both the stopped bus and the bus patrons ♦ Minimizes delay to through traffic	♦ May present problems to bus drivers when attempting to re-enter traffic, especially during periods of high roadway volumes ♦ Is expensive to install compared with curbside stops ♦ Is difficult and expensive to relocate
Open Bus Bay	♦ Allows the bus to decelerate as it moves through the intersection ♦ See Bus Bay advantages	♦ See Bus Bay disadvantages
Queue Jumper Bus Bay	♦ Allows buses to bypass queues at a signal ♦ See Open Bus Bay advantage	♦ May cause delays to right-turning vehicles when a bus is at the start of the right-turn lane ♦ See Bus Bay disadvantages
Bus Bulb	♦ Removes fewer parking spaces for the bus stop ♦ Decreases the walking distance (and time) for pedestrians crossing the street ♦ Provides additional sidewalk area for bus patrons to wait ♦ Results in minimal delay for bus	♦ Costs more to install compared with curbside stops ♦ See Curbside disadvantages

Bus Stop Zone

A bus stop zone is the portion of a roadway marked or signed for use by buses when loading or unloading passengers. The lengths of bus stop zones vary among transit agencies and cities. Representative dimensions for bus stop zones are illustrated in Figure 5-25. If the bus zone is located in an area where parking is permitted, the zone length is marked to keep the area free of parked or stopped cars.



Notes:
1) Add 20 ft to bus stop zones for an articulated bus.
2) Increase bus stop zone by 50 ft for each additional standard 40 ft bus or 70 ft for each additional 60 ft articulated bus expected to be at the stop simultaneously. See Table 3 for the suggested bus stop capacity requirements based on a range of bus flow rates and passenger service times.

1 ft = 0.305 m

Figure 5-25. Typical Types of and Dimensions for On-Street Bus Stops.[16]

Grade

Selection of the roadway grade is related to topography and existing development; however, the grade should be as flat as possible (< 2 percent preferred) for efficient deployment of a wheelchair lift.

Grade Changes

The recommended grade change between a street and a driveway for buses is 6 percent or less.

Roadside Considerations

Buses generally travel in the traffic lane closest to the curb because of their need to make frequent stops. Therefore, consideration of the following bus clearance requirements in roadway design is important:

- Overhead obstructions should be a minimum of 12 ft [3.7 m] above the street surface.
- Obstructions should not be located within 2 ft [0.6 m] of the edge of the street to avoid being struck by a bus mirror.

Lane Width

A traffic lane used by buses should be no narrower than 12 ft [3.7 m] in width because the maximum bus width (including mirrors) is about 10.5 ft [3.2 m]. Desirable curb lane width (including the gutter) is 14 ft [4.3 m].

Curb Height

An appropriate curb height for efficient passenger-service operation is between 6 and 9 inches [152.4 and 228.6 mm]. If curbs are too high, the bus will be prevented from moving close to it, and the operations of a wheelchair lift could be negatively affected. If curbs are too low or not present, older persons and passengers with mobility impairments may have difficulty boarding and alighting.

Curb Radii

The corner curb radii used at intersections can affect bus operations when the bus makes a right turn. A trade-off in providing a large curb radius is that the crossing distance for pedestrians is increased, which increases the pedestrians' exposure to on-street vehicles. This can influence how pedestrians cross an intersection. The additional time that a pedestrian is in the street because of larger curb radii should be considered for signal timing and median treatment decisions.

The design of corner curb radii should be based on the following elements:

- design vehicle characteristics, including bus turning radius;
- width and number of lanes on the intersecting street;
- allowable bus encroachment into other traffic lanes;
- on-street parking;
- angle of intersection;

- operating speed and speed reductions; and
- pedestrians.

Traffic Signals

Bus stops are frequently located at signalized intersections. Traffic signal design should accommodate buses and bus passengers. Basic signal design information is included in Chapter 8 <link>. The following should be considered in designing traffic signal systems in new developments or upgrading/redesigning signals at existing intersections when a bus stop may be installed:

- Location of bus stops should be coordinated with traffic signal pole and signal head location. Bus stops should be located so that buses do not totally restrict other vehicles' visibility of a traffic signal. (These problems could be addressed by using a far-side stop at the intersection.)
- The use of a far-side, curbside stop at a signalized intersection can cause vehicles stopping behind the bus to queue into the intersection. At signalized intersections, if a far-side bus stop is needed, a bus bay is preferred to a curbside stop.
- Nearside stop areas are often located between the advance detectors for a traffic signal and the crosswalk. Detectors should be located at the bus stop to enable the bus to actuate the detector so that the signal controller can call or extend the green light. Without a detector, a bus is forced to wait until other traffic approaching from the same direction actuates the signal controller.
- Timing of traffic signals should also reflect the specific needs of buses. Longer clearance intervals may be needed on high-speed roadways with significant bus traffic so that a bus can accelerate from the bus stop into the intersection.

Sight Distance

Sight distance considerations for bus stops include the following:

- The stopped bus will affect sight distance for pedestrians using the parallel and transverse crosswalks at an intersection.
- The stopped bus will also affect sight distance for parallel traffic and cross traffic. For instance, at a near-side stop, vehicular right turns are facilitated and sight distance is improved when the bus stop is set back from the crosswalk.
- The bus affects the traffic stream as it enters or leaves a stop.
- A bus may stay at a bus stop for an extended period to permit a driver a break or because the bus is ahead of schedule. This is known as a timed stop. The longer stopping period could have a greater impact on sight distance.

A recently completed study on pedestrian crashes found that approximately 2 percent of pedestrian crashes in urban areas and 3 percent of pedestrian crashes in rural areas are related to bus stops. These crashes generally involved pedestrians who stepped into the street in front of a stopped bus and were struck by vehicles moving in the adjacent lane.

This situation develops when the line of sight between the pedestrian and an oncoming vehicle is blocked, or when the pedestrian simply does not look for an oncoming vehicle. This type of crash can be reduced by relocating the bus stop from the near side to the far side of an intersection, thus encouraging pedestrians to cross the street from behind the bus instead of in front of it. This makes pedestrians more visible to motorists approaching from behind the bus. Not only can far-side bus stops reduce the potential for bus stop crashes involving pedestrians, buses are also less likely to obscure traffic signals, signs, and pedestrian movements at intersections as opposed to near-side bus stops.

Waiting or Accessory Pad

A waiting or accessory pad is a paved area at a bus stop provided for bus patrons. It may contain a bench, bus shelter, or other amenities such as trash receptacles or bicycle racks. The size of the waiting pad depends on several factors which commonly include the anticipated number of waiting passengers, the length and width of shelters or benches (if to be present), and the length of the bus. A common dimension for a pad is 8 ft [2.5 m] by 10 ft [3 m]. Waiting pads are provided in addition to the sidewalk to preserve general pedestrian flow. When not adjoining to the sidewalk, a paved connection should be provided to the waiting pad.

The ADAAG[3] provides requirements for the waiting pad to ensure proper wheelchair lift operations. Where new bus stop waiting pads are constructed at bus stops, bays, or other areas where a lift is to be deployed, they shall have:

- a firm, stable surface;
- a minimum clear length of 8 ft [2.4 m] (measured from the curb or vehicle roadway edge) and a minimum clear width of 5 ft [1.5 m] (measured parallel to the vehicle roadway) to the maximum extent allowed by legal or site constraints; and
- a connection to streets, sidewalks, or pedestrian paths by an accessible route.

The slope of the pad parallel to the roadway shall, to the extent practicable, be the same as the roadway. For water drainage, a maximum slope of 1:50 (2 percent) perpendicular to the roadway is allowed.

Access to Bus Stop

Landscaping, berms, security walls, large parking lots, and circuitous sidewalks can decrease the convenience of using transit by increasing the walking time between the origin or destination and the bus stop. Direct access to and from the bus stop is critical to the convenience of using transit. The transit agency can work with local jurisdictions or developers to ensure that direct sidewalks are installed near bus stops from the intersection or adjacent land uses. Additional information on sidewalks is contained in Chapter 5, Section 1, Sidewalks <link>.

Additional Sources of Information

TxDOT sponsored a research project to develop guidelines on buses and surface streets in recognition of the emphasis of integrating transit. The report was entitled *Guidelines for Planning, Designing, and Operating Bus-Related Street Improvements.*[17]

In the mid-1990s, the Transit Cooperative Research Program (TCRP) sponsored the development of a national set of guidelines on bus stop design. TCRP Report 19: *Guidelines for the Location and Design of Bus Stops*[16] was designed to assist transit agencies, local governments, and other public bodies in locating and designing bus stops that consider bus patrons' convenience, safety, and access to sites as well as safe transit operations and traffic flow. The guidelines include information about locating and designing bus stops and checklists of factors that should be considered.

AASHTO through NCHRP sponsored the development of an Interim Guide on transit facilities in 2002. A draft of the *Geometric Design Guide for Transit Facilities on Highways and Streets – Phase I* was available in July 2002[18] and the final version is anticipated in 2005. It will contain guidelines on transit facilities on highways, streets, and off-line transit facilities.

Section 7
Lighting

Overview

Lighting may improve the safety of highway and street intersections, as well as efficiency of traffic operations. Statistics indicate that nighttime crash rates are higher than crash rates during daylight hours. This fact, to a large degree, may be attributed to lower visibility. In urban and suburban areas where there are concentrations of pedestrians and roadside and intersectional interferences, fixed-source lighting has been shown to reduce crashes.

The TxDOT *Highway Illumination Manual*[19] is available on-line. The purpose of the manual is to provide procedures, guidelines, and information concerning highway illumination. It includes the following chapters:

- Introduction;
- Lighting Systems, Highway Eligibility, and Warrants;
- Master Lighting Plans;
- Lighting Agreements;
- Lighting Equipment;
- Lighting Design and Layout;
- Electrical Systems;
- Temporary Lighting; and
- Construction and Maintenance.

Eligibility and Warrants of Lighting Systems

Title 43, Texas Administrative Code, Section 25.11 defines two basic types of roadway lighting systems:

- continuous illumination and
- safety lighting.

The rules also describe instances in which continuous lighting may be classified as safety lighting. The rules specify the types of highways eligible for the spending of state funds on each type of illumination system. The Texas Department of Transportation can only install and maintain lighting systems on eligible roadways where the conditions warrant such installation.

Eligibility. Eligibility requirements for each type of lighting system are described in the relevant sections of the TxDOT *Highway Illumination Manual* <link>.

Warrants. The TxDOT *Highway Illumination Manual* <link> includes warrants to justify the need for and expense of roadway lighting at eligible locations. The criteria are based on roadway conditions that are divided into cases. These cases are coded for ease of reference. The code consists of either “CL” (for continuous lighting) or “SL” (for safety lighting) followed by a dash and a number (for example: CL-2 or SL-4).

Other Advice on When to Consider Lighting

The TxDOT *Highway Illumination Manual* <link> contains the specific requirements for warranting continuous and safety lighting. Other documents include general advice on when to consider roadway lighting.

The 2001 *Green Book*[20] states that intersections with channelization, particularly multiple-road geometrics, should include lighting. Large channelized intersections especially need illumination because of the higher range of turning radii that are not within the lateral range of vehicular headlight beams. Illumination of intersections with fixed-source lighting accomplishes this need.

When lighting is installed on sidewalks or bicycleways (termed pedestrian lighting) along nearby streets and highways, it is essential that the street be lit to the same level as the sidewalk or bicycleway.[19] Although cities or other entities are not obligated to light the entire roadway if they provide pedestrian lighting, it is desirable to mitigate any veiling glare that may be introduced by off-road lighting. Sources of off-road lighting can include automobile retail lots, parking lots, malls, or other brightly illuminated areas. The TxDOT *Highway Illumination Manual* should be consulted for further information <link>.

The *Highway Design Handbook for Older Drivers and Pedestrians*[21] recommends fixed lighting installations wherever feasible where any of the following conditions exist:

- The potential for wrong-way movements is indicated through crash experience or engineering judgment.
- Pedestrian volumes are high.
- Shifting lane alignment, turn-only lane assignment, or a pavement-width transition forces a path-following adjustment at or near the intersection.

Factors to consider in determining whether to install lighting include:

- traffic volumes (especially at low light or dark times),
- pedestrian and bicycle volumes,
- vehicle speed,
- nighttime crash rate,
- intersection geometrics,
- locations where severe or unusual weather or atmospheric conditions exist, and
- general nighttime visibility.

Location

The TxDOT *Highway Illumination Manual* <link> contains guidelines for the placement of conventional lighting poles in relation to other roadway elements. These guidelines apply to all designated routes, whether the poles are installed by construction contract, state forces, municipalities, or others.

Trees

In areas with heavy tree growth, lighting systems may need to be evaluated during the summer months when the potential of blockage by foliage is at its greatest. More importantly, the placement and type of trees should be evaluated ahead of time. A regular pruning and maintenance program is also advised.

Other References Available

Intersection luminaire supports should be located and designed in accordance with current roadside safety concepts. Additional discussion and design guidance can be found in:

- AASHTO's *An Informational Guide for Roadway Lighting*[22] – This guide contains information for the lighting of freeways, streets, and highways other than controlled access facilities, tunnels and underpasses, and rest areas, signs, and maintenance.
- AASHTO's *Roadside Design Guide*[9] – This document presents a synthesis of current information and operating practices related to roadside safety. The roadside is defined as that area beyond the traveled way (driving lanes) and the shoulder (if any) of the roadway itself. The focus of this guide is on safety treatments that minimize the likelihood of serious injuries when a driver runs off the road. Chapter 4 provides information on the use of sign and luminaire supports within the roadside environment. Both small and large signs are included, as well as breakaway and non-breakaway supports.
- AASHTO's *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals*[23] – This document provides breakaway and support requirements.

Section 8
Utilities

Overview

As dictated by both federal[24] and state[25,26] regulations, public utilities are allowed to install transmission lines along and across highway right of way in Texas. These public utilities include lines that transport natural gas, water, electricity, telecommunications, cable television, salt water, and common carrier petroleum and petroleum-related products. Additionally, privately owned lines are normally allowed to cross highway right of way. In many instances, these utilities are installed at or near an intersection.

General Location Guidelines

Generally speaking, when utilities are located within the right of way, they are to be located such that they can be installed and serviced without access from the roadway or ramps.[27] What this means in Texas is that utility lines shall be located to permit access to the lines with minimum interference to highway traffic.[25] Guidelines also stress the importance of minimizing the need for later adjustments to the utilities to accommodate them in future highway improvements.[28]

The Texas Utility Accommodation Policy[25] (UAP) <link> has specific requirements regarding the installation of utility lines within TxDOT right of way. This policy draws on many resources as guidelines to establish standards for utility work or placement and reimbursement cost within the rights of way. When and if a TxDOT standard is found to be more stringent than any other standard, the TxDOT standard shall be the rule. For example, their design must meet not only the Texas requirements but those of various codes, rules, and regulations that dictate the design of specific utilities (e.g., National Electric Safety Code, American Society for Testing and Materials, etc.).[25] Furthermore, utility horizontal and vertical installation should meet with clear roadside practices of TxDOT.[25] The UAP also provides requirements for the placement of utility lines that may impact the design of an intersection. Basic requirements as they relate to various features of utility lines are discussed in the following sections. For additional information, refer to the UAP <link>.

Typical Features

Any utilities located within highway or intersection ROW may have an impact on the design of that intersection. Their presence may include appurtenances that can present challenges to designing an accessible intersection. While TxDOT accommodates utilities within the ROW so that they do not adversely affect safety, design, construction, operation, or maintenance[25], designers should be aware of certain features related to utilities that may impact the intersection. These features include:

- poles,
- guy wires,
- manholes,

- markers,
- vents, and
- aboveground pedestals, equipment housings, or structures.

The placement of these features within the ROW of an intersection should consider pedestrian needs in addition to the UAP requirements.

Overhead Utilities

Overhead utilities typically include power lines, communication, and cable television lines. When installed, they must meet minimum vertical clearance requirements above the roadway. The UAP[25] requires that the clearance above the roadway be no less than 22 ft [6.7 m] for power lines and 18 ft [5.5 m] for communication and cable television lines. Horizontal clearances to obstructions, which vary depending on the location and functional classification of the roadway, are dictated by the horizontal clearances outlined in Table 2-11 of the *Roadway Design Manual*[8] <link> and reproduced in Table 5-1 <link>.

Note that because of the need for specific placement to assist traffic operation, devices such as traffic signal supports, railroad signal/warning device supports, and controller cabinets are excluded from horizontal clearance requirements. These devices however, should be located as far from the travel lanes as practical. These general requirements may not necessarily meet those minimum clearances noted in Chapter 5, Section 4, *Street Furniture and Fixtures*, <link> which summarizes the ADAAG/TAS requirements.[3,4,10] In such cases, the most stringent requirements should dictate placement. Specific requirements for the location of poles <link> and guy wires <link> used in overhead utility installations are discussed below.

Further limitations to the location of overhead utilities are provided in state law.[29] Health and safety statutes should be consulted for details, but the following requirements dictate that at least a 10-ft clearance [3.1 m] between signal hardware and high voltage lines be maintained:

- Equipment work cannot be performed within 10 ft [3.1 m] of an overhead high voltage line.
- Employees cannot come within 6 ft [1.8 m] of an overhead high voltage line.
- Work closer than these limits requires a 48 hr notification be provided to the operator of the overhead line.

Poles

According to the UAP, poles supporting longitudinal overhead lines at an uncurbed intersection in an urban area should be located anywhere from 1 to 3 ft [0.3 to 0.9 m] from the ROW edge.[25] At curbed intersections in urban areas, poles should be located adjacent to the ROW line. Where this is not practical, they should be placed as far behind the outer curbs as possible.[25] If the pole is steel and has a base greater than 3 ft [0.9 m] in diameter, it should not be placed within the ROW except in cases of extreme hardship.[25] These requirements do not specifically consider the presence of sidewalks. Additional placement guidelines should follow those for the placement of street fixtures as outlined in Chapter 5, Section 4 <link>, which addresses ADAAG/TAS requirements. Figure 5-26 and Figure 5-27 are examples of light poles located along a street. In Figure 5-26, the utility pole is placed behind the sidewalk, while Figure 5-27 shows the light pole between the street and the sidewalk. Guidance presented in TRB State of the Art Report 9[11] (*Utilities and Roadside Safety)* is summarized in Chapter 5, Section 6 of this *Guide* <link>.

Figure 5-26. Examples of Light Pole behind Sidewalk.

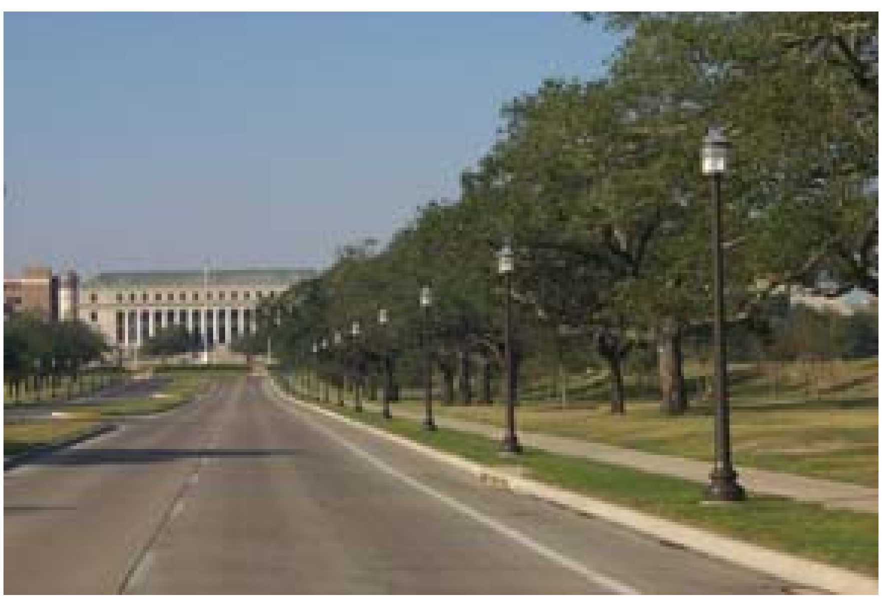


Figure 5-27. Examples of Light Pole between Sidewalk and Street.

Guy Wires

Utility companies should work to minimize the guy wires located within the ROW. However, in the event that they are used, they should preferably be within the pole line or otherwise located such that they do not violate horizontal clearance restrictions.[25] Because of their color, thickness, and typical placement, guy wires can become a tripping hazard or a protruding object for pedestrians. Figure 5-28 illustrates guy wires that accommodate pedestrian movement on a sidewalk, and Figure 5-29 shows a guy wire located parallel to the sidewalk.

Underground Utilities

Underground utilities include power lines, communication lines, cable television lines, natural gas, water, petroleum, and other utilities that are ordinarily installed below ground. These utilities have aboveground appurtenances whose location and size are dictated by the UAP, including, but not limited to, manholes, markers, vents, and aboveground pedestals, equipment housings, or structures. General accommodation requirements for these features are as noted below.

In general, AASHTO guidelines[28] require that any appurtenance that protrudes more than 3.9 inches [100 mm] above the ground line should not be in the clear zone unless no other feasible alternative exists. In such cases, the appurtenance should be breakaway or protected by appropriate traffic barriers.

Manholes or Access Covers

Manholes (also called access covers) are necessary features that provide access to underground utilities. However, they can affect accessibility when located within an intersection. The UAP[25] does not permit manholes in the pavement or shoulders of high-volume roadways except on noncontrolled access highways in urban areas where they are allowed for existing permitted lines. Thus, because the manhole cover cannot be placed in the roadway, it may need to be located near or within the predicted pedestrian route to permit logical access to the utility. In these cases, the requirements set forth by the U.S. Access Board need to be considered in locating the access point. The *Roadway Design Manual*[8] indicates that manholes should not be located within the curb ramp, maneuvering area, or landing <link>. Figure 5-30 illustrates the presence of a manhole on the sidewalk at an intersection, while Figure 5-31 shows an alternative location for a manhole that does not adversely impact the pedestrian access route.

Figure 5-28. Guy Wire to Accommodate Pedestrian Movement.

Figure 5-29. Guy Wire Parallel to Sidewalk.

Figure 5-30. Example of Manhole in Sidewalk at Intersection.

Figure 5-31. Example of Manhole Outside Pedestrian Access Route.

Markers

Whenever installing underground lines such as high pressure gas and liquid petroleum, low pressure gas, and underground power and communications, utilities are required to place readily identifiable markers at each right-of-way line where it is crossed by the utility line and along the right-of-way line for longitudinal lines.[25] As illustrated in Figure 5-32, these markers may vary in design, including a metal stake with a metal sign or a plastic marker or pole, all of which would have writing indicating the type of utility buried beneath. Beyond these general requirements, marker location is not specifically mandated. Therefore, markers could potentially be installed such that they impede intersection accessibility. For this reason, their location should follow mandated horizontal clearances[8] <link to Table 5-1> and accessibility guidelines for the placement of street furniture <link to Chapter 5, Section 1, Street Furniture subsection>.

Figure 5-32. Example of Utility Marker at Intersection.

Vents

The underground installation of pipelines requires vents periodically along the length of the line. AASHTO guidelines[28] state that vent stand pipes for pipelines should be located at the right-of-way line and such that they do not impede pedestrian traffic. The UAP[25] has similar requirements such that the vents shall be placed directly above the pipeline at the right-of-way line and shall not interfere with highway maintenance or be concealed, such as by vegetation. Vents are the only other aboveground appurtenance associated with gas and petroleum lines that are allowed within the right of way. Given that, they should be located away from the sidewalk and pedestrian areas of an intersection. Figure 5-33 illustrates a pipeline vent at the right-of-way line at an uncurbed intersection.

(A) Distant View

(B) Close-up View

Figure 5-33. Example of Utility Vent at Intersection.

Pedestals, Structures, and Housings

In some instances, utility equipment is housed on-site within a structure that can be significantly larger than a single pole or other appurtenance. As with other installations, the UAP[25] allows pedestals, structures, or housings to be installed within the right of way if they:

- will not significantly impede highway maintenance operations, including the height of the supporting slab above the ground line;
- are placed at or near the right-of-way line;
- will not reduce visibility and sight distance such that they create an unsafe condition, particularly at or near highway intersections;
- have dimensions that are minimized, with outside dimensions of the portion aboveground not exceeding 36 inches [0.9 m] (depth), 60 inches [1.5 m] (length), and 54 inches [1.4 m] (height), respectively;
- have a supporting slab which does not project more than 3 inches [76 mm] above the ground line; and
- have an installation that is compatible with adjacent land uses.

Figure 5-34 and Figure 5-35 illustrate various types of equipment structures or housings located at or near intersections. As shown, all of the structures on housings are beyond the accessible areas of the intersections and should not present problems for pedestrians.

Figure 5-34. Example of Utility Pedestals and Structures at Intersection.

Figure 5-35. Example of Equipment Housing at Intersection.

Section 9
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Chapter 6
Drainage

Contents:

Section 1
Drainage Objectives

Overview

According to the Texas Administrative Code:[1]

> "In general, it shall be the duty and responsibility of the department to construct, at its expense, a drainage system within state highway right of way, including outfalls, to accommodate the storm water that originates within and reaches state highway right of way from naturally contributing drainage areas."

Drainage is an important consideration in the design of an intersection. The development of the drainage design for the roadway affects (or is affected by) roadway grades, roadway cross section, curb ramp placement, intersection detailed design, and intersection location.

Detailed design information for storm water drainage design is contained in Chapter 10 of TxDOT's *Hydraulic Design Manual*;[2] the material presented in this chapter represents those aspects of hydraulic design influencing or affected by intersection design.

Section 2
Cross Slope

Overview

The design of the pavement and roadway cross section depends to a large degree on compromises between hydraulic efficiency and driver, vehicle, and pedestrian needs. Because none of these considerations can be neglected, designers develop designs that consider all types of design constraints. Designers should also consider and accommodate the ultimate traffic control at the intersection (i.e., signalization if appropriate), especially with regard to the use of valley gutters that may or may not continue through the intersection.

Sidewalks

Sidewalks and other pedestrian facilities such as curb ramps should be designed so they do not accumulate water (requiring that slopes be provided for drainage) yet also accommodate pedestrian needs (requiring reasonably flat surfaces). Chapter 5, Section 1 of this report provides guidance on permissible sidewalk grades and cross slopes <link>.

Pavement Cross Slopes

The cross slope on a roadway allows the pavement to drain, preventing water from infiltrating the pavement structure and allowing vehicles to use the roadway during storm events. Steeper cross slopes are more efficient from a hydraulic viewpoint but can pose safety problems if they are too steep or change too quickly. The discussion that follows is in reference to tangent sections; designers should consult the *Roadway Design Manual*[3] and Chapter 3 of this manual <link> to determine appropriate superelevation rates for horizontal curves.

Two-Lane Roadways. Two-lane roadways typically feature a centerline crown. The cross slopes are:

- Typical: 2 percent.[3]
- Minimum: not less than 1 percent.[3]
- Areas with heavy rainfall: can be increased to 2.5 percent on high-type pavements (i.e., asphalt or Portland cement concrete).[4]
- Roadways with curb and gutter: the lower ranges of cross slopes should not be used, to limit the water flowing along the curb to the outer half of the lane.

Divided Roadways. Divided roadways generally have uniform cross slopes that have high points on the median side; occasionally, however, the high points are placed at the centerline of the pavement sections on each of the individual roadbeds. Sloping the pavement to the outer edge allows collecting water with inlets on only one side of the pavement, minimizing the number of storm sewer inlets and trunk lines.

Cross slopes of 1.5 to 2 percent are typically used on divided roadways and urban streets. Careful consideration to providing adequate drainage should also be used when designing superelevated roadways. The introduction of superelevation at horizontal curves can result in the construction of flat areas on the alignment if the superelevation is rotated through horizontal at the low or high point of a vertical curve.

Multilane Roadways. Roadways with three or more lanes per direction should desirably use a steeper slope on the outermost lane(s) than on the interior lanes. A slope of 2 percent (minimum 1 percent) is typically used on the inner lanes. Each successive pair of outside lanes may have their cross slope increased by 0.5 to 1 percent.

Crossover

The difference in cross slope (see Figure 6-1) between adjacent pavement surfaces should be limited to reduce adverse affects on the motorist:

- Cross slope difference between the shoulder and the travel lanes should not exceed 6 to 7 percent.[4]
- Difference between lanes is normally limited to 4 percent because of the influence on drivers when they traverse the crown line.
- Difference between lanes in areas of high rainfall can be increased to 5 percent if maximum cross slopes are used.

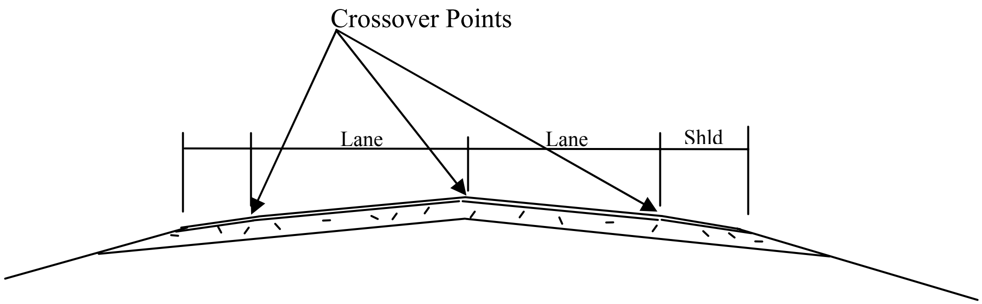

Figure 6-1. Crossover Points between Lanes and Shoulder.

Section 3
Profile

Overview

Drainage affects the design of the vertical profile of roadways because it is desirable that concentrated water flows not cross major traffic movements (Figure 6-2). It is also disruptive for traffic to travel across sharp breaks in the profile of the roadway.

Figure 6-2. Water Flow across Street at Intersection.

Minor Roadway Grades Warped to Fit Major Roadway

When minor roadways intersect with major roadways, the grades should generally favor the major roadway. Figure 6-3 illustrates warping the grades on the minor roadway to fit the cross section of the major roadway. This provides a smooth profile on the major roadway, and is acceptable on the minor roadway if traffic is expected to stop or travel slowly through the intersection.[5] Additional information on roadway grades at intersection is included in Chapter 3, Section 5 <link>.

Sketches illustrating designs intended to prevent water from flowing across the intersection, preserve sight distance, and provide a reasonably smooth ride are shown in Figure 6-4 (major roadway with a centerline crown) and Figure 6-5 (major roadway superelevated).[6]

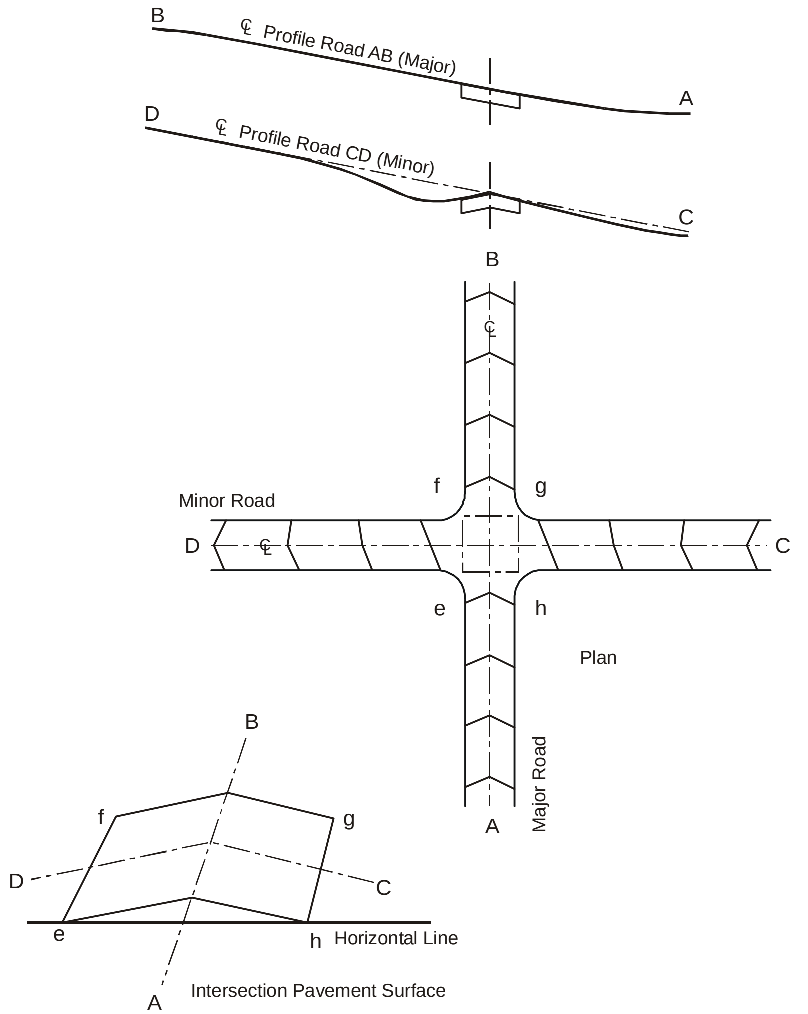

Figure 6-3. Minor Street Intersecting Major Street.[7]

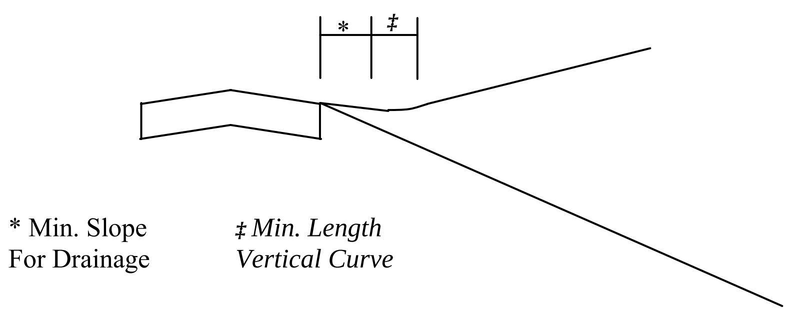

Figure 6-4. Normal Crown on Major Roadway, Stop Condition on Minor Roadway.[6]

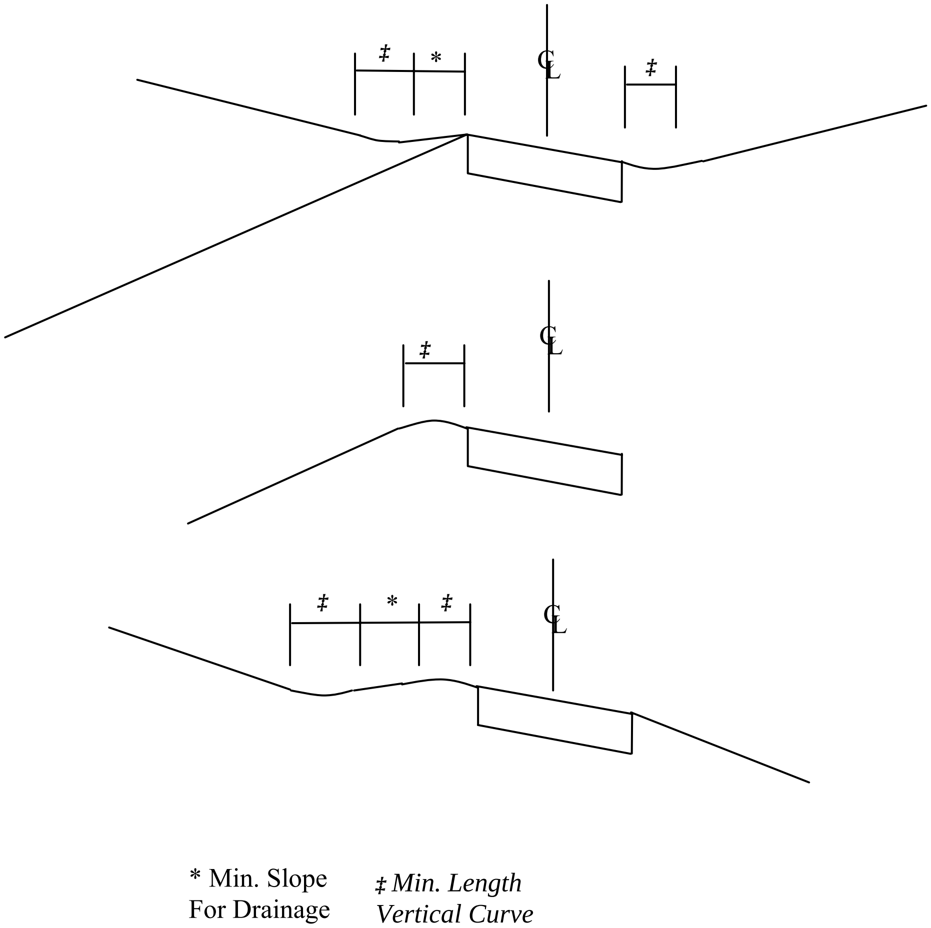

Figure 6-5. Superelevated Major Roadway, Stop Condition on Minor Roadway.[6]

"Table Top" Design: Centerline Grades Matched and Flow Lines Adapted

Another way of setting intersection gradelines is to match centerline grades and create a "table top" in the intersection. Illustrated in Figure 6-6, this method creates an intersection that has sheet flow to one corner.[5] Although most acceptable for use on roadways with narrow paved sections,[5] (thus limiting the water accumulation) the design is also used for larger intersections. The resulting smooth profiles through the intersection for both roadways provide a smooth ride for motorists continuing through the intersection and are suitable for signalized intersections.

Use of this design generally allows compliance with ADA requirements for cross slope in the crosswalk if the table is flat enough. Care should be taken to ensure that excessive amounts of water do not accumulate at one curb ramp. The use of contour plots to design and review the drainage and roadway tie-ins is recommended.

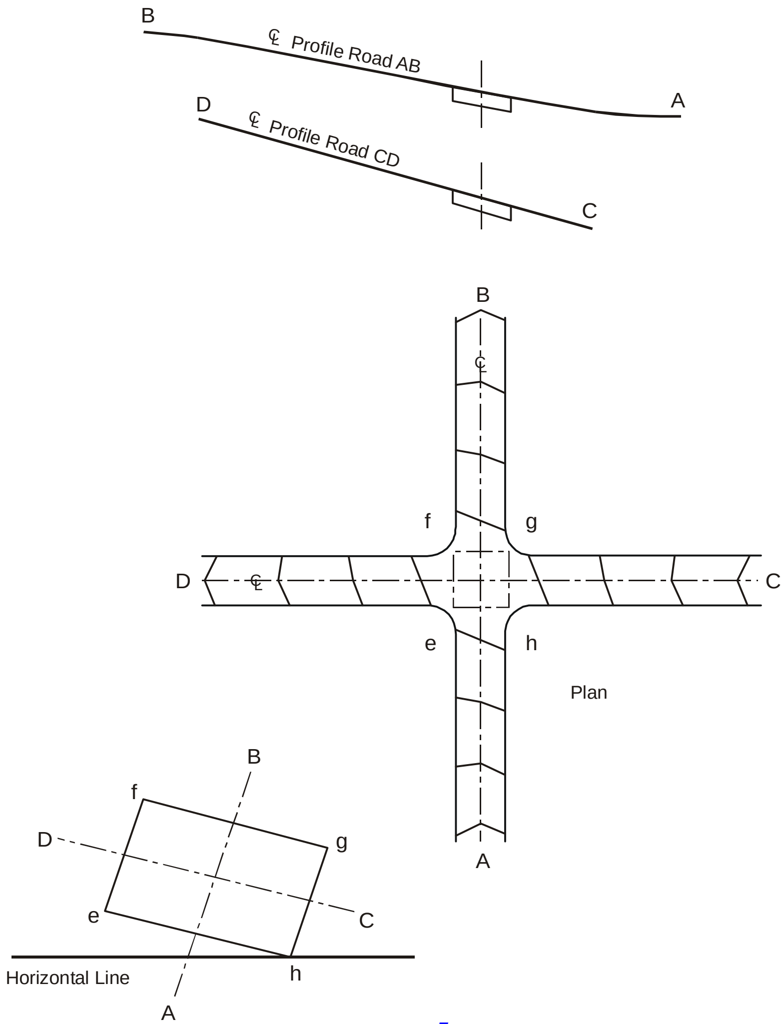

Figure 6-6. "Table Top" Design.[7]

Matched Cross Sections

An intersection design technique that is *not* recommended is to match cross sections on both roadways.[5] The design usually requires adjusting the centerline profiles and is illustrated in Figure 6-7. Resulting in an uncomfortable ride for motorists on both roadways, the design should be avoided.

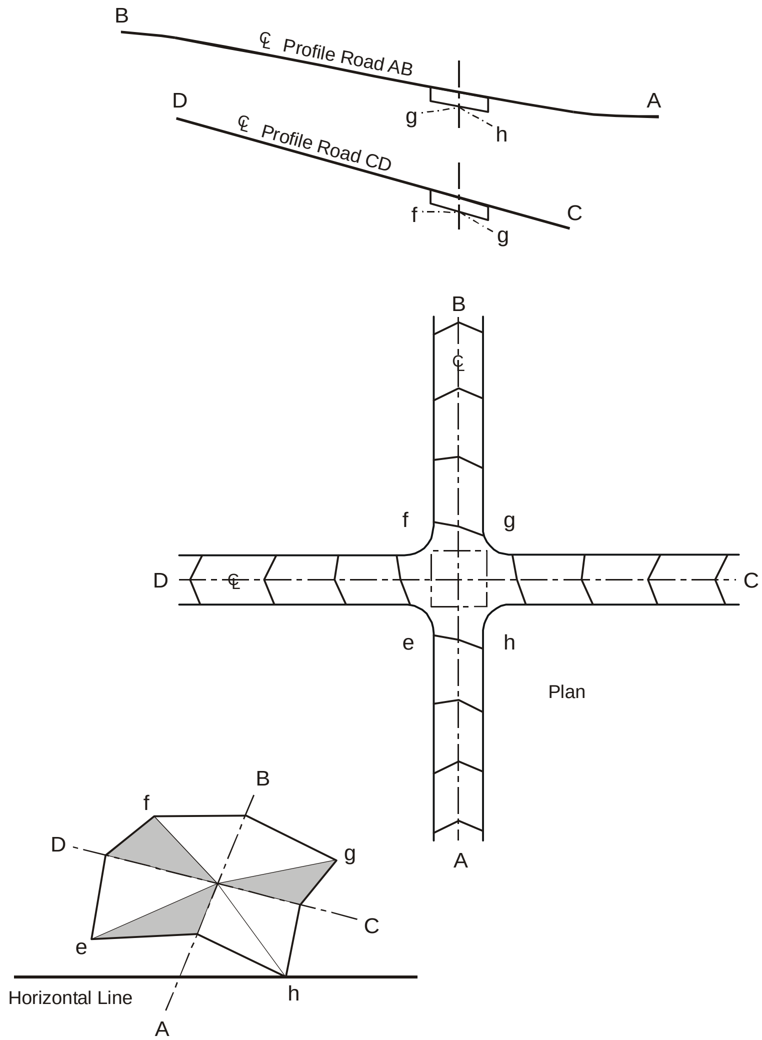

Figure 6-7. Cross Section Held Constant on Both Roadways, Technique Not Recommended Because It Results in an Uncomfortable Ride on Both Roadways.[7]

Section 4
Curb and Gutter

Overview

Curb and gutter is used to direct and control the movement of storm water, control access, and/or provide delineation or channelization.

Curb Type

Curbs should normally be used on low-speed facilities only. Curbs should only be used on high-speed facilities when needed for drainage and then they should be of the sloping type and located at the outer edge of the shoulder.[3] The design characteristics of these types of curbs can be found in TxDOT's *Roadway Design Manual*, Chapter 2, Section 6 <link>.

Ponding

The use of curb and gutter at intersections introduces the issue of ponding. Because grades are complicated by the presence of side roads, the potential for ponding occurring due to a design or construction problem is increased. Designs should be reviewed for the potential of ponding; the most common technique used is the development of a contour plot at close elevation intervals that is then reviewed for "bird baths." If ponding is determined to be likely, the designer should revise the intersection grade plan by:

- revising side street grades,
- changing cross slope on the main roadway or side street, or
- revising main roadway grades.

Ponding can also occur because of construction error. Because of the convergence of multiple gradelines and complicated curbing layouts, construction may not result in the exact grading the designer intended. Techniques used to provide better information to the inspector or contractor in the field include:

- provision of contour layouts,
- detailed curb and gutter grades (i.e., elevations every 25 ft [8 m] or closer) at corners and other critical locations, and/or
- elevation grid maps for intersections.

Raised Medians and Islands

Designers should consider the potential for raised medians and islands to trap or concentrate water. Breaks and/or inlets should be provided to eliminate concentrated flow or ponding (see Figure 6-8).

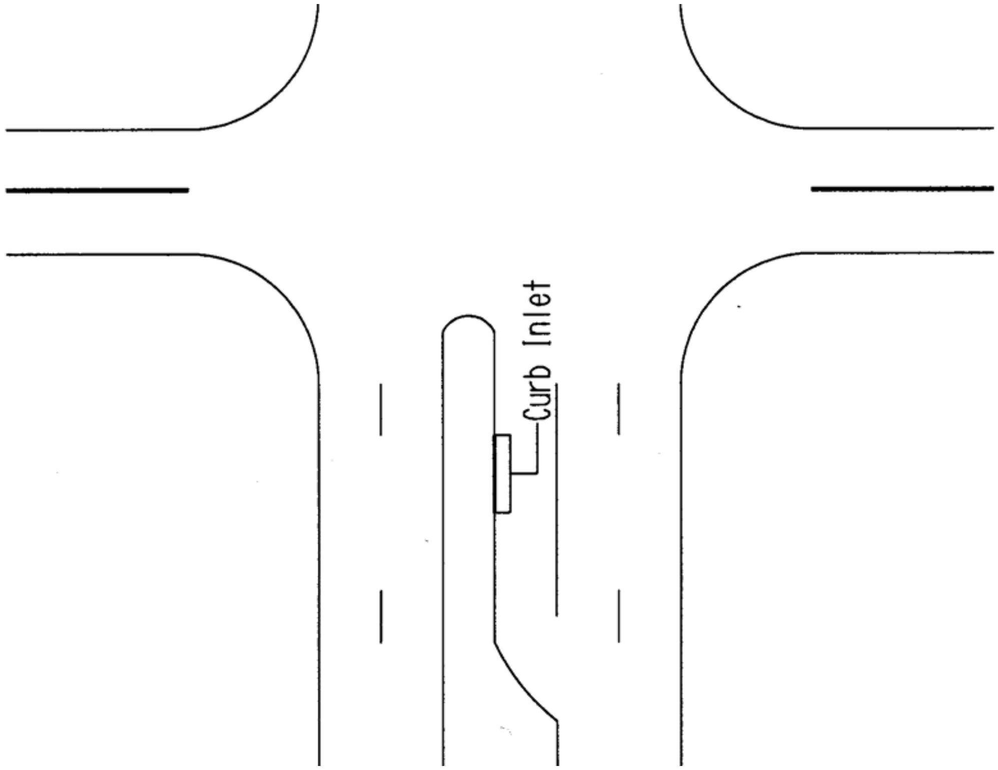

Figure 6-8. Median with Inlet Placed to Avoid Trapping Water.

Storm Drain Systems

Storm drain systems are typically placed in curb and gutter sections to remove water from the roadway. Inlet placement and design should reflect the need to remove concentrated water flow and accumulations of water from the pavement. Chapter 10 of the *Hydraulic Design Manual* should be consulted for further detailed design information on storm drain inlets <link>.

Inlet Placement. Inlets are normally placed to limit ponding (i.e., water flow in the outer part of the cross section against the curb). The *Hydraulic Design Manual*[2] provides the following ponding limits.

- Limit ponding to one-half the width of the outer lane for the main lanes of interstate and controlled access highways.
- Limit ponding to the width of the outer lane for major highways, which are highways with two or more lanes in each direction, and frontage roads.
- Limit ponding to a width and depth that will allow the safe passage of one lane of traffic for minor highways.

With respect to intersections, inlets on curbed roadways should be placed:

- upstream of intersections and crosswalks to intercept the water in the gutter prior to entering the intersection,[3]

- prior to the change in cross slope at any locations where the pavement crown is warped,[1] or
- away from the curb radius and curb ramps present at the intersection.

Carryover. Many designs of on-grade inlets utilize carryover to increase efficiency (see Chapter 10, Section 5 of the *Hydraulic Design Manual* <link>). In these designs, inlets are designed to intercept only a portion of the flow in the gutter at any one point. The rate of gutter flow not intercepted is called carryover. Although the use of carryover or "bypass flow" is generally desirable in storm drain design because it results in a more efficient hydraulic design, its use should normally be avoided at inlets upstream of intersections or driveways because it allows water to flow into the intersections or driveways.[2]

Inlet Type. The design of an intersection may also guide the selection of the storm drain inlet type.

Curb Opening Inlet. Probably the most common type of inlet is the curb opening inlet, shown in Figure 6-9 and Figure 6-10. Shown with a depressed gutter in front of the inlet, this depression increases the efficiency of the inlet but may have a detrimental effect on traffic if too deep. According to TxDOT's *Hydraulic Design Manual*[2], the depth of the depression (shown in Figure 6-9) should be:

- 0 to 1 inches (0 to 25 mm) where the gutter is within the traffic lane,
- 1 to 3 inches (25 to 76 mm) where the gutter is outside the traffic lane or in the parking lane, and
- 1 to 5 inches (25 to 127 mm) for lightly traveled city streets that are not on a highway route.

The use of depressed gutters should be limited in bicycle lanes to avoid including an obstacle in the path used by bicyclists.

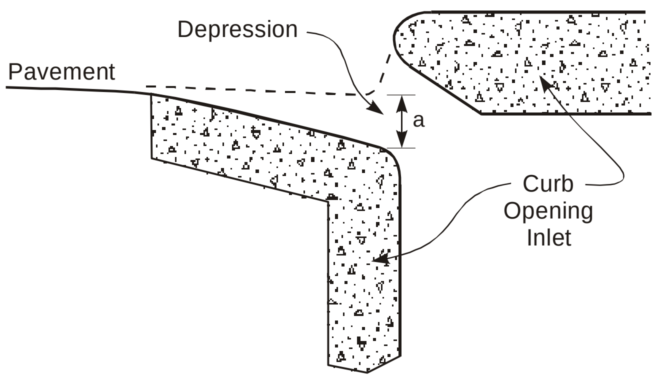

Figure 6-9. Depression at Curb Opening Inlet.

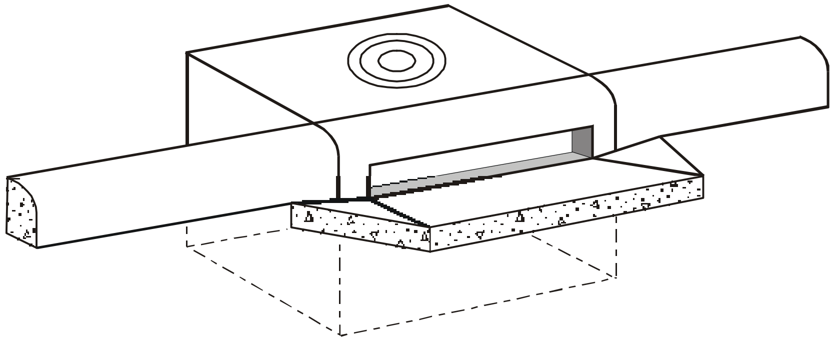

Figure 6-10. Curb Opening Inlet.

Grate Inlets. Space limitations, unusual grades, or placement adjacent to various roadway features may lead to the use of grate inlets near intersections (Figure 6-11).

Because grates may represent a hazard for bicyclists, special consideration should be given to the design of the inlet. Although a parallel-bar grate is the most efficient type of gutter inlet, efficiency is reduced when crossbars are added for bicycle safety. Where bicycle traffic is a design consideration, the curved vane grate and the tilt bar or "vane" grate (see Figure 6-12) are recommended for both their hydraulic capacity and bicycle safety features. In certain locations where leaves may create constant maintenance problems, the parallel bar grate may be used more efficiently if bicycle traffic is prohibited.

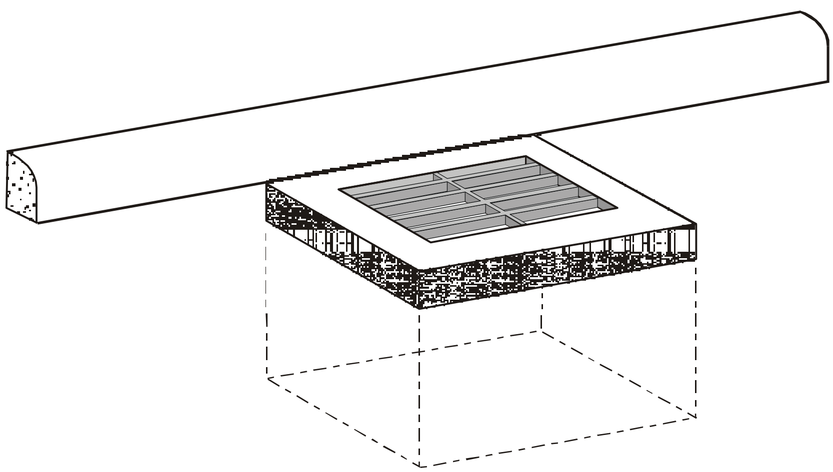

Figure 6-11. Grate Inlet.

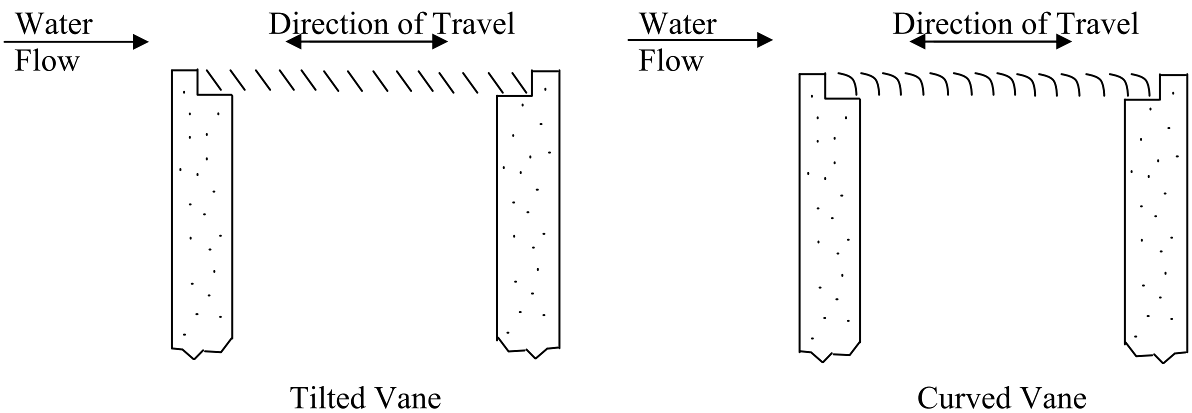

Figure 6-12. Tilted Vane (or "Bar") and Curved Vane Grate Inlets.

Combination Inlets. Combination inlets usually consist of some combination of a curb-opening inlet, a grate inlet, and a slotted drain. In a curb and grate combination (Figure 6-13), the curb opening may extend upstream of the grate. In a grate and slotted drain combination, the grate is usually placed at the downstream end of the grate. The design of combination inlets, because they use grates, should have a similar consideration as grate inlets with regard to bicyclists.

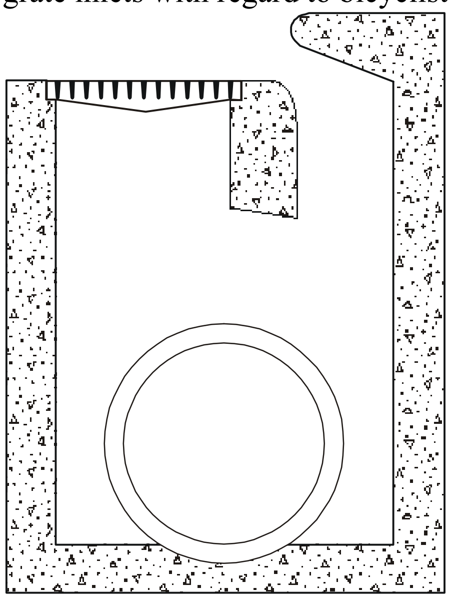

Figure 6-13. Example of Combination Inlet.

Slotted Drain Inlet. If it is necessary to intercept sheet flow or place an inlet across a driveway or intersection, the use of a slotted drain may be desirable (Figure 6-14).

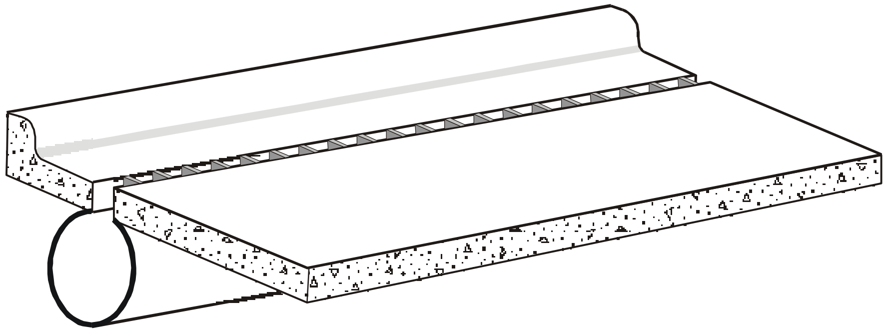

Figure 6-14. Slotted Drain.

Drainage Structures Near Railroad Tracks

Drainage structures near railroad tracks have special design considerations because of the railroad loads imposed on the structures. Figure 6-15 provides the boundary of the area requiring this type of design. Designers should coordinate with the bridge planning engineer to ensure that any special requirements are met.

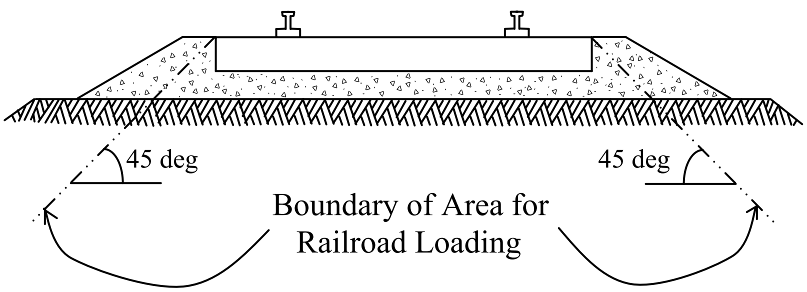

Figure 6-15. Diagram Showing Area Requiring Consideration for Railroad Loading.

Section 5
Ditches

Overview

Urban roadway sections sometimes include ditch sections on one or more of the intersection legs. Because of the likelihood of vehicle excursions at intersections it is even more critical that horizontal clearance and sideslope requirements be met at these locations. Design consideration should be given to clearance from both sets of travel lanes.

Horizontal Clearance

Horizontal clearance for rigid objects or steep slopes is discussed in Chapter 5, Section 2, Horizontal Clearance, of this manual <link>. Horizontal clearance requirements are provided in Chapter 2, Section 6, Horizontal Clearance, of the *Roadway Design Manual*[3] <link>. Criteria are provided for rural, urban, and suburban roadways.

Ditches

Ditch front and back slopes should be designed in accordance with requirements given in the *Roadway Design Manual*.[3] Controls are provided for front slopes and back slopes in the following sections. Ditches may sometimes be used behind curbs. If so, the horizontal clearance requirements may be only 1.5 to 3 ft [0.5 to 1 m], but if practical, relatively flat slopes are used.

Front Slopes. Shown in Figure 6-16, front slopes should normally be constructed at 1V:6H or flatter.[3] Steeper slopes up to 1V:4H still permit the use of typical maintenance equipment. Slopes up to 1V:3H may be used in constrained circumstances. Slopes steeper than 1V:3H are sometimes used at bridge headers or where stable soils are present but may require the use of riprap to prevent erosion.

If slopes steeper than 1V:3H are used in the horizontal clearance area, the use of longitudinal barriers should be considered. If slopes of 1V:3H to 1V:4H are used in the horizontal clearance area, obstructions should be avoided at the toe of the slope because vehicles are unlikely to recover and stop prior to reaching the bottom of the slope.

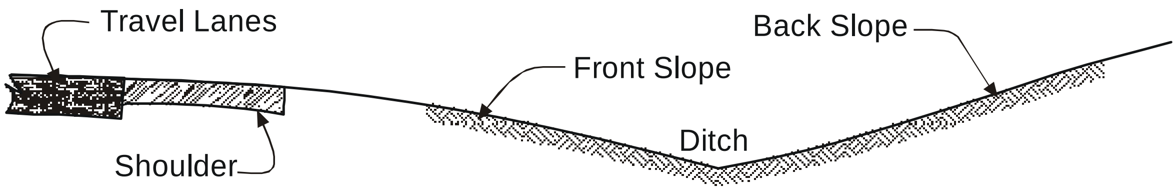

Figure 6-16. Ditch Elements.

Back Slopes. Back slopes of 1V:4H are typically used to facilitate mowing operations.[3] If steep front slopes are used, flatter back slopes are used and vice versa to provide a more forgiving roadside environment. If rock formations are present, steeper (or even vertical) back slopes may be used.

Section 6
Relationship to Pedestrian Facilities

Overview

Drainage facilities should be designed to operate effectively and efficiently, but other considerations also influence design. Curb ramps provided for the disabled will not be usable for several hours or days after a rain event if their design and location is not considered in the drainage plan.

Sidewalk Characteristics

To prevent ponding water it is desirable to provide a cross slope on sidewalks, but this must be tempered by ADAAG/TAS requirements. A maximum cross slope of 2 percent is permitted for sidewalks. It is advisable to specify a 1.5 percent cross slope in the plans to allow for construction tolerances in the field.

Curb Ramps and Crosswalks

If present, storm drain inlets should be located upstream of curb ramps and crosswalks (see Chapter 6 Section 4 <link>). Hydraulic designs should not utilize carryover at these locations. Care should be taken to avoid ponding at curb ramp locations (see Figure 6-17).

Figure 6-17. Ponding at Curb Ramp (Older, Non-Compliant Curb Ramp).

Metal Grates

The use of metal inlet grates should be avoided in pedestrian areas. When avoidance is not practical, ADAAG/TAS requirements must be met with the grate under consideration, with any opening measuring less than 0.5 inches [1.3 cm] in the direction of pedestrian travel.

Section 7

References

[1] Texas Administrative Code, Title 43 Transportation, Part 1,Texas Department of Transportation, *Chapter 15 Transportation Planning and Programming*, SubChapter E Federal, State, and Local Participation, Rule 15.54 Construction. Adopted effective September 26, 1996; amended to be effective January 1, 1998, amended to be effective November 22, 1998; amended to be effective February 21, 1999. http://info.sos.state.tx.us/pls/pub/readtac$ext.ViewTAC. Viewed March 7, 2004.

[2] Texas Department of Transportation. *Hydraulic Design Manual*. April 2002. http://manuals.dot.state.tx.us:80/docs/colbridg/forms/hyd.pdf. Accessed September 18, 2002.

[3] Texas Department of Transportation. *Roadway Design Manual*. Revised April 2002. http://manuals.dot.state.tx.us:80/docs/coldesig/forms/rdw.pdf. Accessed August 30, 2002.

[4] American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*. AASHTO, Washington, D.C., 2001.

[5] Stover, V.G., M. Zubel, E. Holy, and B. Thompson. *A Short Course on City Street Design.* Texas Transportation Institute and Texas Engineering Extension Service, The Texas A&M University System, College Station, Texas, January 1990.

[6] Ohio Department of Transportation. Ohio Location and *Design Manual, Volume 1 – Roadway Design*. December 1992, Revised August 19, 2002. http://www.dot.state.oh.us/roadwayengineering/L&D%20Vol1_link.htm. Accessed August 30, 2002. (Section 401); and J.E. Leisch & Associates. *Planning and Design Guide for At-Grade Intersections.* Sponsored by Governor's Highway Safety Program Mississippi-Tennessee, Evanston, Illinois.

[7] *Design Standards and Policy Guidelines.* City of Fort Worth, Texas, July 1987, in V.G. Stover, M. Zubel, E. Holy, and B. Thompson's *A Short Course on City Street Design.* Texas Transportation Institute and Texas Engineering Extension Service, The Texas A&M University System, College Station, Texas, January 1990.

Chapter 7
Street Crossing

Contents:

Section 1
Curb Ramps and Blended Transitions

Overview

Curb ramps and blended transitions provide access between the sidewalk or the ground and the street for people who use wheelchairs and scooters, people pushing strollers and pulling suitcases, and children on bicycles. A curb ramp and level landing is to be provided wherever a new or upgraded public sidewalk crosses a curb. The TxDOT *Roadway Design Manual*[1] states that curb ramps must be provided in conjunction with each project where the following types of work are performed:

- resurfacing projects, including overlays and seal coats, where a barrier exists to a sidewalk or path;
- construction of curbs, curb and gutter, and/or sidewalks;
- installation of traffic signals that include pedestrian signals; and
- installation of pavement markings for pedestrian crosswalks.

Curb ramps should be designed to provide the least slope consistent with the curb height, available corner area, and underlying topography. A level landing is necessary for turning, maneuvering, or bypassing the sloped surface. Proper curb ramp design is important to users either continuing along a sidewalk path or attempting to cross the street. Utility poles, traffic signs, signals, signal control boxes, drainage structures, pedestrian call buttons, and street name signs are to be carefully located so they do not obstruct the installation of curb ramps or the pedestrian's ability to safely cross the road. ***Application 7-1*** ***<link>*** provides discussion on the selection of design elements at a specific intersection being considered for improvement.

TxDOT standard sheet "PED-02"[2] may be referenced for additional information in the configuration of curb ramps. The sheet has been approved by the Texas Department of Licensing and Regulation.

Where Required

A curb ramp or blended transition should be provided wherever the pedestrian route crosses a curb, including:

- intersections;
- midblock crosswalks;
- medians and islands traversed by crosswalks, alleys, accessible parking aisles, passenger loading zones; and
- locations where the public sidewalk ends and pedestrian travel continues in the roadway.

A curb ramp or blended transition is not required where the pedestrian route crosses a driveway and the elevation of the pedestrian route is maintained.

At any intersection in the public right of way that has at least one corner served by a public sidewalk or a pedestrian route, all corners of the intersection served by a crosswalk should have curb ramps or blended transitions. This eliminates the possibility of a pedestrian traveling across the road to find no refuge at the other end of the crosswalk.

Curb Ramp Components

Although there are a variety of designs, each type of curb ramp comprises some or all of the following elements (see Figure 7-1).

- ***Landing*** – level area of sidewalk at the top of a perpendicular curb ramp or the bottom of a parallel curb ramp for turning. Landing slopes are not permitted to exceed 2 percent in any direction.
- ***Flare*** – sloped transition on the side of a perpendicular curb ramp. The maximum slope is 10 percent. The path along the flare has a significant cross slope and is not considered an accessible path of travel. When the sidewalk is set back from the street, returned curbs may replace flares where pedestrians would not be expected to cross the returned curb (i.e., a non-walking surface is provided).
- ***Sloping Area*** – sloped transition between the street and the sidewalk, with a maximum slope of 8.3 percent.

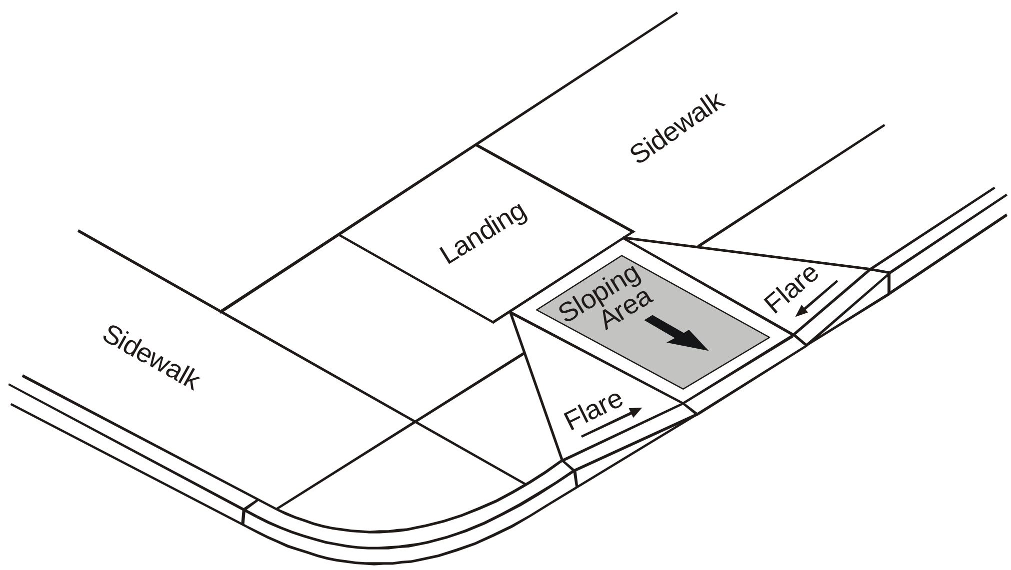

Figure 7-1. Components of a Curb Ramp.

Curb Ramp Types

The appropriate type of curb ramp to be used is a function of sidewalk and border width, curb height, curb radius, and topography of the street corner. Four types of ramps are commonly used in street corner designs:

- perpendicular,
- parallel,
- combination, and
- diagonal.

Detailed dimensions for each curb ramp type are shown on TxDOT's PED[2] standard sheets.

Perpendicular Curb Ramps. The path of travel along a perpendicular curb ramp is oriented at a 90-degree angle to the curb face. It is aligned perpendicular to the curb where it crosses the curb, even if it crosses the curb within the radius of the corner. If a perpendicular approach is not provided, pedestrians who use wheelchairs could face a change in cross slope, resulting in one wheel being off the ground.

Perpendicular curb ramps are usually installed in pairs at a corner (see Figure 7-2). Two accessible perpendicular curb ramps are generally safer and more usable for pedestrians than a single diagonal curb ramp. An example of perpendicular curb ramps is shown in Figure 7-3.

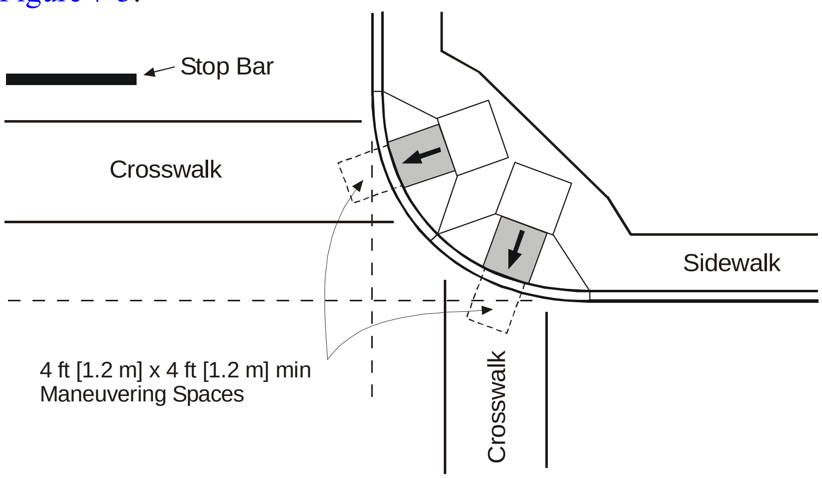

Figure 7-2. Perpendicular Curb Ramp.

Figure 7-3. Photo of Perpendicular Curb Ramps.

Parallel Curb Ramps. The path of travel along a parallel curb ramp is a continuation of the sidewalk. Figure 7-4 shows the schematic of a parallel curb ramp, while Figure 7-5 is a photograph of a parallel curb ramp. Parallel curb ramps provide an accessible transition to the street on narrow sidewalks. However, if the landing on parallel curb ramps is not sloped toward the gutter (no more than 2 percent), water and debris can pool there and obstruct passage along the sidewalk. Careful analysis of the hydraulics related to the landing, gutter slope, and roadway crown must be performed to avoid ponding water at the landing. Parallel curb ramps also require those wishing to continue along the sidewalk to negotiate two ramp grades, unless a wide buffer zone permits the sidewalk to continue behind the parallel curb ramp.

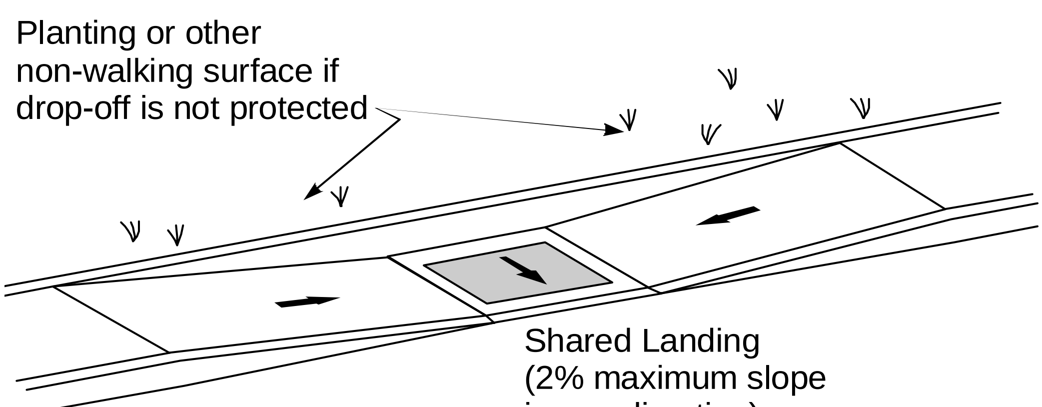

Figure 7-4. Parallel Curb Ramps.

Figure 7-5. Photo of Parallel Curb Ramp.

Combination Curb Ramps. When a curb ramp includes components of both perpendicular and parallel curb ramps, it is known as a combination curb ramp. Figure 7-6 shows examples of combination curb ramps.

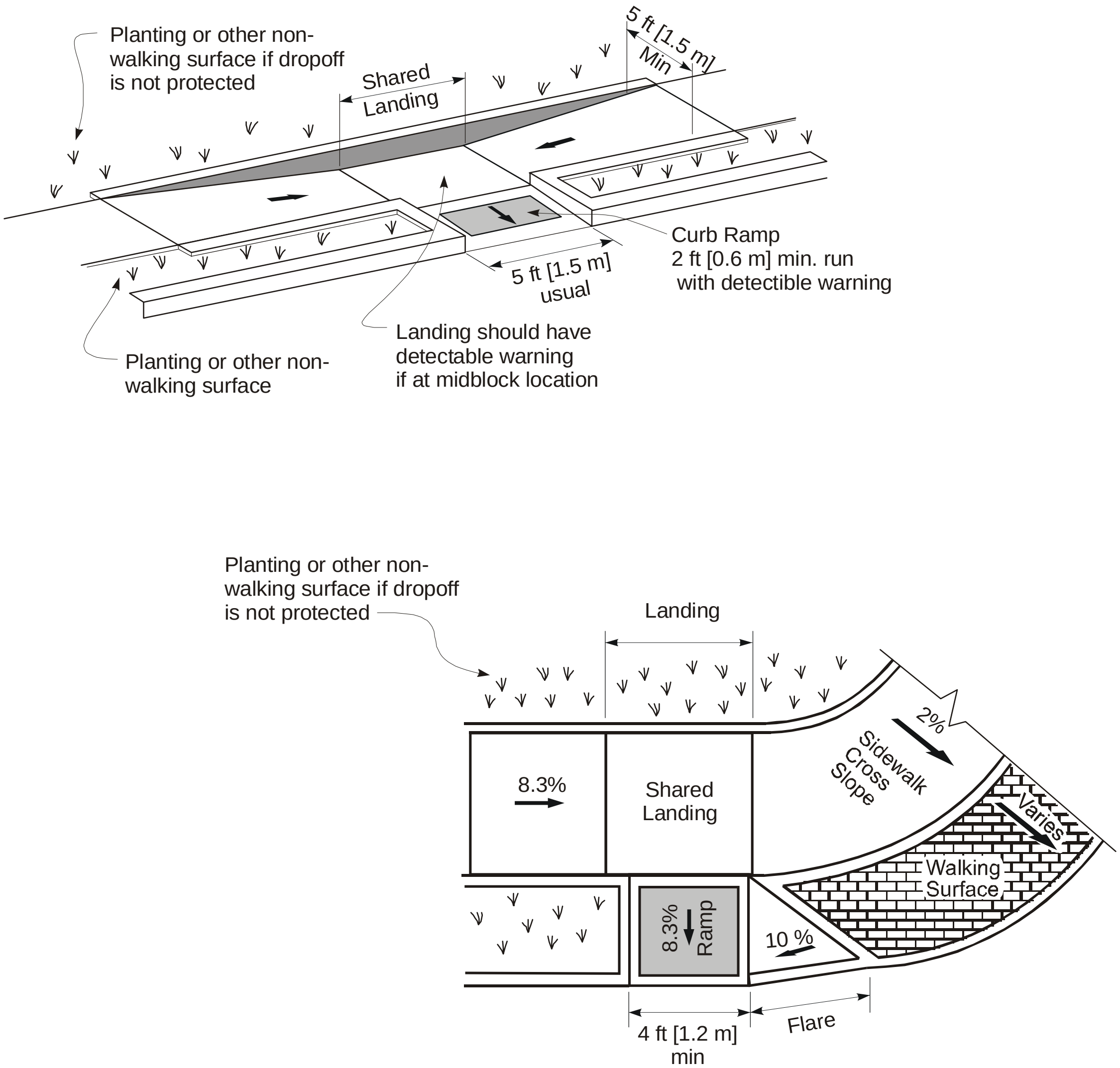

Figure 7-6. Examples of Combination Curb Ramps.

Diagonal Curb Ramps. Diagonal curb ramps are single curb ramps installed at the apex of a corner to serve two crossing directions (see Figure 7-7). Diagonal curb ramps force pedestrians descending the ramp to proceed into the intersection before turning to the left or right to cross the street. A clear space of 4 ft × 4 ft [1.2 m × 1.2 m] is necessary to allow curb ramp users in wheelchairs enough room to maneuver into the crosswalk.

A designer's ability to create a clear space at a diagonal curb ramp might depend on the turning radius of the corner. For example, a tight turning radius requires the crosswalk line to extend too far into the intersection and exposes pedestrians to oncoming traffic. Diagonal curb ramps also provide no directional orientation information to persons with visual impairments. Diagonal curb ramps should only be used as the last alternative. Special ADAAG and TAS requirements apply to diagonal curb ramps. Refer to ADAAG[3] and TAS[4] and the PED[2] standard sheet for more information.

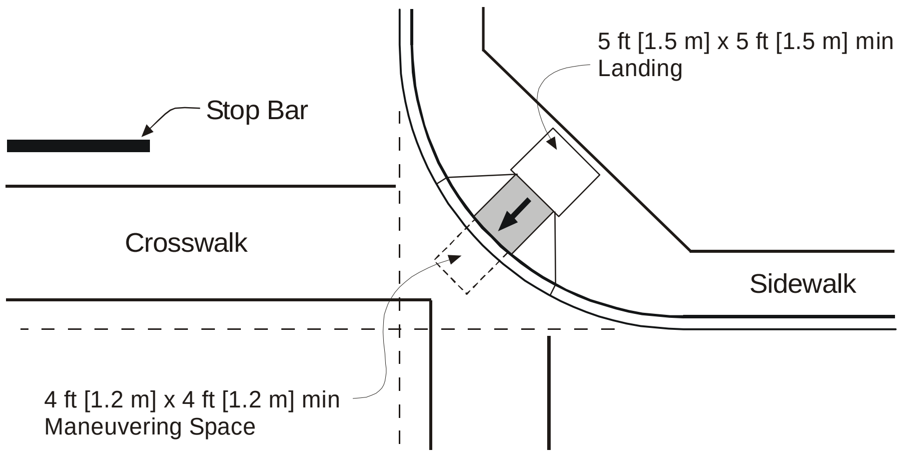

Figure 7-7. Diagonal Curb Ramp.

Blended Transitions

An example of a blended transition is shown in Figure 7-8. As with curb ramps, blended transitions shall have the following:

- clear width (excluding flares) of 48 inches (1.2 m) minimum,
- detectable warning (2 ft [0.6 m] wraparound that requires prior approval by TDLR as being within compliance),
- close slope of less than 2 percent in any direction,
- no grade breaks, and
- clear maneuvering space in street of 4 ft × 4 ft [1.2 m × 1.2 m] minimum (see Figure 7-2).

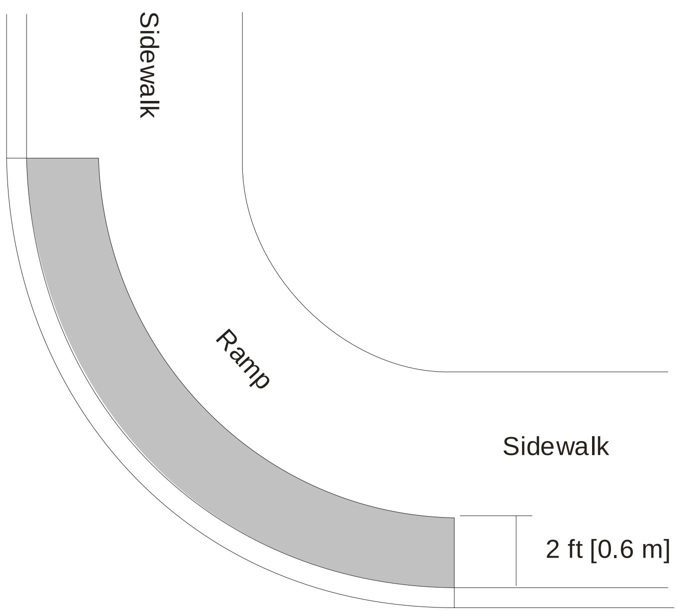

Figure 7-8. Example of a Blended Transition.

Selection of Curb Ramp Type

Selection of the appropriate type of curb ramp at each location involves a variety of considerations. Curb ramps should be considered in the following order of preference: perpendicular, parallel or combination, and diagonal. When determining whether a particular type of curb ramp is feasible, the designer should make every attempt to locate other features such as sign and signal supports, curb inlets, and fire hydrants so that the most preferable type of curb ramp can be provided.

Placement

At marked crossings, the bottom of a curb ramp run should be wholly contained within the markings of the crosswalk. For perpendicular or diagonal curb ramps, there should be a minimum 4 ft × 4 ft [1.2 m × 1.2 m] maneuvering space beyond the curb line that is wholly contained within the crosswalk (marked or unmarked) and outside the path of parallel vehicular traffic. Intersections may have unique characteristics that can make the proper placement of curb ramps difficult, particularly in retrofit situations. Following are fundamental guidelines for consideration in dealing with curb ramp placement:

- Perpendicular curb ramps should be built 90 degrees to the curb face, and their full width at the toe (exclusive of flares) must be within the crosswalk. Aligning the ramp to the crosswalk, if possible, will enable the visually impaired pedestrian to more safely navigate across the intersection and exit the roadway on the adjoining curb ramp.
- All curb ramps need to avoid storm drain inlets, which can catch wheelchair casters or cane tips.
- Curb ramps need to be adequately drained. A puddle of water at the base of a ramp can hide pavement discontinuities. Puddles can also freeze and cause the user to slip and fall.
- Curb ramps must be situated so that they are adequately separated from parking lanes. Regulatory signs and parking enforcement can limit vehicles from blocking or backing across a crosswalk or curb ramp. Even better, curb extensions physically prevent parked cars from encroaching into the curb ramp. Additional information on curb extensions is in Chapter 5, Section 5 <link>.

Width

The minimum width of curb ramps is 4 ft [1.2 m] exclusive of the flared sides.

Landings

Landings are unobstructed level areas used for turning (including U-turns), accessing pedestrian signal call buttons, resting, passing, and waiting for a safe crossing time. They are needed in public sidewalks before pedestrians cross into the roadway, even if the public sidewalk and the roadway are at the same elevation. Landings provide a level area (less than 2 percent cross slope in any direction) for users to wait, maneuver into or out of a curb ramp, or to bypass the ramp altogether. A landing should have a minimum clear dimension of

5 ft × 5 ft [1.5 m × 1.5 m] square or a 5 ft [1.5 m] diameter circle. Landings should also be provided at raised medians or channelizing islands or a cut-through should be provided.

Grade

The maximum grade of a curb ramp is 8.3 percent, which is a 1:12 slope. Lesser grades should be used when possible.

Flares

Curb ramp flares are graded transitions from a curb ramp to the surrounding sidewalk or terrain. Flares are not intended to be part of the accessible routes and are typically steeper than the curb ramp with slopes. A maximum flare slope of 10 percent is permitted to help prevent possible tripping by any pedestrian.

Flares are only needed in locations where the ramp edge abuts a non-walking surface. A returned curb edge may be used where the sides of the curb ramp abut grass landscaping or travel across the ramp is blocked by obstruction. Returned curbs that align with the crosswalk are a useful orientation cue to provide direction for visually impaired pedestrians.

Cross Slope

The maximum cross slope is 2 percent. Flatter grades and slopes should be used where possible. Cross slope requirements also apply to the continuation of the pedestrian route through the crosswalk. Sidewalks immediately adjacent to the curb or roadway may be offset to avoid a non-conforming cross slope at driveway aprons by diverting the sidewalk around the apron as shown in Figure 7-9. See PED[2] standard sheet for more information.

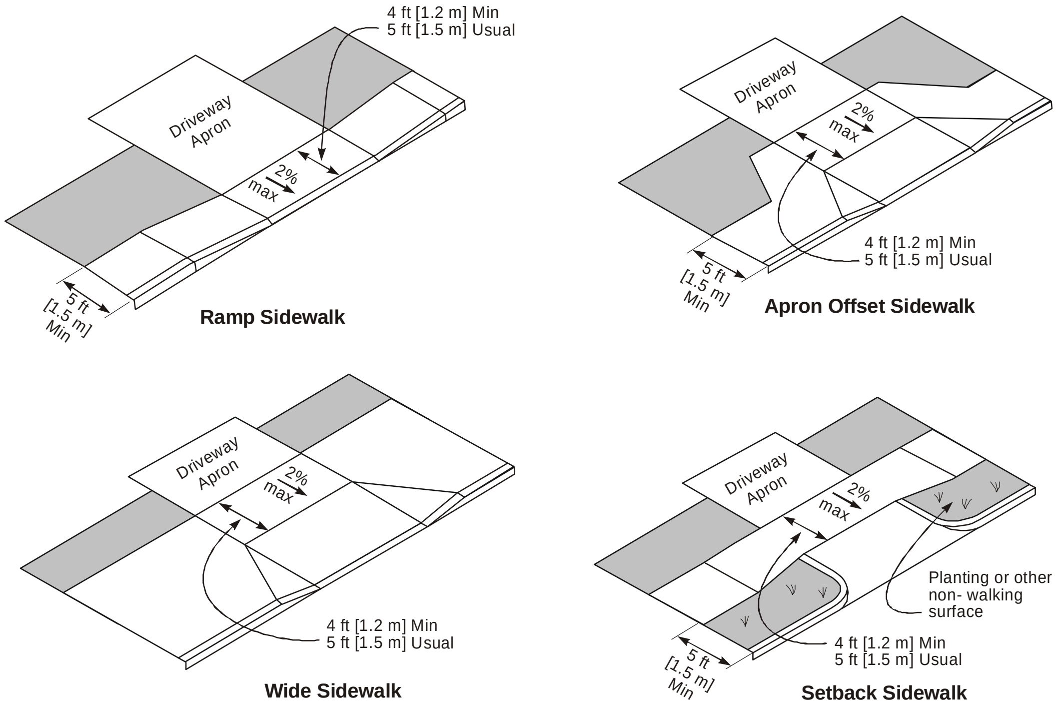

Figure 7-9. Sidewalks at Driveway Aprons.

Counter Slopes

The counter slopes of gutter or road surfaces at the foot of a curb ramp may not exceed 1:20. When possible, the algebraic difference in grade between the curb ramp and the street should be ≤ 11 percent.

Surfaces

Surfaces of blended transitions, curb ramps, and landings should be stable, firm, and slip resistant. The *Draft Guidelines for Accessible Public Rights of Way*[5] is recommending that gratings, access covers, and other appurtenances shall not be located on curb ramps, landings, blended transitions, and gutter areas within the pedestrian access route.

Detectable Warnings

A detectable warning is a standardized feature built in or applied to walking surfaces to warn visually impaired pedestrians before they enter a roadway or vehicular way. Detectable warnings alert visually impaired pedestrians that they should stop and determine the nature of the hazard before proceeding further. The two components of a detectable warning surface are texture and light reflective value contrast. A truncated dome surface is required on all curb ramps and blended transitions to mark the street edge.

TxDOT's PED[2] standard sheet contains provisions for the detectable warning surface. Although the standard depicts a brick paver product, other products are available for use. Contact the Design Division field section for more information.

The material used to provide visual contrast shall be an integral part of the walking surface and should contrast visually with adjoining surfaces by at least 70 percent.

A proposed change to ADAAG[5] is to have the truncated domes installed in a 24 inch [610 mm] strip at the curb line (rather than full length) for the full width of the curb ramp. The use of this 24 inch [610 mm] strip has also been encouraged by the Federal Highway Administration. However, until TAS changes, the full width and depth requirement remains in effect in Texas. The shaded area on each of the curb ramps on the PED standard sheet indicates the proper placement of the detectable warning surface.

Section 2
Crosswalks

Overview

A crosswalk is the portion of roadway designated for pedestrians to use in crossing the street. It may be marked or unmarked. A legal crosswalk exists regardless of whether it is marked (see following section on Texas state law). Figure 7-10 illustrates examples of marked, unmarked, and midblock crosswalks.

The purposes for marked crosswalks are:

- to warn motorists to expect pedestrian crossings and
- to indicate the preferred crossing locations.[6]

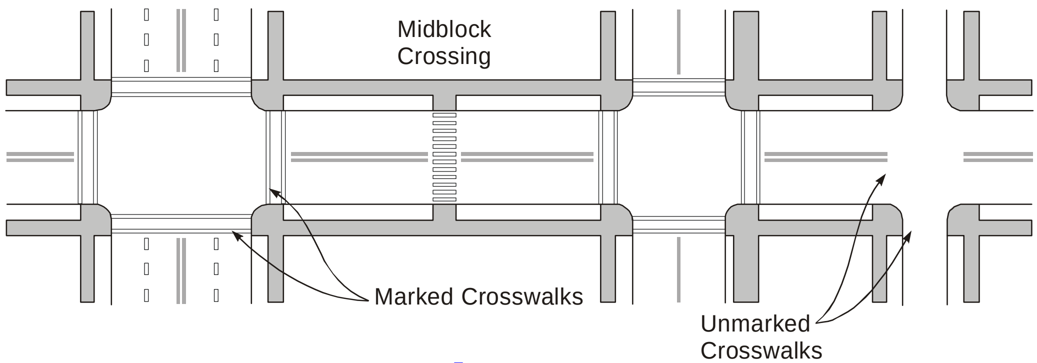

Figure 7-10. Types of Crosswalks.[7]

Pedestrians are most vulnerable to injury from motor vehicles at intersections; therefore, designers should be sensitive to the needs of pedestrians in the design and operation of an intersection. Crosswalks should be designed to minimize exposure of pedestrians to motor vehicles. Where practical they should be designed at right angles, and the radius of curb returns should be no greater than is necessary for a reasonable design vehicle operating at a low speed. Over-designed curb radii increase crossing times for pedestrians and encourage higher speeds of turning vehicles that conflict with pedestrians. At high-volume intersections, designers often limit marked crossings to encourage pedestrians to cross at specific locations in an effort to minimize the number of pedestrian and vehicle conflict areas.

Considerations when marking crosswalks include the following:

- Crosswalk locations should be convenient for pedestrian access.
- Crosswalk markings alone are unlikely to benefit pedestrian safety. Ideally, crosswalks should be used in conjunction with other measures, such as curb extensions, to improve the safety of a pedestrian crossing. This is particularly true on multilane roads with average daily traffic above 10,000.
- Marked crosswalks can assist persons with low vision.

- Curb ramps are to be within the crosswalk markings so that pedestrians do not have to leave the crosswalk to access the curb ramp.

Texas State Law

Definitions. Texas State law (Transportation Code of Texas, Sec. 541.302) defines a crosswalk as "(a) the portion of a roadway, including an intersection, designated as a pedestrian crossing by surface markings, including lines; or (b) the portion of a roadway at an intersection that is within the connections of the lateral lines of the sidewalks on opposite sides of the highway measured from the curbs or, in the absence of curbs, from the edges of the traversable roadway." A very similar definition is included in the *Texas Manual on Uniform Traffic Control Devices*.[8]

The law defines a *marked crosswalk* as a pedestrian crossing that is designated by surface markings and an *unmarked crosswalk* as the extension of a sidewalk across intersecting roadways (see Figure 7-10). Thus Texas State law recognizes both marked and unmarked crosswalks but makes no legal distinction between the two in assigning pedestrian right of way.

A *midblock crossing* is a pedestrian crossing that is not located at a roadway intersection (see Figure 7-10). If a midblock crossing is not designated by a marked crosswalk, then pedestrians must yield the right of way to motorists.

An *uncontrolled location* is a roadway intersection or other midblock crossing that is not controlled by either a traffic signal or a Stop sign. Uncontrolled locations can be the most challenging places to provide a safe pedestrian crossing.

Texas Law Pertaining to Pedestrian Crossings. Texas State law (Transportation Code of Texas, Sec. 552.003) includes the following regulations regarding pedestrian crossings:

- Vehicle operators must yield the right of way to pedestrians in a crosswalk if no traffic signal control is in place or in operation (Sec. 552.003(a)).
- A pedestrian may not suddenly proceed into the path of a vehicle so close that it is impossible for the vehicle operator to yield (Sec. 552.003(b)).
- A pedestrian must yield the right of way to vehicle operators when crossing the roadway at a place a) other than a marked or unmarked crosswalk at an intersection, or b) where a pedestrian tunnel or overhead pedestrian crossing has been provided (Sec. 552.005 (a)).
- When traffic control signals are in operation at adjacent intersections, pedestrians may cross only in a marked crosswalk (Sec. 552.005(b)).
- Vehicle operators emerging from or entering an alley, building entrance, or private road or driveway must yield the right of way to a pedestrian approaching on a sidewalk extending across said alley, building entrance, or private road or driveway (Sec. 552.006(c)).

Slopes

The Texas Accessibility Standards require that cross slope requirements of a sidewalk also apply to the continuation of the pedestrian route through the crosswalk.[4] Cross slopes are to not exceed 1:50 (2 percent). The running slope in a crosswalk (cross slope of the roadway being crossed) should be ≤ 5 percent.

Crosswalk Markings

Information on crosswalk markings is provided in Chapter 9 <link>. Different styles of markings are available. Figure 7-11 illustrates the standard and ladder styles. As shown in the photos, the ladder markings are more visible to an approaching driver. Information on the relative placement of the curb ramp with the crosswalk markings is presented in Chapter 7, Section 1 <link>.

(A) Standard

(B) Ladder

Figure 7-11. Examples of Crosswalk Markings.

Other Crossing Treatments

In addition to installing marked crosswalks (or, in some cases, instead of installing marked crosswalks), there are other treatments that can be considered to provide safer and easier crossings for pedestrians at selected locations. Examples of these pedestrian improvements include:

- Provide raised medians (or raised crossing islands) on multilane roads.
- Install traffic signals and pedestrian signals where warranted, and where pedestrian crossing challenges exist.
- Reduce the exposure distance for pedestrians by:
  - reducing curb radii,
  - providing curb extensions (see discussion in Chapter 5, Section 5 <link>), or
  - providing refuge islands.
- Consider the installation of advance stop lines when marked crosswalks are used on uncontrolled multilane roads. The advance stop lines may be installed as much as 30 ft [9.1 m] prior to the crosswalk (with a STOP HERE FOR CROSSWALK sign) in each direction to reduce the likelihood of a multiple-threat pedestrian collision (condition where vehicle in near lane limits view between pedestrian and vehicle in second through lane). See Chapter 9, Section 3, Placement of Stop and Yield Lines <link> for additional information.
- Locate bus stops on the far side of uncontrolled marked crosswalks.
- Install traffic-calming measures to slow vehicle speeds and/or reduce cut-through traffic. Each of these measures has positive and negative considerations and needs to be evaluated carefully. Some of these traffic-calming measures are better suited to local or neighborhood streets than to arterial streets. Measures may include the following:
  - raised crossings (raised crosswalks, raised intersections);
  - street-narrowing measures (chicanes, slow points, "skinny street" designs);
  - alternative intersection designs (traffic mini-circles, diagonal diverters); and
  - others (see ITE *Traffic Calming, State of the Practice*[9] for further details).
- Provide adequate nighttime street lighting for pedestrians in areas with nighttime pedestrian activity where illumination is inadequate.

Application 7-2 ***<link>*** discusses the process used for selecting appropriate treatments at an intersection.

Discussion on potential treatments for pedestrian crossings is included in:

- ***Application 7-3*** ***<link>*** for major street crossings,
- ***Application 7-4*** ***<link>*** for residential street crossings,
- ***Application 7-5*** ***<link>*** for signal crossings for pedestrians,
- ***Application 7-6*** ***<link>*** for signalized intersections, and

- ***Application 7-7*** **<*link*>** for school-related crossings.

Safety Benefits of Marked Crosswalks

Five years of pedestrian crashes at 1000 marked crosswalks and 1000 matched unmarked comparison sites were studied for sites that did not have a traffic signal or Stop sign on the approaches.[10] The sites were located across the United States. Detailed data were collected on traffic volume, pedestrian exposure, number of lanes, type of median, speed limit, and other site variables. The results revealed the following:

- On two-lane roads, the presence of a marked crosswalk alone at an uncontrolled location was associated with no difference in pedestrian crash rate when compared with an unmarked crosswalk.
- On multilane roads with volumes above 12,000 vehicles per day, having a marked crosswalk was associated with a higher pedestrian crash rate (after controlling for other site factors) compared with an unmarked crosswalk.
- Raised medians provided significantly lower pedestrian crash rates on multilane roads, compared with roads without a raised median.
- Older pedestrians were overrepresented in the crash data relative to their crossing exposure.

Based on the findings, improvements were recommended to provide for safer pedestrian crossings, including adding traffic signals (with pedestrian signals) when warranted, providing raised medians, and implementing speed-reducing measures.[10]

The objective of another study was to determine the effect of crosswalk markings on driver and pedestrian behavior at unsignalized intersections. A before-and-after evaluation of crosswalk markings was conducted at 11 locations in 4 U.S. cities. Observed behavior included pedestrian crossing location, vehicle speeds, driver yielding, and pedestrian crossing behavior. The study indicated that drivers approach a pedestrian in a crosswalk somewhat slower and that crosswalk usage increases after markings are installed. No evidence was found indicating that pedestrians are less vigilant in a marked crosswalk. No changes were found in driver yielding or pedestrian assertiveness. The authors concluded that marking pedestrian crosswalks at relatively low-speed, low-volume, unsignalized intersections is a desirable practice based on the sample of sites used in the study.[11]

Suggested Guidelines for Crosswalk Installation

Considerable controversy exists regarding the effectiveness of marked crosswalks in relation to pedestrian crash prevention. The *TMUTCD* indicates that marked crosswalks generally serve to alert road users of a pedestrian crossing point and to identify for the pedestrians the optimal crossing point. Guidelines on when to install marked pedestrian crosswalks were developed in an FHWA report entitled *Safety Effects of Marked vs. Unmarked Crosswalks at Uncontrolled Locations.*[10]

Right-Turn Lane

For pedestrian crossings where the right-turn lane is channelized, it is recommended that:

1. An adjacent pedestrian refuge island conforming to *TMUTCD*, ADAAG, and the *Green Book* be provided. Additional information on the refuge island is in Chapter 4, Section 5 <link>.
2. The location of a crosswalk across the channelized area should be carefully considered. Some engineers think the crosswalk should be placed as close as possible to the approach leg to maximize the visibility of pedestrians to approaching drivers. However, pedestrians traveling along the cross street are likely to take the shortest path and cross near the downstream end of the turn lane. Additionally, visually impaired pedestrians will cross near the downstream end to remain parallel to the flow (and audible cues) of traffic.

Midblock Crossing

Where it is considered desirable to install midblock crosswalks, advance pedestrian warning signs should be considered to warn motorists of pedestrian crossing activity. Markings may be difficult to see during adverse weather conditions or if located even on a gentle crest vertical curve. Other actions that should also be considered when installing a midblock crosswalk include positioning the crosswalk near a streetlight (or installing additional lighting) and installing a pedestrian refuge island for the crosswalk (especially if more than three lanes total are to be crossed). Examples of treatments used at uncontrolled locations such as in-roadway warning lights, are available in ***Application 7-3*** <link>.

A minimum enhancement that benefits pedestrians is a raised median island. This allows pedestrians who cross midblock to focus on one direction of traffic at a time, simplifying the crossing task. More information about medians can be found in Chapter 4, Section 5 <link>. Other treatments for midblock crossings are discussed in ***Application 7-4*** <link>.

Median Island

Information regarding the use of a median as a pedestrian refuge is provided in Refuge Islands <insert link to Chapter 4 Section 5> and should be consulted for further information on refuge areas.

Section 3

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Chapter 8
Signals

Contents:

Section 1
General

Overview

A traffic control signal, also called a traffic signal, is any highway traffic signal by which traffic is alternately directed to stop and permitted to proceed.[1] The primary function of traffic control signals is to assign the right of way at intersecting streets where without such control an excessive delay or hazard to vehicles and/or pedestrians would result.

Advantages and Disadvantages

A properly designed, operated, and maintained traffic control signal can be a valuable device for the control of vehicle and pedestrian traffic.[2] Table 8-1 lists some advantages and disadvantages of traffic control signals.

Table 8-1. Advantages and Disadvantages of Traffic Control Signals.

Advantages of appropriate and justified traffic control signals
♦ Provides for the orderly movement of traffic for all modes.
♦ Increases the traffic-handling capacity of the intersection if proper physical layouts and control measures are used, and if the signal timing is reviewed and updated on a regular basis (every 2 years) to ensure that it satisfies current traffic demands.
♦ Reduces the frequency and severity of certain types of crashes, especially right-angle collisions.
♦ Provides, if coordinated, for continuous or nearly continuous movement of traffic at a definite speed along a given route under favorable conditions.
♦ Interrupts heavy traffic at intervals to permit other traffic, vehicular or pedestrian, to cross.
Disadvantages of improper or unjustified traffic control signals
♦ Creates excessive delay.
♦ Encourages excessive disobedience of the signal indications.
♦ Causes increased use of less adequate routes as road users attempt to avoid the traffic control signal.
♦ Increases the frequency of certain types of collisions (especially rear-end collisions).

Need for Traffic Control Signal

Traffic signals assign right of way to various traffic movements, which result in significant influence on traffic flow and on the vehicles and pedestrian traffic that they control. Therefore, it is important that the selection and use of such an important traffic control device be preceded by a thorough engineering study of roadway and traffic conditions.

A traffic study consists of a comprehensive investigation of existing physical and operating conditions. Details on the information required for a study and how to obtain the data are contained in Chapter 3 of the TxDOT *Traffic Signal Manual*[3] <link> and in Section 4C.01 of the *TMUTCD*[1] <link>.

The investigation of the need for a traffic control signal shall include an analysis of the applicable factors contained in the traffic signal warrants. The warrants are presented in the

TMUTCD[1] <link>. These warrants are minimum conditions that justify signal installations. Traffic signals should not be installed at any location unless one (or more) of the signal warrants is satisfied. Signals may be warranted at locations based on estimated traffic volumes associated with a new development, like an entrance to a new regional shopping mall. However, if traffic conditions at an intersection meet warranting criteria, traffic signals do ***not*** have to be installed at that location. Engineering judgment must be used to determine if traffic signal installations are both justified and appropriate.

Plan Requirement for PS&E

Information on the paperwork that needs to be submitted with a plans, specifications, and estimates package is in the *Plans, Specifications, and Estimates Preparation Manual*[4] <link>.

Depending on the type and size of a project, some of the sheets may be combined or eliminated in specific PS&E packages. Following is the list of sheets generally included in a PS&E submission for a traffic signal:

- Title Sheet
- Estimate and Quantity Sheet
- Condition Diagram Sheet
- Plan Sheet
  - Existing geometry and adjacent development
  - Existing traffic control
  - Existing utilities
  - Existing right of way
  - Proposed highway improvements
  - Proposed installation including the proposed location of all major items of equipment; such as poles, foundations, luminaries, conduits, signal heads and faces, ground (or pull) boxes, detectors, controllers, etc.
  - Proposed additional traffic control such as striping, stop lines, signs, etc.
- Elevation Sheet
  - Traffic signal elevation sheets
  - Utilities elevation sheets
- Standard sheets or special detail sheets should include sufficient detail on the following:
  - Poles
  - Ground box
  - Wiring diagrams
  - Conduit and conductor tables
  - Detectors
  - Concrete foundations

- Power source
- Roadway illumination
- Down-guys
- Vehicle and pedestrian signal head mounting details
- Phasing sheet
- Work area protection
- Traffic control plan

TxDOT maintains the standard sheets on their Web site.[5]

Section 2
Signal Faces

Overview

The portion of the traffic signal that is most visible to the motorists and pedestrians is the signal head. The signal head is an assembly that generally is mounted over the traffic lanes or adjacent to the roadway that contains the displays for controlling which traffic stream enters the intersection. The different elements of a signal head are shown in Figure 8-1. A signal head is composed of different signal sections, with each signal section consisting of a housing, a signal lens, and a light source. Each signal section contains one of the signal indications displayed at an intersection; either a "ball" or "arrow" indication. The portion of the signal head that faces traffic and displays the indications to drivers and pedestrians is called the signal face.

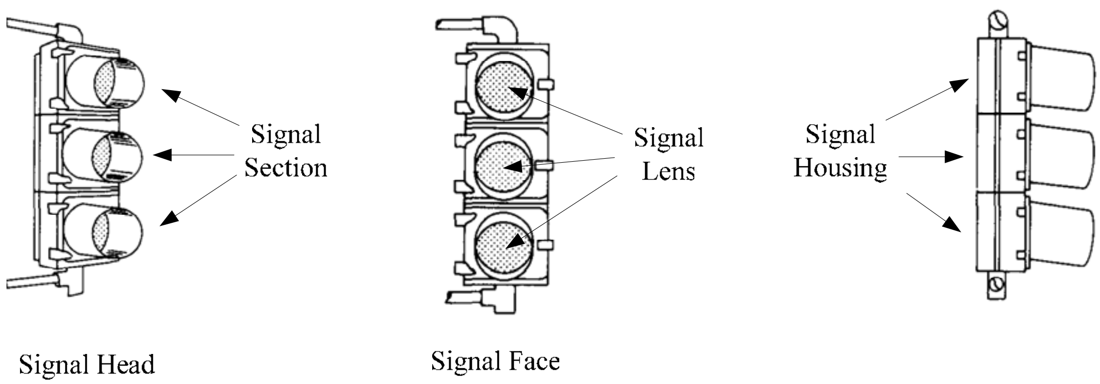


Figure 8-1. Components of a Three-Section Traffic Signal Head.

The purpose of signal heads is to convey clear and concise information to drivers, enabling them to make proper decisions and to take appropriate action. Signal heads must be designed and installed with uniform size, color, arrangement, and placement. The *TMUTCD*[1] specifies the signal requirements for each approach to an intersection or a midblock location. The user should consult the *TMUTCD* for the specific details.

Size of Vehicular Signal Lenses

The *TMUTCD* allows two sizes of vehicular signal lenses: 8 inch [203 mm] and 12 inch [305 mm]. Section 4D.15 of the *TMUTCD* provides specific situations where a 12 inch signal lens is to be used, as well as guidance where use of 12 inch signal lenses is recommended. In general, 12 inch lenses are installed at all new signalized locations, and they are required at intersections that have the following characteristics:

- one (or more) high-speed approach having vehicular speeds greater than 40 mph [64 km/h];
- additional visibility is needed because:
  - the signal is unexpected by motorists,
  - the signal location is isolated (especially in a rural area),

- the intersection is very wide, or
- there is a mixture of signal indications (i.e., arrow indications or lane-use control signals);

- ♦ limited sight distance exists on one or more of the approaches; or
- ♦ older drivers constitute a significant percentage of the driving population.

In some cases, different sizes of signal lenses may be used in the same signal face, but this practice is not encouraged.

Type and Number of Signal Faces

Following are requirements for the type and number of signal faces:

- ♦ A minimum of two signal faces is required for the major movement on the approach, even if the major movement is a turning movement. The two signal faces should be visible continuously from a point at least the minimum sight distance indicated in Table 8-2 in advance of and measured to the stop line.
- ♦ Left-turn signal faces are determined by the left-turn phasing selected (permissive only, protected only, or protected/permissive).
- ♦ Right-turn signal faces are determined by the right-turn phasing selected (permissive only, protected only, protected/permissive, or variable right-turn).
- ♦ If two or more right-turn lanes are provided for a separately controlled right-turn movement, or if a right-turn movement represents the major movement from an approach, two right-turn signal faces should be provided.
- ♦ Supplemental signal faces should be used if engineering judgment has shown that they are needed to provide adequate signal head visibility in advance of the signalized location. If supplemental signal faces are used, they should be located to provide optimum visibility for the movement to be controlled. ***Application 8-1*** <link> describes a situation where supplemental signals were used.

Table 8-2. Minimum Sight Distance Requirements.[1]

US Customary		Metric	
85th Percentile Speed (mph)	**Minimum Sight Distance (ft)**	**85th Percentile Speed (km/h)**	**Minimum Sight Distance (m)**
20	175	30	50
25	215	40	65
30	270	50	85
35	325	60	110
40	390	70	140
45	460	80	165
50	540	90	195
55	625	100	220
60	715		

Location of Signal Faces

Following is an overview of appropriate locations of signal faces. The designer should refer to the *TMUTCD*[1] for specific details.

- At least one and preferably both signal faces should be located at:
  - not less than 40 ft [12 m] beyond the stop line;
  - not more than 120 ft [37 m] beyond the stop line if 8-inch signal lenses are used, unless a supplemental near-side signal face is provided;
  - not more than 150 ft [46 m] beyond the stop line if 8-inch signal lenses are used and a supplemental near-side signal face is provided;
  - not more than 180 ft [55 m] beyond the stop line if 12-inch signal lenses are used, unless a supplemental near-side signal face is provided; and
  - as near as practical to the line of the driver's normal view, if mounted over the roadway.
- The Federal MUTCD[6] summarizes the horizontal location of signal face as shown in Figure 8-2.
- Required signal faces for through traffic on any one approach are to be located not less than 8 ft [2.4 m] apart when measured horizontally perpendicular to the approach between the centers of the signal faces.
- If supplemental signal faces are used, then left-turn arrows are not used in near-right signal faces and right-turn arrows are not used in far-left signal faces. A farside, median-mounted signal face is considered a far-left signal for this application.

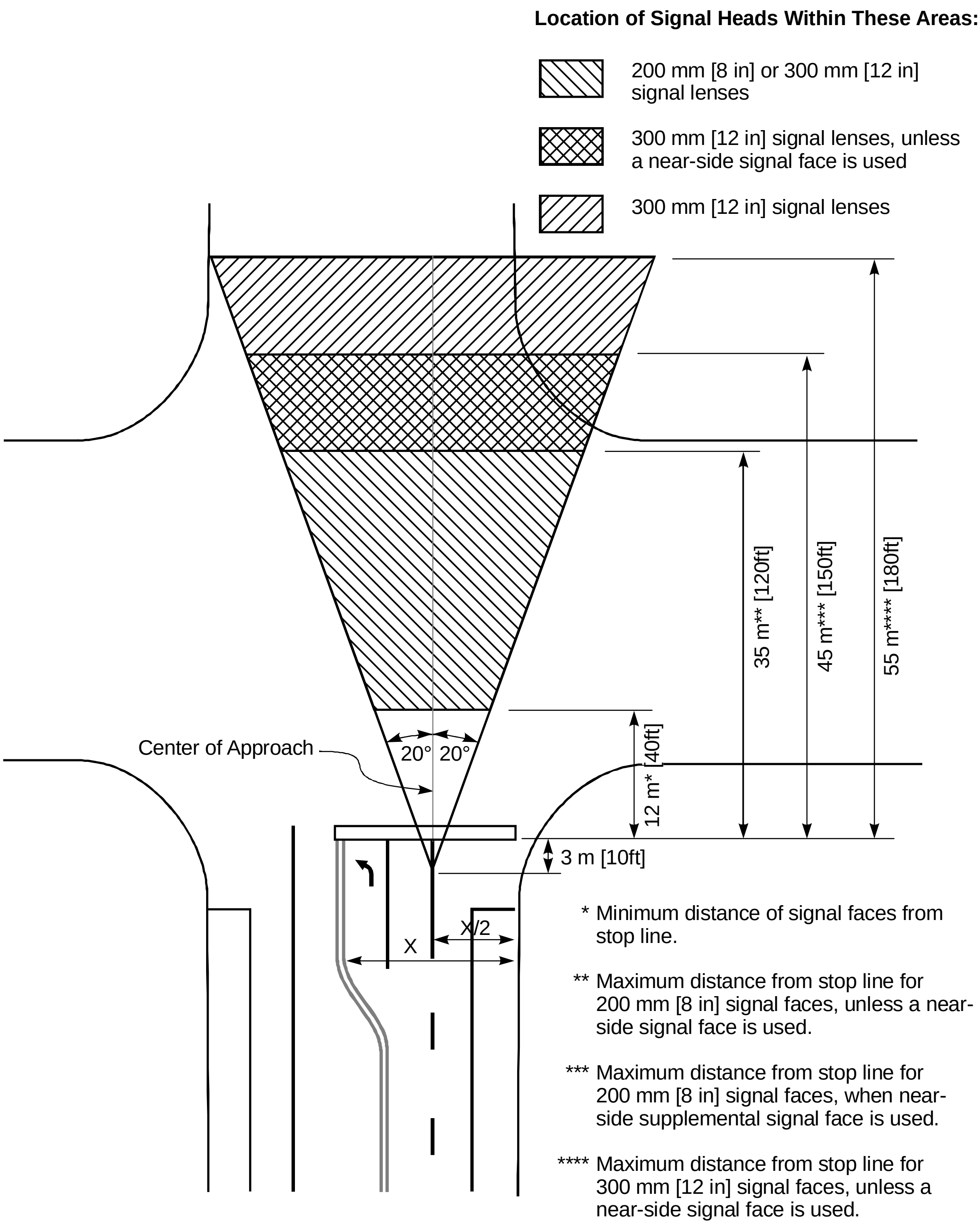


Figure 8-2. Federal MUTCD Horizontal Location of Signal Faces.[6]

Visibility of Signal Indications

Visibility of signal indications to approaching vehicles is the primary consideration in signal head placement, aiming, and adjustment. In general, the signal face(s) for through traffic should be aimed to give the approaching driver as much opportunity as practicable to see the signal indications in advance of the stop line. Where grades, curves, or obstructions exist (bridge beams, overhead sign bridges, etc.), special care must be taken to ensure that drivers have an opportunity to respond to the signal indication in a safe manner. Minimum sight distances are shown in Table 8-2.

Several problem areas can affect or degrade the visibility of signal indications. Following are known problem areas and potential solutions.

Sun Phantom. During periods of direct sunlight on the signal face, the driver may have difficulty determining which signal indication is actually illuminated because all appear to have the same intensity. Methods to reduce or eliminate this problem include:

- using louvers and visors to aid in directing the signal indication specifically to approaching traffic,
- careful aiming of the signal head,
- providing alternate illumination methods (e.g., fiber optic, neon),
- adding backplates, and
- installing supplementary signal heads if at different viewing angle.

Background Interference. When viewed against a bright background sky or background lighting such as intensive advertising displays, signal indications may lose a part of their contrast value and conspicuity. The signal indication may become lost in the midst of such visual clutter. The placement of a signal backplate will enhance signal conspicuity.

Backplates make it easier for the motorist to distinguish traffic signal displays from tree or sky background (see Figure 8-3). The use of backplates enhances the contrast between the traffic signals and their surroundings for both day and night conditions, which is also helpful to older drivers. While a backplate would be helpful at any signal, areas of greatest need include:

- east-west approaches that experience sun glare, and
- any direction for a high-speed approach.

Because backplates add considerable wind loading to traffic signals, it is not considered feasible to place a backplate on a signal that is suspended by a single span wire. This problem can be overcome by installing a second span wire attached to the bottom of the signal. Backplates can attach easily to signals installed on mast arms.

Figure 8-3. Example of Signal Backplates.

Conflicting Signals. The *TMUTCD*[1] notes that “In cases where irregular street design necessitates placing signal faces for different street approaches with a comparatively small angle between their respective signal lenses, each signal lens shall, to the extent practical, be shielded or directed by signal visors, signal louvers, or other means so that an approaching road user can see only the signal lens(es) controlling the movements on the road user’s approach.” The driver needs a clear view of signal indications to avoid confusion. For example, a driver in a through lane with a green ball display may become confused if confronted with a clear view of a red ball display for an adjacent left-turn lane. Another common example is found where closely spaced adjacent intersections are both signalized. The traffic signal located at the downstream intersection may encourage motorists from the upstream intersection to move forward in response to two “green” indications when the upstream intersection approach has two “red” indications. Signal head placement, shielding, or optical programming can reduce this problem. Special signal faces, such as visibility-limited signal faces, have been used such that the road user does not see signal indications intended for other approaches before seeing the signal indications for their own approach, if simultaneous viewing of both signal indications could cause the road user to be misdirected.

Glare. Signal indications that perform effectively during daylight hours are sometimes too intense at night, creating undesirable glare. Automatic dimming devices can reduce the brilliance of the signal.

Vertical Placement

The *TMUTCD* establishes minimum and maximum vertical clearances for both the bottom and top of the signal housing at an intersection, respectively. The bottom of the signal housing located over a roadway (including the brackets and any related attachments) must be a minimum of 15 ft [4.6 m] above the pavement, while the top of the housing should not be located more that 25.6 ft [7.8 m] above the pavement. The TxDOT Traffic Control Standard Sheets provide illustrations of vertical placement requirements.[5]

Section 3
Signal Support Systems

Overview

There are two primary locations for mounting traffic signal heads at an intersection:

- beside the travel way with a post-top mounting and
- over the travel way with an overhead mounting, using span wires or poles with mast arms.

The five primary design considerations in selecting the type of mounting to be used are:

- conspicuity of the signal face,
- consistency of signal face locations along the corridor,
- clarity of message,
- safety of the road users, and
- minimized obstructions for pedestrians.

Post-Mounted Signal Systems

The basic configuration for post-mounted signals is shown in Figure 8-4. This is the typical configuration found in central business districts where numerous intersections are signalized, one-way streets are common, and the use of overhead installations create a "cluttered" environment. This type of design also is found in older sections of cities where streets and rights of way are narrow.

As streets become wider and curb returns become longer, the use of post-mounted signals become less desirable, especially when the streets allow two-way traffic. As shown in Figure 8-5, an attempt to provide signal heads within the cone of vision required by the *TMUTCD* (20 degrees from the center of the approach) with adequate separation between the two signal heads becomes more difficult. (The solid arrows in Figure 8-4 and Figure 8-5 indicate the location of signal heads and directions the heads are facing.)

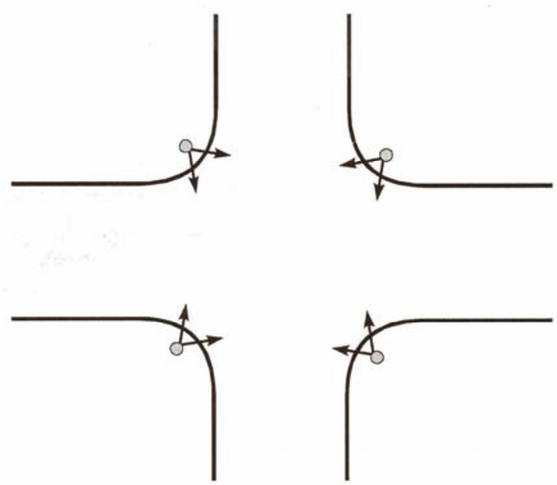


Figure 8-4. Post-Mounted Signals.[7]

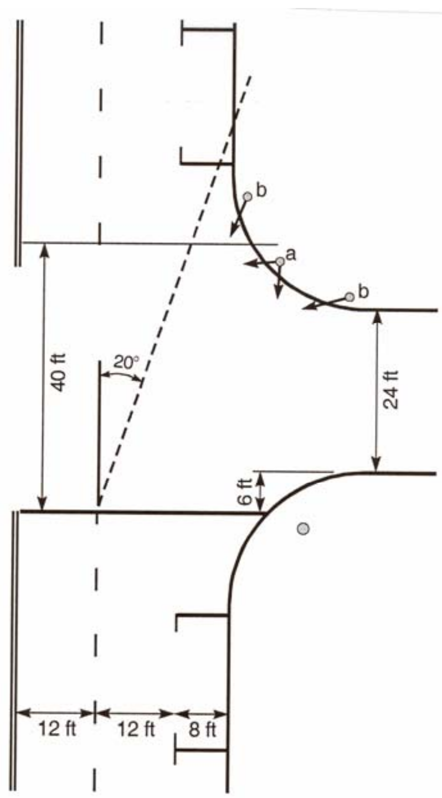


Figure 8-5. Potential Sign Conspicuity Problems with Side-Mounted Signals.[7]

Post-mounted signal installations may create design or operational concerns that include the following:

- Under normal conditions, especially where four-lane streets intersect narrow streets, it is difficult to meet the minimum distance requirements (40 ft [12.2 m]) of the *TMUTCD.*
- The signal heads are consistently near or outside the limits of the desirable cone of vision, even where minimum distance requirements can be met. The signal faces are,

therefore, in less conspicuous positions than if they were closer to the center of the cone.

- Where a curb return has a radius of over 10 ft [3 m], consideration should be given to using the two-post design, as shown in Figure 8-5. This will reduce the distance of a signal head from the center of the approach and increase its distance from the stop line.
- Because of the potential conspicuity problem with post-mounted signals as primary indications, each signal head location, the cone of vision, and the minimum distances should be plotted on a sketch before final design is selected to ensure that minimum distance requirements can be met.
- Moving the stop line further back from the approach or adding a crosswalk may bring the signal head within the cone of vision and may satisfy minimum distance requirements.
- In commercial areas, buildings may contain lighted displays or multicolor-lighted advertising signs that compete with the signal display and distract motorist attention. This is particularly critical at night. Although the signal face may be visible, it may not be sufficiently conspicuous to capture the driver’s attention if it is located at the edge of the driver’s cone of vision.

In view of the potential conspicuity problem, post-mounted signal heads as primary indications should only be allowed on narrow approaches with relatively low travel speeds.

If post-mounted signal heads are selected for installation at an intersection, the designers should:

- Locate support posts so they do not conflict with curb ramps, landings, and sidewalks.
- Minimize the use of median-mounted traffic signal supports posts.
- Install median-mounted traffic signal support posts only in medians 5 ft [1.5 m] (or greater) in width to maintain a 2-ft [0.6 m] clearance on each side of the signal head.
- Provide breakaway design for any traffic signal support posts mounted in the median.
- Verify visibility of the signal faces where vertical or horizontal curves affect the motorist’s view of the approach to the intersection.

Span Wire Traffic Signal Installations

There are a variety of ways to install the poles and span wires. The more common are:

- two-pole simple span and
- box span.

Two-Pole Simple Span. In the two-pole simple span, poles should be installed on the far right corners of the major roadway approaches as shown in Figure 8-6. Installing the poles on the far right of the major or wider approaches affords the best opportunity for meeting the requirement for minimum distance from the stop line. A potential challenge with this design is the location of the poles with respect to the curb ramps. Similar to post-mounted signal heads, it is difficult to meet the minimum sight distance requirement to signal faces at intersections with minor roadways, however overall conspicuity is markedly improved. This type of installation is generally used as a temporary application and not used in a permanent setting.

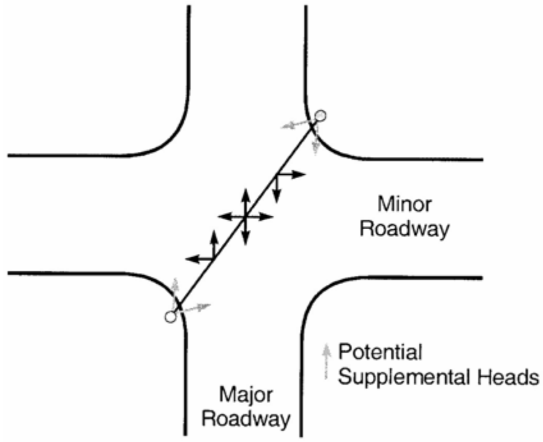


Figure 8-6. Span Wire Mounting: Two-Pole Simple Span.[7]

Box Span. The box span uses four poles at the intersection corners with the span wire stretched between the poles to "box in" the intersection. Figure 8-7 shows a typical box-span layout. Signal faces are placed over the roadway on the far side of each approach. The box span permits the same flexibility in locating the signal heads with respect to approach lanes, as does the simple span, while overcoming the problems of requirements for minimum distance from the stop line.

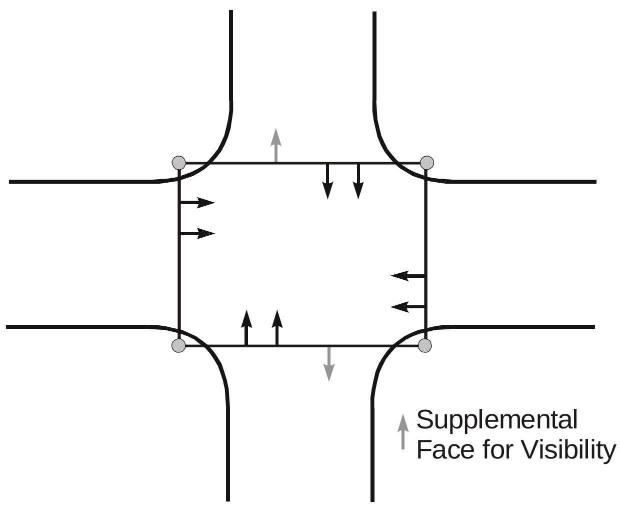


Figure 8-7. Span Wire Mounting: Box Span.[7]

A variety of signal phasing and pedestrian signal head requirements can be accommodated using the box-span concept.

The box span may have problems when applied to offset intersections or extremely wide intersections. It may be necessary to locate poles in odd locations or add additional poles to create a variety of angles to ensure that signals are visible and are located less than 120 ft [37 m] from the stop line if 8 inch lenses are used or less than 150 ft [46 m] from the stop line if 12-inch lenses are used. Where these conditions exist, consideration should be given to suspending a span wire "box" using connector span wires to the poles. This balances pole loading and permits signal faces to be moved toward the approaches. Figure 8-8 shows a typical application of this modified box-span concept.

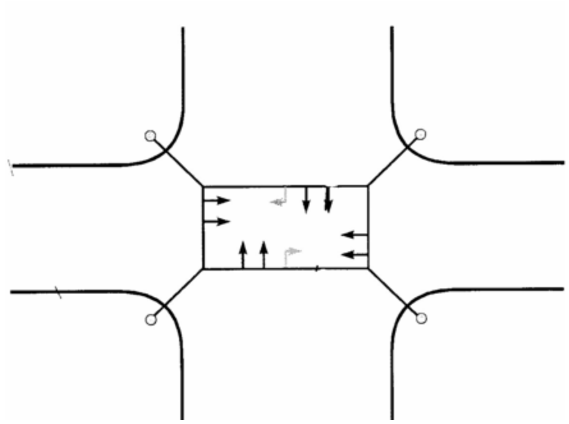


Figure 8-8. Span Wire Mounting: Cable Box.[7]

Mast Arm Signal Head Installations

Mast arm signal head mounting provides a means of installing some or all of the signal heads overhead, without span wire or overhead signal wiring. Mast arm mounting also can be easily used with post-mounted signals to meet all general visibility and clarity requirements.

Figure 8-9 and Figure 8-10 show the two distinct types of simple mast arm installations. In the first, the primary face is placed overhead and can be located to provide maximum conspicuity. The second head is mounted at a lower height on the pole itself and is easily seen from a stop bar position. The second type places both faces overhead in a primary sight line. Either type meets *TMUTCD* requirements.

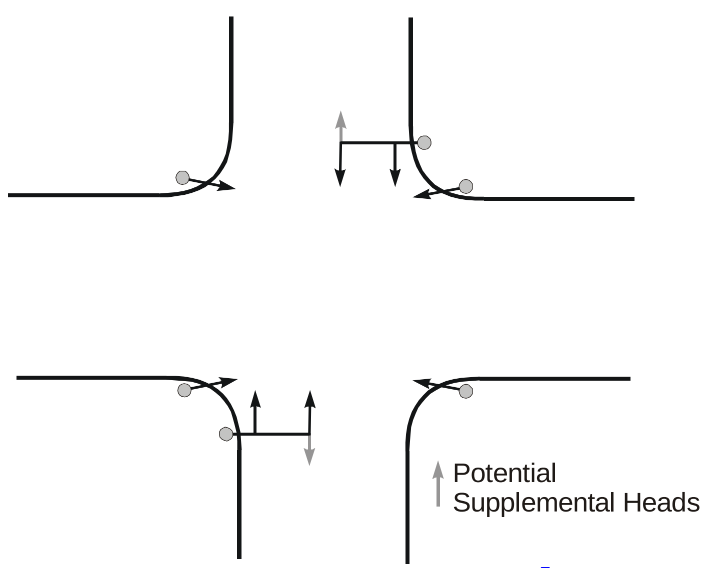


Figure 8-9. Typical Mast Arm Mounting.[7]

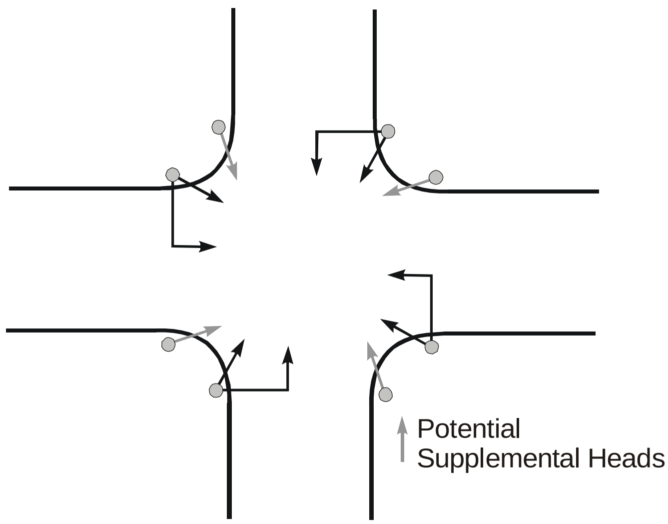


Figure 8-10. Mast Arm Mounting with Post-Mounted Signals.[7]

If roadway widths are narrow, or if opposite approaches are slightly offset, or intersections with one-way streets (including frontage roads), two mast arms may be mounted on the same pole. Generally, this type of installation is not found at wide intersections. The advantage of installing two mast arms on a single pole is the cost savings associated with fewer pole (and foundation) installations.

As intersection approach widths increase, and as mast arms are lengthened to reach the desired point in the approach, cost may become a factor. A mast arm is a simple cantilever structure and increased loadings on the mast arm (both static and dynamic) caused by longer mast arms may require substantially stronger signal poles, stronger mast arms, and larger foundations. Mast arm lengths up to 60 ft [18 m] are common, and longer mast arms are available. Designers should consider a signal bridge where long mast arms are required.

Advantages and Disadvantages

Table 8-3 lists advantages and disadvantages of the various signal support systems.

Table 8-3. Advantages and Disadvantages of Signal Support Systems (Based on Information in *Traffic Engineering Handbook*).[7]

Advantages	Disadvantages
Post-Mounted	
♦ low installation costs, ♦ generally considered most aesthetically acceptable, ♦ provide good visibility where there are wide medians with left-turn lanes and protected phasing exists, and ♦ unlimited vertical clearance for the roadway.	♦ require underground wiring that may offset initial cost advantages, ♦ may not provide locations that meet minimum conspicuity requirements, ♦ may not provide mounting locations such that a signal face with clear meaning is provided, ♦ can have height limitations that may provide problems at an approach on a vertical curve, and ♦ are subject to vehicular impact if installed close to the roadway particularly in medians.
Span Wire	
♦ low installation costs, ♦ minimum number of poles to clutter sidewalk area, ♦ ease of installation with little or no underground work required, ♦ ability to combine with utility poles, ♦ capability for good lateral placement of signal heads for maximum conspicuity, and ♦ ability to use long spans so that poles may be placed outside the clear zone.	♦ poor signal head locations with respect to the stop bar for small minor roadways; ♦ sometimes considered aesthetically objectionable because of signal head clutter over the roadway; and ♦ poor pedestrian visibility of signal faces.
Box Span	
♦ easy installation with little or no underground work; ♦ allowance of excellent lateral placement of signal faces for maximum conspicuity; ♦ allowance of good signal placement with respect to the stop bar; ♦ substantially lower span length and loading than with the simple two-pole span; ♦ convenient pole locations for supplemental signal heads, pedestrian signal heads, and pedestrian detectors; and ♦ ability to use “internal boxes” to reduce signal head to stop bar distance at extremely wide intersections.	♦ requirement of four posts, which is more costly installation than simple span design, ♦ addition of two poles to intersection clutter, and ♦ can be seen as aesthetically unpleasing, as with all span wire mount.
Mast Arm	
♦ allowance of excellent lateral placement and placement relative to the stop bar for maximum conspicuity; ♦ potential to provide post locations for supplementary signals or pedestrian signal heads and pedestrian push buttons; ♦ generally accepted as the most aesthetically pleasing method for installing overhead signals, particularly in developed areas; ♦ rigid mountings provide the most positive control of signal movement in wind; and ♦ provides rigid platform for Video Imaging Vehicle Detection System (VIVDS) installation.	♦ generally the highest purchase and installation costs, ♦ proper placement of signal heads may be difficult on very wide approaches, and ♦ it may be difficult to keep the mounting poles out of the clear zone on very wide approaches.

Pole Placement

The primary safety concern regarding signal supports is pole placement. Poles should be located:

- as far away from the roadway as practical or
- behind existing traffic barriers.

Locating and placing signal foundations often is difficult due to existing underground utilities, especially when unexpected utilities are found during construction.

The TxDOT *Roadway Design Manual*[8] notes that because of the need for specific placement to assist traffic operations, devices such as traffic signal supports, railroad signal/warning device supports, and controller cabinets are excluded from horizontal clearance requirements. However, these devices should be located as far from the travel lanes as practical. Other non-breakaway devices should be located outside the prescribed horizontal clearances or these devices should be protected with a barrier. Chapter 5, Section 2 <link> provides additional information on horizontal clearance.

Particular design care is needed in areas:

- with high-speed traffic,
- without shoulders or parking lanes,
- on the outside of a curve, or
- that feature heavy turning movements.

Additionally, the following items should be considered when placing signal supports and cabinets:

- Signal supports should be placed as far as practical from the edge of the traveled way without adversely affecting the visibility of the signal indications.
- The signal support or controller cabinet should not obstruct the sidewalk or pedestrian access from the sidewalk to the crosswalk.
- The signal housing and other equipment should not protrude more than 4 inches [102 mm] into the pedestrian area if located between 27 and 80 inches [686 and 2032 mm] above the surface. Refer to TxDOT PED Standard Sheet for more information.[9]
- Pole supports for overhead signal installations should not be placed in medians due to increased chance of being hit and potential for interference with crossing pedestrians.

References that provide additional considerations on pole placement include the following:

- American Association of State Highway and Transportation Officials *Roadside Design Guide*,[10]
- The *Americans with Disabilities Act Accessibility Guidelines,*[11] and
- The Texas Accessibility Standards.[12]

Application 8-2 <link> discusses issues considered during the development of a signal design for an intersection.

Intersection Design Considerations for Traffic Signal Accommodation

According to the *TMUTCD*, traffic signals must be warranted before they are installed at an intersection. Therefore, most traffic signal installations are constructed after an intersection has been designed and constructed. Many traffic signals are installed at intersections that have long operated with Stop sign control, but because of increased traffic volumes, Stop signs are no longer adequate to provide efficient and safe operations.

There is little doubt, however, that intersections of two urban arterials will eventually be signalized. Also, there are other intersections identified by traffic engineers as eventually needing traffic signals at some time in the future. If the designer of an intersection recognizes that the intersection being designed likely will be signalized, there are design features that can be incorporated into the geometric design of the intersection that will expedite or assist in the eventual installation of traffic signals. These design features to consider include the following:

- right of way that accommodates the following:
  - anticipated underground supports for the ultimate location of the support poles (especially if long length mast arms will be the ultimate design for the signal),
  - desired clearance to the ground-mounted controller, and
  - sidewalk location including how the signal supports and controller will affect the design near the intersection;
- underground conduit that preserves the space for signal wiring and that fits within existing utilities; and
- placement of underground utilities so that adequate space is reserved for signal pole foundations.

Application 8-3 <link> discusses a situation where the anticipated signal at an intersection is considered.

Section 4
Signal Cabinet Placement

Overview

There are three basic categories of controller cabinets (see Figure 8-11):

- pole-mounted,
- pedestal-mounted, and
- base-mounted.

Cabinets are constructed primarily of sheet aluminum or steel, and the style and size depend on the type and amount of equipment needed for the signalized location. Where mounting space is limited, such as on a narrow sidewalk, two small cabinets may be used in place of a single large cabinet. Accessory cabinets, usually smaller in size, may house an overflow of components where mounting space is at a premium or where later alterations of operation require more equipment space.[7]

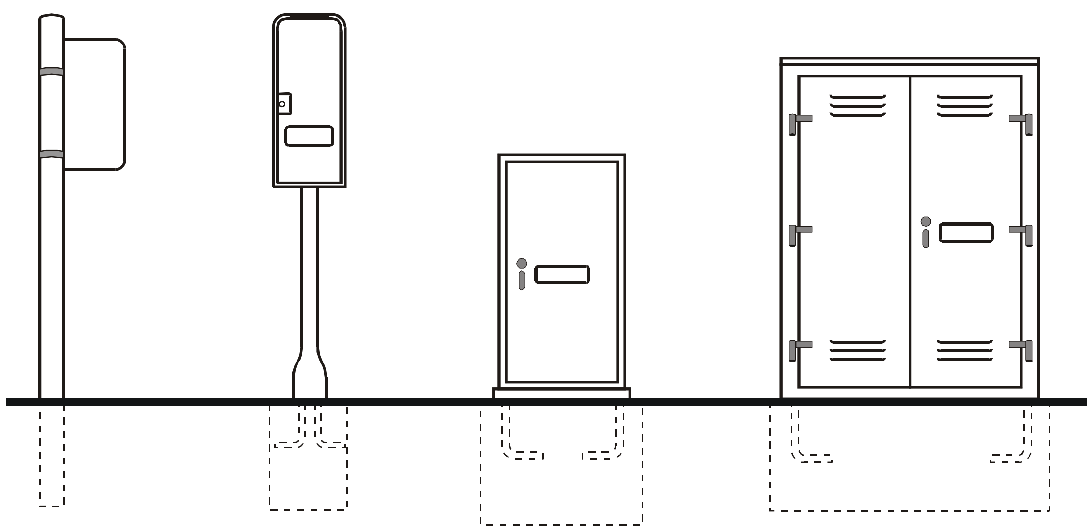


Figure 8-11. Types of Controller Cabinet Mountings.[7]

Cabinet Placement

Reference should be made to the following documents when placing a cabinet:

- AASHTO *Roadside Design Guide*[10],
- TxDOT PED Standard Sheet[9],
- U.S. Access Board *Americans with Disabilities Act Accessibility Guidelines*[11],
- U.S. Access Board *Draft Guidelines for Accessible Public Rights-of-Way,*[13] *and*
- Texas Accessibility Standards.[12]

Additionally, the following items should be considered when placing signal supports and cabinets.

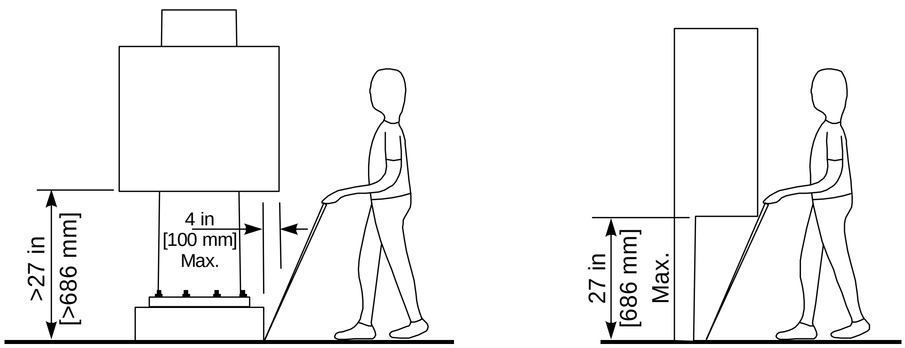
The cabinet should be placed:

- where it is not likely to be damaged by errant vehicles;
- where it is easily accessible by maintenance staff;
- in a location to provide a good view of the entire intersection;
- near a power source;
- where it will not be in conflict with pedestrians, bicyclists, or other road users;
- so that the front door faces away from the intersection to give technicians the clearest view of the approaches;
- in a well-drained area; and
- to minimize sight obstructions for vehicles making right turn on red.

Where a sidewalk does not exist, there should be a paved pad on which the technicians can stand while working on the equipment.

The cabinet should *not*:

- restrict sidewalk areas,
- impede access to curb ramps and sidewalks,
- be located near the curb return or on channelization islands, or
- protrude more than 4 inches [102 mm] from the base support into a pedestrian area (see Figure 8-12 for an example of additional curb or foundation to provide the maximum 4 inch [102 mm] overhang).



When an obstruction of a height greater than 27 in [686 mm] from the surface would create a protrusion of more than 4 in [100 mm] into the pedestrian circulation area, construct additional curb or foundation at the bottom to provide a maximum 4 in [100 mm] overhang.

Protruding objects of a height less than or equal to 27 in [686 mm] are detectable and do not require additional treatment.

Figure 8-12. Detection Barrier for Vertical Clearance < 80 inches [2032 mm]. [9]

Section 5
Pedestrian Signals

Overview

Pedestrian signal heads provide special types of traffic signal indications exclusively intended for controlling pedestrian traffic. These signal indications consist of the illuminated symbols of:

- A WALKING PERSON, symbolizing WALK, and
- An UPRAISED HAND, symbolizing DON'T WALK.

The need for separate pedestrian signal heads and accessible pedestrian signals should be determined by engineering judgment, and meet the requirements of the accessibility guidelines.[9,11,12]

Use of Pedestrian Signal Heads

The *TMUTCD*[1] states that pedestrian signal heads should be used under any of the following conditions:

- if it is necessary to assist pedestrians in making a safe crossing or if engineering judgment determines that pedestrian signal heads are justified to minimize vehicle-pedestrian conflicts;
- if pedestrians are permitted to cross a portion of a street, such as to or from a median of sufficient width for pedestrians to wait, during a particular interval but are not permitted to cross the remainder of the street during any part of the same interval; and/or
- if no vehicular signal indications are visible to pedestrians, or if the vehicular signal indications that are visible to pedestrians starting or continuing a crossing provide insufficient guidance for them to decide when it is safe to cross, such as on one-way streets, at T-intersections, or at multiphase signal operations. [Note, the 2003 MUTCD[6] has added the word "reasonably" before safe in this condition.]

Size, Location, and Height of Pedestrian Signal Heads

Pedestrian signal indications should be conspicuous and recognizable to pedestrians at all distances from the beginning of the controlled crosswalk to a point 10 ft [3 m] from the end of the controlled crosswalk during both day and night. Pedestrian signal heads are to be positioned and adjusted to provide maximum visibility at the beginning of the controlled crosswalk.

TxDOT requires that pedestrian signals have visors so that the sign is not readily visible outside of the crosswalk. (This helps encourage more pedestrians to cross in the crosswalks.) Pedestrian signal locations should be designed so that pedestrians will have a clear view of the signals as they reach the intersection. After the pedestrian signals are installed, each crosswalk should be inspected to ensure that traffic signs, trees, utility poles, and other obstacles do not block the view of the signal indication. It may be advisable to install pedestrian signals in the medians on wide streets, particularly where there are high numbers of older or visually impaired pedestrians.

Pedestrian Push Button Detectors

When pedestrian actuation is used, pedestrian push button detectors should be:

- easy to use;
- conveniently located near each end of the crosswalk, and in close proximity to the curb ramp landing; and
- fully accessible to disabled pedestrians.

Pedestrian Push Button

Signs. Signs are to be mounted adjacent to or integral with pedestrian push button detectors, explaining their purpose and use. The *TMUTCD* identifies signs that may be used. At certain locations, a sign in a more visible location may be used to call attention to the pedestrian push button. Push buttons should clearly indicate which crosswalk signal is actuated by each push button. The ADAAG draft rule[11] includes the following proposed requirements:

- Pedestrian signal devices will provide tactile and visual signs on the face of the device or its housing or mounting indicating crosswalk direction and the name of the street containing the crosswalk served by the pedestrian signal. Additional requirements for the signs included in the draft rule are:
  - Signs are to include a tactile arrow aligned parallel to the crosswalk direction (the draft ADAAG provides minimum dimensions).
  - Signs are to include street name information aligned parallel to the crosswalk.
  - Where provided, graphic indication of crosswalk configuration will be tactile.

Two Crosswalks. If two crosswalks, oriented in different directions, end at or near the same location, the positioning of pedestrian detectors and/or the legends on the pedestrian detector signs should clearly indicate which crosswalk signal is actuated by each pedestrian detector. At signalized intersections with accessible pedestrian signals where two pedestrian push buttons are provided, the push buttons should be separated by a distance of at least 10 ft [3 m]. This enables pedestrians who have visual disabilities to distinguish and locate the appropriate push button.

Additional Pedestrian Detectors. If the pedestrian clearance time is sufficient only to cross from the curb or shoulder to a median having sufficient width for pedestrian storage, and the signals are pedestrian actuated, an additional accessible pedestrian detector shall be provided in the median. The use of additional pedestrian detectors on islands or medians where a pedestrian might become stranded should be considered.

Mounting Height. Pedestrian push buttons should be installed at a mounting height of approximately 42 inches [1.1 m] maximum above the sidewalk.

Illumination. If used, a pilot light or other means of detection indication installed with a pedestrian push button should not be illuminated until actuation. Once it is actuated, it should remain illuminated until the pedestrian's green or WALKING PERSON (symbolizing WALK) signal indication is displayed.

Accessible Pedestrian Signals. Information on characteristics of a pedestrian push button for an accessible pedestrian signal installation is included in the following section on accessible pedestrian signals <link>.

Size and Contrast. Push buttons and tactile arrows should be 2 inches [51 mm] across, and have high visual contrast. Tactile arrows should point in the same direction as the associated crosswalk.[11]

Wheelchair Detectors

Wheelchair detectors have been shown to be beneficial in areas where a significant number of powered wheelchair users are found. An inductive loop may be used for this purpose if it is designed so that both of the wheels of most wheelchairs will be on top of, or nearly on top of, the loop wires. Microwave, ultrasonic, and mat detectors also may be used as detectors.

Accessible Pedestrian Signals

Accessible pedestrian signals (APSs) provide information in non-visual format (such as audible tones, verbal messages, and/or vibrating surfaces). When used, accessible pedestrian signals are to be used in combination with pedestrian signal timing and comply with the TAS.[12]

Installation. The *TMUTCD* notes that installation of accessible pedestrian signals at signalized intersections should be based on an engineering study, which should consider the following factors:

- potential demand for accessible pedestrian signals;
- a request for accessible pedestrian signals;
- traffic volumes during times when pedestrians might be present, including periods of low traffic volumes or high right-turn-on-red volumes;
- complexity of traffic signal phasing; and
- complexity of intersection geometry.

In addition, accessible pedestrian signals may be required by ADAAG in the future at all new or updated pedestrian signal installations, or when existing traffic signal installations are upgraded.

Activations. At accessible pedestrian signal locations with pedestrian actuation, each push button shall activate both the walk interval and the accessible pedestrian signals.

Push Button Location. Push buttons for accessible pedestrian signals should be located as follows:

- adjacent to a level all-weather surface, accessible to a wheelchair occupant and connected to an accessible route to the curb ramp;
- within 5 ft [1.5 m] of the crosswalk extended;
- within 10 ft [3 m] of the edge of the curb, shoulder, or pavement; and
- parallel to the crosswalk to be used.

Figure 8-13 illustrates an example of a placement for push buttons. This placement allows someone needing the vibrotactile information regarding the crossing signal to have that available while remaining lined up and ready to cross. A disadvantage of this placement is that a wheelchair could have wheels on the curb ramp when accessing the push button. Each intersection has unique elements and designers should consider the best location for push buttons for the specific geometrics at each corner, with emphasis on convenience for visually disabled pedestrians and also those with mobility impairments.

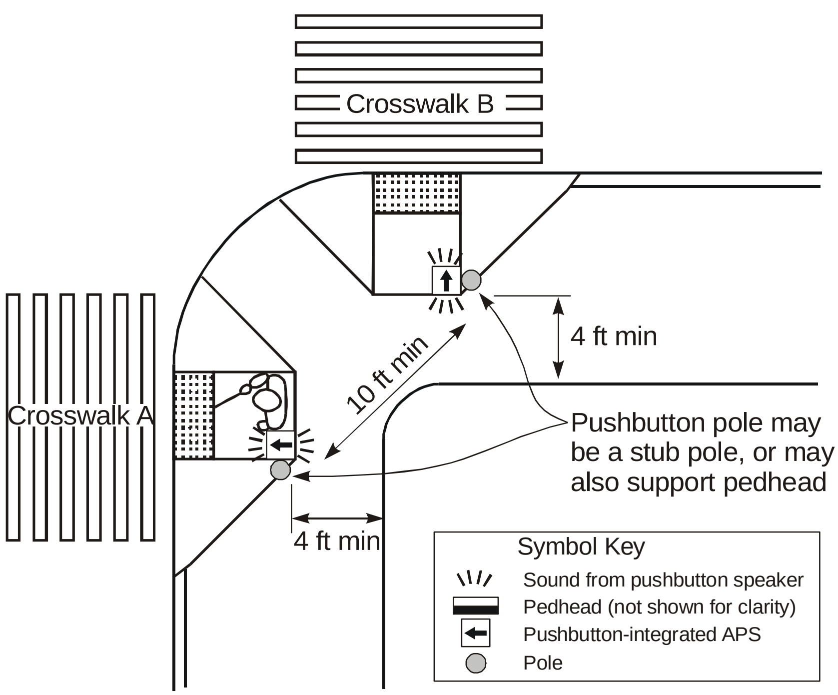


Figure 8-13. Recommended Placement for Pedestrian Push Buttons — Integrated APS in New Construction.[14]

Locator Tone. A push button locator tone is a repeating sound that informs approaching pedestrians that they are required to push a button to actuate pedestrian timing and that enables visually impaired pedestrians to locate the push button.

Audible Tones. Audible tones are sounds that inform a pedestrian that the "WALK" indication has been illuminated. Audible pedestrian tones should be carefully selected to avoid misleading pedestrians who have visual disabilities.

According to the *TMUTCD*, when accessible pedestrian signals have an audible tone(s), they should have a specific tone for the walk interval, and be audible from the beginning of the associated crosswalk. If the tone for the walk interval is similar to the push button locator tone, the walk interval should have a faster repetition rate than the associated push button locator tone. The accessible walk signal tone should be no louder than the locator tone, except when there is optional activation to provide a louder signal tone for a single pedestrian phase. Accessible pedestrian signals that provide verbal messages may provide similar messages in languages other than English. Verbal messages can provide a visually impaired pedestrian with the same key information necessary to make their crossing.

The name of the street to be crossed may also be provided in accessible format, such as Braille or raised print.

Vibrotactile Pedestrian Devices. A vibrotactile pedestrian device communicates information about pedestrian timing by touch through a vibrating surface. Vibrotactile pedestrian devices, where used, shall indicate that the walk interval is in effect and for which direction it applies through the use of a vibrating directional arrow or some other means.

Additional Information. Additional information on accessible pedestrian signals is contained in *Accessible Pedestrian Signals: Synthesis and Guide to Best Practices* available on the web at www.access-board.gov/news/aps-report.htm.[14]

Pedestrian Intervals and Signal Phases

WALKING PERSON (symbolizing WALK). When pedestrian signal heads are used, a WALKING PERSON (symbolizing WALK) signal indication should be displayed only when pedestrians are permitted to leave the curb or shoulder.

UPRAISED HAND (symbolizing DON'T WALK). A pedestrian clearance time should begin immediately following the WALKING PERSON (symbolizing WALK) signal indication. A flashing UPRAISED HAND (symbolizing DON'T WALK) signal indication should be displayed during the pedestrian clearance interval. The remaining portions of the pedestrian clearance time should consist of the yellow change interval and any red clearance interval (prior to a conflicting green being displayed), during which a flashing or steady UPRAISED HAND (symbolizing DON'T WALK) signal indication should be displayed.

Signal Lenses Not Illuminated. At intersections equipped with pedestrian signal heads, the pedestrian sign indications shall be displayed except when the vehicular traffic control signal is being operated in the flashing mode. At those times, the pedestrian signal lenses shall not be illuminated.

Walk Interval. The walk interval is the time period during which a pedestrian facing the WALKING PERSON signal indication may start to cross the roadway in the direction of the signal indication. Ideally, the walk interval should be at least 7 seconds in length so that pedestrians will have adequate opportunity to leave the curb or shoulder before the pedestrian clearance time begins. However, if it is desired to maximize the length of an opposing signal phase, and if pedestrian volumes are minimal, walk intervals as short as 4 seconds may be used.

Pedestrian Clearance Time. Current engineering practice is to set the pedestrian clearance time to be sufficient to allow a pedestrian crossing in the crosswalk who left the curb or shoulder during the WALKING PERSON (symbolizing WALK) signal indication to walk to:

- ♦ the center of the farthest travel lane or
- ♦ to a median of sufficient width to accommodate pedestrian storage.

Typically, the walk speed used to determine pedestrian clearance time is 4 ft/sec [1.2 m/sec]. However, even when this practice was developed, this walking speed was about the average walking speed of the pedestrians tested. More recently, engineers are recognizing that the elderly population is growing rapidly and the use of the 4 ft/sec [1.2 m/sec] walking speed does not provide them sufficient crossing times. Pedestrians with some disabilities also require additional crossing times. Therefore, to provide adequate crossing times for all individuals, the use of slower walking speeds and longer crossing lengths is recommended. A pedestrian crossing speed of 3.5 ft/sec [1.07 m/sec] is now generally preferred for design purposes. Also preferred is to use the far edge of the farthest travel lane rather than the center of that lane.

Other considerations for determining pedestrian clearance times include:

- ♦ Draft revisions to the ADAAG[11] require a walking speed of 3.0 ft/sec [0.9 m/sec] be used and increasing the length of crossing for calculating crossing times.
- ♦ Walking speeds as slow as 2.5 ft/sec [0.76 m/sec] may be appropriate at some locations.
- ♦ The National Committee on Uniform Traffic Control Devices is reviewing a proposal to time the walk indication for a pedestrian to reach the far curb rather than just the center of the farthest travel lane.

Passive pedestrian detection equipment, which can detect pedestrians occupying the crosswalk and extend the length of the pedestrian clearance time for that particular cycle, may be used instead of lower walking speeds per the *TMUTCD.*[1]

- ♦ The *Highway Design Handbook for Older Drivers and Pedestrians*[15] states that to accommodate the shorter stride and slower gait of less capable (15th percentile) older pedestrians, and their exaggerated "start-up" time before leaving the curb, pedestrian control-signal timing based on an assumed walking speed of 2.8 ft/s [0.85 m/s] is recommended.
- ♦ Some actuators can provide additional time by depressing the pedestrian button for a specified period of time.
- ♦ In all situations, engineering judgment along with an understanding of the types of users at the intersection is needed to determine the most appropriate design parameters.

Crossing to Median. Where the pedestrian clearance time is sufficient only for crossing from the curb or shoulder to a median of sufficient width for pedestrian storage, additional measures should be considered, such as median-mounted pedestrian signal or additional signing.

Extra Crossing Time. Extra crossing time may be needed at signals with school crossing guards or with high pedestrian volumes to clear the queues of pedestrians waiting to cross. These locations should be evaluated on a case-by-case basis.

Other Improvements. Improvements that can be made to expedite pedestrian movements at intersections include:

- incorporating a pedestrian phase in the signal sequence, rather than on-demand, in locations with high pedestrian use;
- placing pedestrian push buttons in locations that are easy to reach from the level landing at curb ramps, facing the sidewalk and clearly in line with the direction of travel (this will improve operations, as many pedestrians push all buttons to ensure that they hit the right one);
- motion detectors (both infrared and video) are being experimented with; these automatically change the signal phase when a pedestrian approaches.

Section 6
Detectors

Overview

Detectors are used to sense the passage or the presence of all road users within a specified zone. Data developed from detectors may be used for a variety of functions, including the following:

- actuation of traffic signal controllers;
- calculation of traffic speed, traffic density, and traffic and pedestrian volumes;
- emergency vehicle preemption;
- incident detection; and
- special vehicle priority control.

Generally, the selection of detectors to be used at a signalized intersection is based primarily on the operational conditions at the intersection and the type of phasing selected for the signal operation. The design of the intersection will have a direct effect on the signal phasing selected, but minimal effect on the detectors used at the location. Nevertheless, an understanding of signal design and operation, including an understanding of detectors and their functions, is important to the intersection designer. Also, the type of detector to be used may need to be accommodated during the initial design of the intersection so the pavement surface does not have to be cut later for detector installation.

Detection

Pulse detection is the sensing of a vehicle arrival within the detection zone with a short single pulse. The detector output will not indicate the presence of the vehicle in the detection zone even if the vehicle stops in the detection zone.

Presence detection is the sensing of a road user (vehicle or pedestrian) while in the detection zone, whether stopped or moving. Presence detectors will continuously send a signal of a user's presence as long as the user is in the detection zone. Most presence detectors can be adjusted to ignore a road user stopped within the detection zone after a period of time and then to detect new users as they enter the zone. Presence detectors can also be adjusted to put out a single pulse instead of a continuous indication of the user.

Detector Type

The detector system is the backbone of a traffic management and data collection system. Without accurate and reliable detectors that generate real-time data, system operators cannot make the best decisions. Detectors can generally be grouped in the following two categories:

- ***Intrusive detector systems.*** Intrusive detector systems require intrusion into or onto the pavement or roadway during installation or maintenance. Examples of intrusive detectors are inductive loops (ILDs) and road tubes.
- ***Non-intrusive detector systems.*** Non-intrusive detector systems substantially reduce interference with traffic operations because they do not need to be installed into or on the roadway. Non-intrusive systems are typically installed over the roadway or beside the roadway. Examples include video image systems, infrared devices, and acoustic systems.

Selection of Detector

The selection of a particular detector type depends on:

- the function to be performed (i.e., traffic control signal actuation);
- the need for passage detection, presence detection, or both;
- the roadway characteristics;
- pavement condition; and
- the level of maintenance skill available.

Care should be taken to ensure that the installation, operation, and maintenance capabilities of the operating agency are consistent with the requirements of the selected unit.

There is currently no single detector that can meet TxDOT's total detection and data collection needs. If accuracy under all weather and lighting conditions were the only criteria for selection, the inductive loop would still be the detector of choice. However, on high-volume urban freeways and streets, installing and maintaining in-pavement systems have become both costly and present safety concerns to installation and maintenance personnel.

Video image systems are becoming very popular in urban areas. Video detection provides more flexibility in locating or relocating detection areas, is not affected by maintenance activities on roadways, and has proven to be very effective in detecting all types of vehicles. Video detection is less effective when rigid supports for video equipment cannot be found close to the intersection and when detection is needed for distances far from the intersection. Additional information on using video detection is available in the following two TxDOT reports: *Intersection Video Detection Field Handbook*[16] and *Intersection Video Detection Manual*.[17]

The answer to the dilemma as to which detector is best will involve engineering judgment, and considering whether and to what extent accuracy can be compromised.

Pedestrian Detectors

Push Button. See Chapter 8, Section 5, Pedestrian Signals <link> for a discussion of push button detectors. Push button detectors are by far the most common pedestrian detectors. Pedestrians expect to see push buttons when pedestrian signals are installed. Therefore, pedestrians may have to be informed of the presence of another type of detector and be instructed to position themselves to be detected at the crossing.

Mats. Mats are pressure detectors placed at a point where pedestrians gather to await a signal to begin crossing a roadway. Because mats are activated by pressure, they are effective for wheelchairs of all sizes and types as well. Mats require no action on the part of the pedestrian, so locating a push button and pressing it are unnecessary. Mats also hold the promise of being less subject to vandalism than push buttons.

Other Pedestrian Detectors. Microwave, video, and ultrasonic detectors will also detect pedestrians. However, usage of these devices is minimal.

Preemption

Preemption by Emergency Vehicles. Various mechanisms may be used to preempt traffic signals so that emergency vehicles are provided the right of way as soon as practical. This type of preemption is typically used at intersections adjacent to fire stations and on commonly traveled routes. Communication with the traffic signals may be provided by direct wire, modulated light, or radio. The agency requesting the preemption is normally responsible for supplying the interconnect and any additional hardware required for the preemption.[3]

Preemption by Railroad Equipment. Traffic signals near railroad grade crossings can be connected to the railroad equipment to initiate a traffic signal preemption sequence. The railroad installs sensors on the tracks that send an electrical input to the traffic signal controller as the train passes over the sensors. Preemption of a traffic signal by the railroad signals is required if the traffic signal is at an intersection that is within 200 ft [60.96 m] of a railroad grade crossing. Preemption should be considered wherever traffic may back up over the crossing due to traffic signals or other traffic congestion.[3]

Traffic signal preemption requires an agreement with the railroad, and additional information is provided in the *Traffic Operations Manual, Railroad Operations Volume.*[18]

Multiple Preemptions. Multiple preemptions are allowed at the same location. Priority must be given to each preempt. Railroad preemption always overrides emergency vehicle preemption.

Detectors. Detectors assigned to detect vehicles that require preemption or priority response by the intersection controller or signal system are of two general types: emitter/receiver and position-of-vehicle. Emitter/receiver types are used extensively for preemption because of their communications range and message-content capability. Preemption response times must be based on the worst-case starting position of the controller, making long-range notification highly desirable.

Priority

Under priority control the green phase is extended beyond its normal termination in order to assist the priority vehicle in moving through the intersection.

Bus Priority. Individual vehicles are equipped or positioned so that the signal controller recognizes their presence. If the signal is displaying green when the vehicle arrives, the green phase will be extended to a preset maximum or until the vehicle clears the intersection, whichever is first.

Light Rail Priority. Individual cars or sets of rail cars are detected by their position so that the signal controller recognizes their presence. If the signal is displaying green when they arrive, the green phase will be extended to a preset maximum or until the vehicles clear the intersection, whichever is first. A separate signal phase may be called to serve the light rail line, allowing it a leading departure or a lagging departure. This phase is skipped when no light rail vehicle is calling for service.[7]

Bicycle Detectors

Bicycles are especially difficult for detectors that depend on the disturbance of magnetic fields because most bicycles have minimal amounts of metal. As a result, bicycles often require specialized detectors, such as an inductive loop-detector configuration known as a quadrapole, microloop sensors in sets of two or more, and microwave or ultrasonic detectors; video detection is another alternative that is quite promising. Some cities have successfully used special markings to indicate bicycle stop positions that are more likely to result in the detection of the bicycle. Figure 8-14 illustrates the use of detectors for bicyclists.

Where traffic signals function with "on-call" detection (with loop detectors), there are several improvements that can be made to benefit cyclists:

- placing loop detectors in bicycle lanes on side street to trip the signal;
- placing loop detectors in bicycle lanes to prolong green phase when a bicyclist is passing through (the upcoming yellow phase may not allow enough time for a cyclist to cross a wide intersection); and
- increasing the sensitivity of existing loop detectors in bicycle lanes, and painting stencils to indicate to cyclists the most sensitive area of the loop.

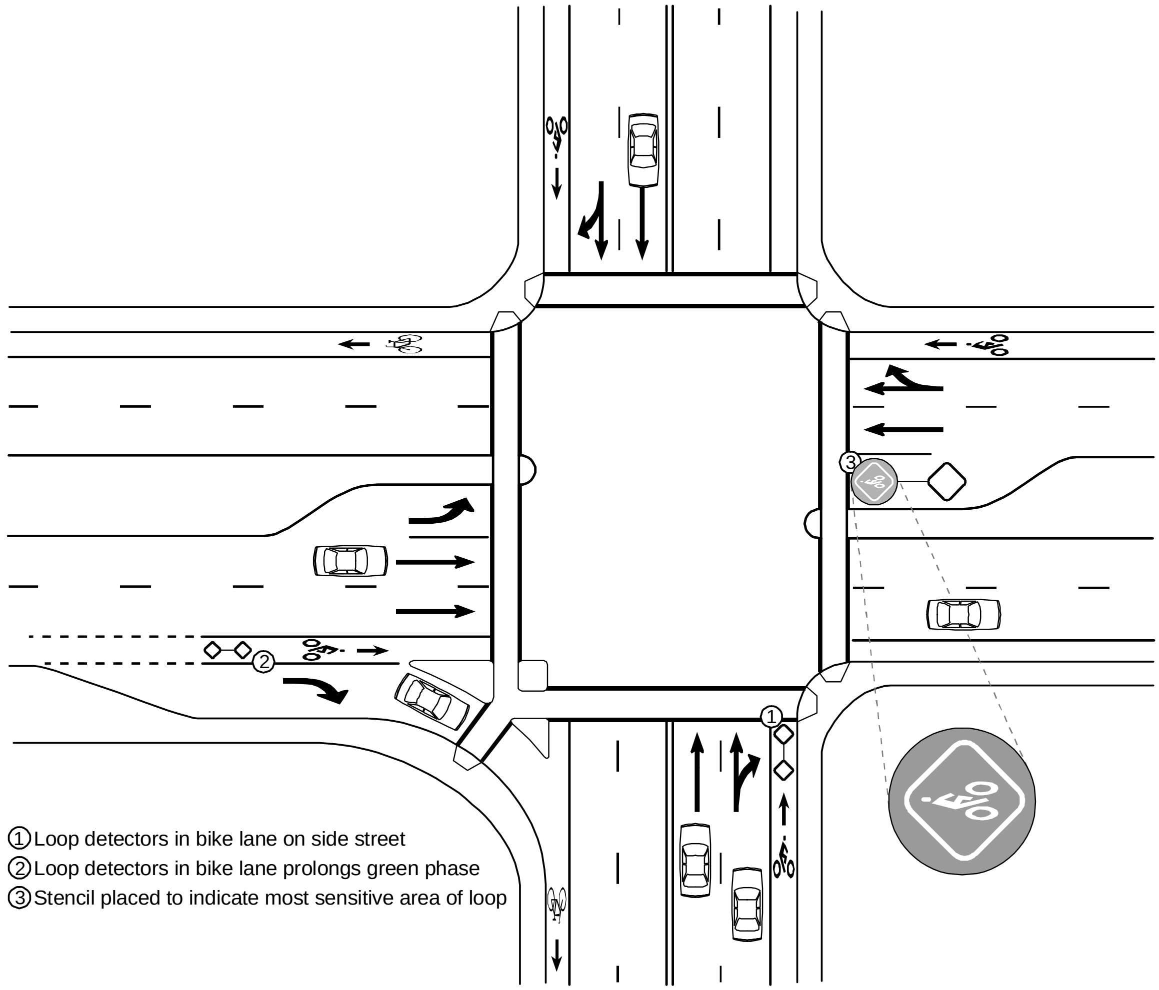


Figure 8-14. Signalized Intersection Sensitive to Bicycles (Based on Oregon Bicycle and Pedestrian Plan).[19]

Section 7

Right Turn on Red

Overview

Texas law allows vehicles to turn right after coming to a stop when facing a red indication at a signalized intersection if:

- The turn can be completed in a safe manner.
- There are no signs prohibiting a right turn during the red indication.
- There are no pedestrians in the crosswalk on the half of the roadway in which the vehicle is traveling.

The right-turn-on-red maneuver provides an opportunity to increase the operational efficiency of a traffic signal by reducing the demand for a green indication. The use of RTOR is especially effective at locations with an exclusive right-turn lane.

Right Turn on Red at a Pedestrian Crossing

Where RTOR is permitted and pedestrian crosswalks are marked, the *TMUTCD* states that the word message TURNING TRAFFIC MUST YIELD TO PEDESTRIANS should be used. The information should be posted in an overhead or roadside location that is easily visible to the motorist prior to initiating the turning maneuver.[15]

A recent study[20] indicates that traffic signs prohibiting RTOR during specified hours were effective at increasing driver compliance with stop lines. The number of drivers turning right on red without stopping was reduced from 39 percent to 19 percent.

Prohibition of Right Turn on Red

Factors that impact the decision to prohibit RTOR include:[1,21]

- sight distance (see Chapter 3, Section 1 for information on determining needed intersection sight distance <link>);
- pedestrian traffic;
- bicycle traffic;
- conflicting traffic volumes;
- signal phasing;
- site conditions;
- operational experience (i.e., safety problems);
- presence of dual right-turn lanes, at least from the inside lane; and
- skewed intersections (angle less than 75 degrees or greater than 105 degrees).

To reduce confusion with the meaning of the red arrow (right-turn), it is recommended that a steady red ball be used at signalized intersections where a right turn is prohibited. The NO TURN ON RED sign (R10-11a, R10-11b, or R10-11c) should supplement the red ball indication.[2] The sign should be installed near the appropriate signal head.[1,15]

Recommended Practice

The Institute of Transportation Engineers is developing a Recommended Practice on the Prohibition of Turns on Red. The purpose of the ITE Recommended Practice is to promote safe movement of vehicular traffic, pedestrians, bicyclists, and other road users while providing for efficient movement of traffic. It notes that because each intersection should be evaluated on an individual basis, the guidelines presented within the Recommended Practice are qualitative and nonspecific. The ITE Web site (http://www.ite.org/standards/index.asp) can be checked to determine whether the Recommended Practice has been adopted by ITE.

Section 8

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Chapter 9
Markings

Contents:

Section 1
General

Overview

Roadway markings are an expected, integral, and critical element of the roadway transportation system. They have been proven to be an effective, cost-efficient, and safety-enhancing element of the roadway delineation system. Roadway markings are located directly within the user's cone of vision, and they provide continuous information that helps the road user to correctly position the vehicle in the roadway.

Markings have two general purposes:

- to provide guidance for highway users and
- to optimize roadway efficiency.

Proper vehicle guidance promotes highway safety. In some cases, markings are used to supplement the regulations or warnings of other traffic control devices such as signs or traffic signals. In other cases, markings are the only means of effectively conveying certain regulations, warnings, and information in clearly understandable terms without diverting the driver's attention from the roadway. In addition, the capacity of a highway is often increased by the orderly and proper regulation of traffic flow, which results from correct application of pavement markings.

As with all traffic control devices, markings must be readily recognized and understood and comply with the *TMUTCD*.[1] TxDOT recently sponsored the development of a *Pavement Marking Handbook*[2] that ties information together on selecting, specifying, and inspecting markings. The Handbook is targeted toward two audiences: engineering personnel and field personnel. The portion for engineering personnel provides information on selecting pavement marking materials for various applications. The portion for field personnel provides information on pavement marking installation and inspection. The appendices of the handbook provide additional information about TxDOT specifications, procedures, and standards applicable to pavement markings.

Types of Markings

Roadway markings are generally classified as either:

- longitudinal markings,
- transverse markings, or
- other delineation.

Longitudinal markings are generally placed parallel to the roadway (see Figure 9-1), and they serve to provide positive guidance by defining the limits of a road user's field of safe travel (such as lane lines, centerlines, and edge lines). Longitudinal markings are also used to inform road users of areas where it is not safe or where they are not permitted to travel (such as no passing zones, gore areas, islands, and painted medians).[3] Additional information on longitudinal markings is in Chapter 9, Section 2 <link>.

Figure 9-1. Example of Longitudinal Pavement Markings.

Transverse markings are generally those that are placed perpendicular to the roadway. They will be white unless otherwise specified in the *TMUTCD*.[1] Transverse lines should be proportioned to provide visibility equal to that of longitudinal lines because of the low approach angle at which pavement markings are viewed. Pavement marking letters, numerals, and symbols are to be installed in accordance with the *Standard Alphabets for Highway Signs and Pavement Markings Reference Guide*.[4] Transverse markings include:

- stop and yield lines,
- crosswalk lines,
- parking space markings, word and symbol markings (see Figure 9-2 for an example),
- speed measurement markings,
- curb markings,
- preferential lane word and symbol markings, and
- other symbol markings.

Additional information on transverse pavement markings is discussed in more detail in Sections 3 and 4 of this chapter <link>.

In addition to markings applied to the surface of a roadway, delineation such as post-mounted delineators, object markers, and colored pavements are part of the marking system. Information on raised pavement markers is in Section 5 <link>.

Figure 9-2. Example of Transverse Pavement Markings (Arrow and Crosswalk).

Retroreflectivity

Retroreflectivity is the scientific principle of returning light back to its source. Under most circumstances, vehicle headlights provide the major source of light available during night driving. As shown in Figure 9-3, the light rays from headlight beams shining on a nonreflective marking are reflected in all directions, and only a very small proportion of the light is returned directly back to the light source (driver's vehicle) and to the driver's eye. When the light rays shine on a retroreflective marking, much more light is returned to the vehicle's light source, and the markings are therefore more visible to the driver.

There are two common retroreflective techniques used for markings and delineators:

- spherical (glass beads) and
- corner cube (prismatic).

Glass beads are most commonly used and were the earliest form of retroreflectors used for night visibility. They can also be imbedded in preformed or thermoplastic tapes.

Corner-cube reflectors utilize a trihedral-angled mirror reflection. In this system, three mirrored surfaces are arranged at a proper angle to receive the rays of headlights on one of the three mirrors. Light rays are reflected to a second mirrored surface, then to the third, and finally outward back toward the light source on a path parallel to the entering direction. The corner-cube delineators are many times brighter than those made from retroreflective sheeting (glass beads), and white retroreflectors of either type are brighter than yellow. To obtain wide-angle retroreflection, the different manufacturers use various configurations of the optical elements.[3]

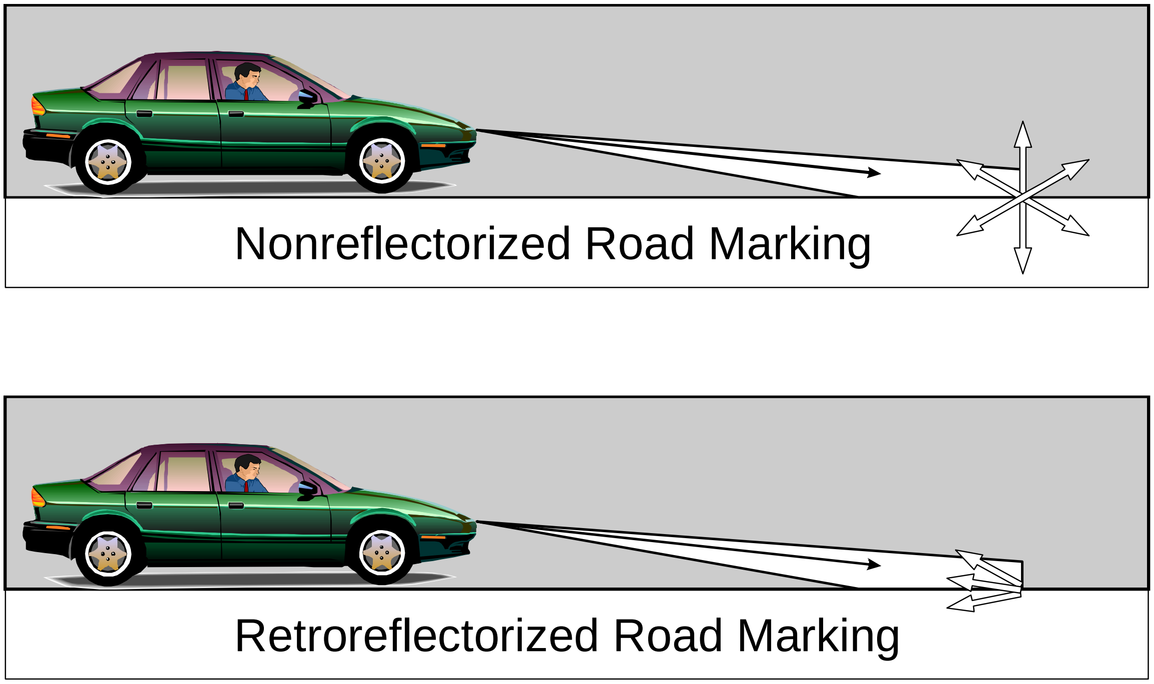


Figure 9-3. Light Reflection Characteristics.[3]

Color and Patterns of Pavement Markings

The United States uses the following colors for pavement markings:

- Yellow is used to separate opposing traffic on two-way roadways and as the left edge line on one-way roadways (such as divided highways). Yellow also delineates the separation of two-way left-turn lanes and reversible lanes from other lanes. In this manner, the color yellow always defines the leftmost side of the travel path for a vehicle (with the exception of reversible lanes).
- White lines delineate the separation of traffic flows in the same direction or mark the right edge of the pavement.
- Red markings delineate roadways not to be entered or used by the viewer of those markings.
- Blue may be used to supplement white parking spaces markings for designating spaces for persons with disabilities or as a background color for the wheelchair symbol pavement marking.

Widths and patterns provide the following:

- Solid lines are restrictive in character.
- Broken lines are permissive in character.
- Line width indicates the degree of emphasis.
- Double lines indicate maximum restrictions or prohibitions.
- Dotted lines provide guidance.

Specified applications of some of the most important U.S. pavement marking applications are listed in Table 9-1. The basic application configurations of pavement markings are shown in the *TMUTCD* and should be consulted for specific application information.

Table 9-1. Selected Pavement Marking Applications. [5]

Type of Marking	Function	Marking	Color
Longitudinal Lines	Separate opposing traffic	Broken or solid centerline	Yellow
	Indicate no passing zone	Solid line	Yellow
	Separate lanes traveling in the same direction	Broken or solid lane lines	White
	Indicate right edge on one or two-way road	Solid edge line	White
	Indicate left edge on one-way road	Solid edge line	Yellow
Transverse Lines	Indicate stopping location on intersection approach	Stop line	White
	Indicate pedestrian crossing area	Crosswalk	White
Note: Only some of the most important markings are listed. There are other types of markings.			

Visibility of Markings

Light-colored pavements may not provide sufficient contrast with the markings. Black may be used in combination with yellow, white, red, or blue markings. When used in combination with other colors, black is not considered a marking color, but only a contrast–enhancing system for the markings.

Materials and Costs of Pavement Markings

The performance and costs of different materials vary greatly. It is also important to recognize that there are some materials that are more appropriate for a set of circumstances than other materials. The useful life of a pavement marking material often varies widely based on many factors. Materials should be selected that will meet or exceed the performance requirements at the lowest cost. To maximize cost-effectiveness, material selection should be based on:

- roadway surface type,
- amount of traffic disruption expected when reapplying materials,
- traffic volumes, and
- expected remaining service life of the pavement.

The TxDOT *Pavement Marking Handbook*[2] provides information that is intended to help the engineer or designer select the appropriate marking material for a given roadway and to develop the appropriate specifications. It must be noted that engineering judgment should always apply in the material selection process. Supporting pavement marking material information, including TxDOT specifications and test methods, is included in the appendices of the Handbook.

A majority of the pavement markings placed on TxDOT roadways over the past five years fall into one of three categories: thermoplastic, water-based paint, and preformed tape. However, other materials exist that have shown positive performance either in Texas or elsewhere. The *Pavement Marking Handbook* contains in-depth descriptions of several commercially available materials and typical uses.

Section 2
Longitudinal Pavement Markings

Overview

Longitudinal markings are continuous along a length of roadway, and as such, they provide a constant stream of information that cannot be provided by signs or signals. They are to be positioned so that they are near the center of the driver's visual field.

A curb, by definition, incorporates some raised or vertical element. Curbs serve any or all of the following purposes: drainage control, roadway edge delineation, potential to build in restricted right of way, aesthetics, delineation of pedestrian walkway, reduction of maintenance operations for shoulders and ditches, and assistance in orderly roadside development. High-visibility treatments, such as reflectorized paints or other reflectorized surfaces or applied thermoplastics, can make curbs more conspicuous.

Widths and Patterns of Longitudinal Pavement Markings

The widths and patterns of longitudinal pavement markings are specified in the *TMUTCD.*[1]

Standards for Longitudinal Pavement Markings

The standards for various longitudinal pavement markings are included in the *TMUTCD*[1] in the following sections.

- The standards for Yellow Centerline and Left Edge Line Pavement Markings and Warrants are included Section 3B.01.
- The standards for No-Passing Zone Pavement Markings and Warrants are included in Section 3B.02.
- The standards for Other Yellow Longitudinal Pavement Markings are included in Section 3B.03.
- The standards for White Lane Lines and Right Edge Line Pavement Markings and Warrants are included in Section 3B.04.

Extensions through Intersections or Interchanges

Where highway design or reduced visibility conditions make it desirable to provide control or to guide vehicles through an intersection or interchange, dotted line markings should be used to extend longitudinal line markings through an intersection or interchange area. These conditions may include:

- offset intersections,
- skewed intersections,
- complex intersections,

- multileg intersections,
- curved roadways, or
- where multiple turn lanes are used.

Pavement markings extended into or continued through an intersection or interchange area are:

- the same color as the line markings they extend and
- at least the same width as the line markings they extend.

Where greater restriction is required, solid lane lines or channelizing lines should be extended into or continued through intersections.[1]

Figure 9-4 shows an example of pavement markings for offset lanes. This situation should be avoided unless there are significant constraints. Preferably the approaches would be realigned so that the vehicles travel a straight path through the intersection.

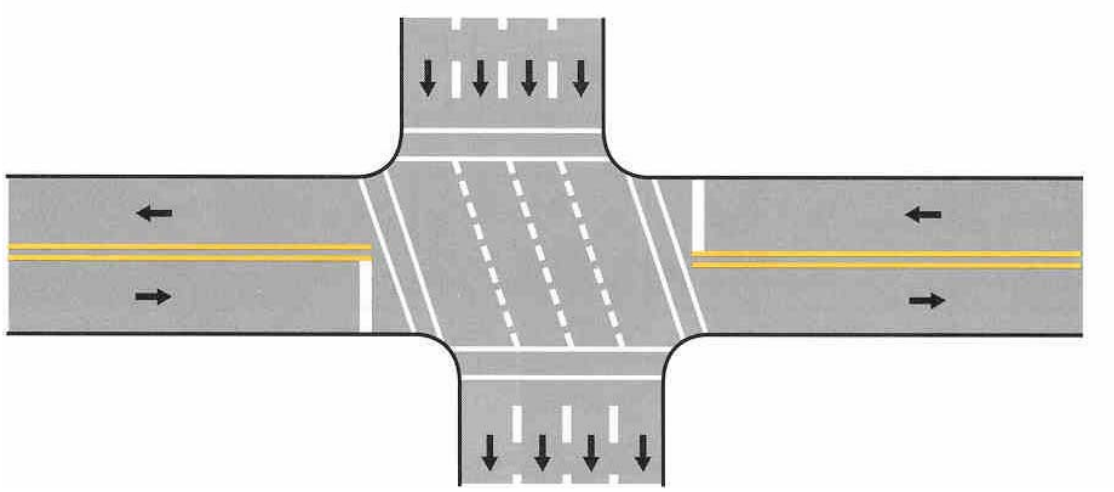


Figure 9-4. Typical Pavement Marking with Offset Lane Lines Continued through the Intersection.[1]

Figure 9-5 shows an example of dotted line markings for a left turn. These markings are commonly called cat tracks or puppy dog tracks. ***Application 9-1*** <link> shows the typical signs and markings for a dual left turn.

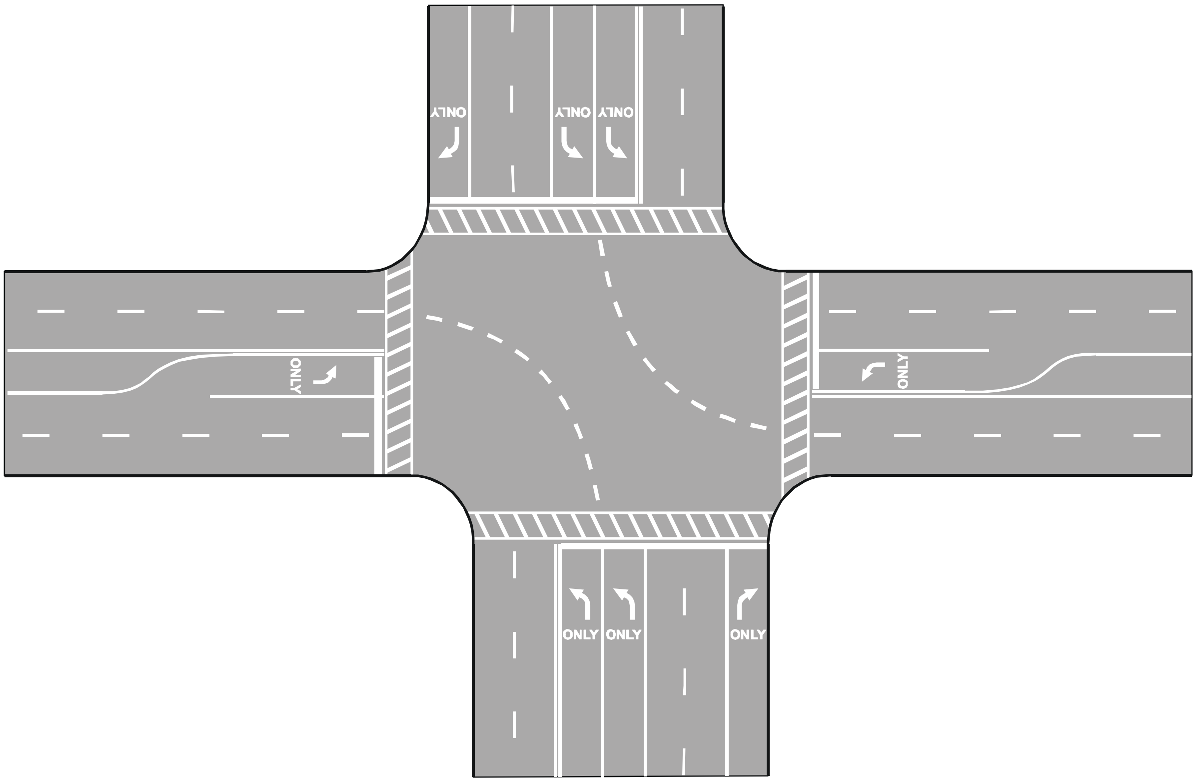


Figure 9-5. Typical Dotted Line Markings to Extend Longitudinal Lane Line Markings.

Other Longitudinal Pavement Markings

The *TMUTCD*[1] also includes information on Lane Reduction Transition Markings (Section 3B.09), Approach Markings for Obstructions (Section 3B.10), and Preferential Lane Longitudinal Markings for Motorized Vehicles (Section 3B.23).

Curb Markings

Curb markings are most often used to indicate parking regulation or to delineate the curb. The colors of marked curbs are to conform to the general principles of markings. In areas where curb markings are frequently obliterated by snow and ice accumulation, signs are to be used with the curb markings.

Guidance for curb markings includes:

- When curb markings are used without signs to convey parking regulations, a legible word marking regarding the regulation (such as “No Parking” or “No Standing”) should be placed on the curb.
- Retroreflective solid yellow markings should be placed on the noses of raised median and curbs of islands that are located in the line of traffic flow where the curb serves to channel traffic to the right of the obstruction.
- Retroreflective solid white markings should be used when traffic may pass on either side of the island.

- Where the curbs of the islands become parallel to the direction of traffic flow, it is not necessary to mark the curbs unless an engineering study indicates the need for this type of delineation.
- Curbs at openings in a continuous median island need not be marked unless an engineering study indicates the need for this type of marking.

The *Highway Design Handbook for Older Drivers and Pedestrians*[6] recommends that island curb sides and curb surfaces should be treated with reflectorized paint or other types of pavement marking material.

Section 3
Transverse Markings: Lines

Overview

Stop and yield lines are used for added emphasis and visibility to supplement Stop and Yield signs.

Crosswalk markings are used to guide pedestrians to an appropriate crossing location and to warn road users of a pedestrian crossing location. Additional information on crosswalks is included in Chapter 7—Street Crossing, Section 2 <link>.

Marking of parking space boundaries encourages more orderly and efficient use of parking spaces where parking turnover is substantial. Parking space markings tend to prevent encroachment into fire hydrant zones, bus stops, loading zones, approaches to intersections, curb ramps, clearance spaces for islands, and other zones where parking is restricted.

Details on the use and dimensions for transverse markings are in the *TMUTCD*.[1]

Stop Lines

If used, stop lines:

- should consist of solid white lines extending across approach lanes to indicate the point at which the stop is intended or required to be made;
- should be used to indicate the point behind which vehicles are required to stop in compliance with a Stop sign, traffic control signal, or some other traffic control device;
- should be 12 to 24 inches [305 to 610 mm] wide;
- should be placed to allow sufficient sight distance for all approaches to an intersection; and
- should be placed at least 40 ft [12 m] in advance of the nearest signal indication at midblock signalized locations.

The *Older Driver Design Handbook*[6] recommends the use of 24-inches [610 mm] wide stop lines at the end of channelized left-turn lanes as a countermeasure to wrong-way movements.

Yield Lines

If used, yield lines:

- consist of a row of isosceles triangles pointing toward approaching vehicles extending across approach lanes to indicate the point at which the yield is intended to be or required to be made,

- may be used to indicate the point behind which vehicles are required to yield in compliance with a Yield sign,
- should have individual triangles having a base 12 to 24 inches [0.3 to 0.6 m] wide and a height equal to 1.5 times the base, and
- should have a 3 to 12 inch [76 to 305 mm] space between the triangles.

Typical yield line layouts are shown in Figure 9-6.

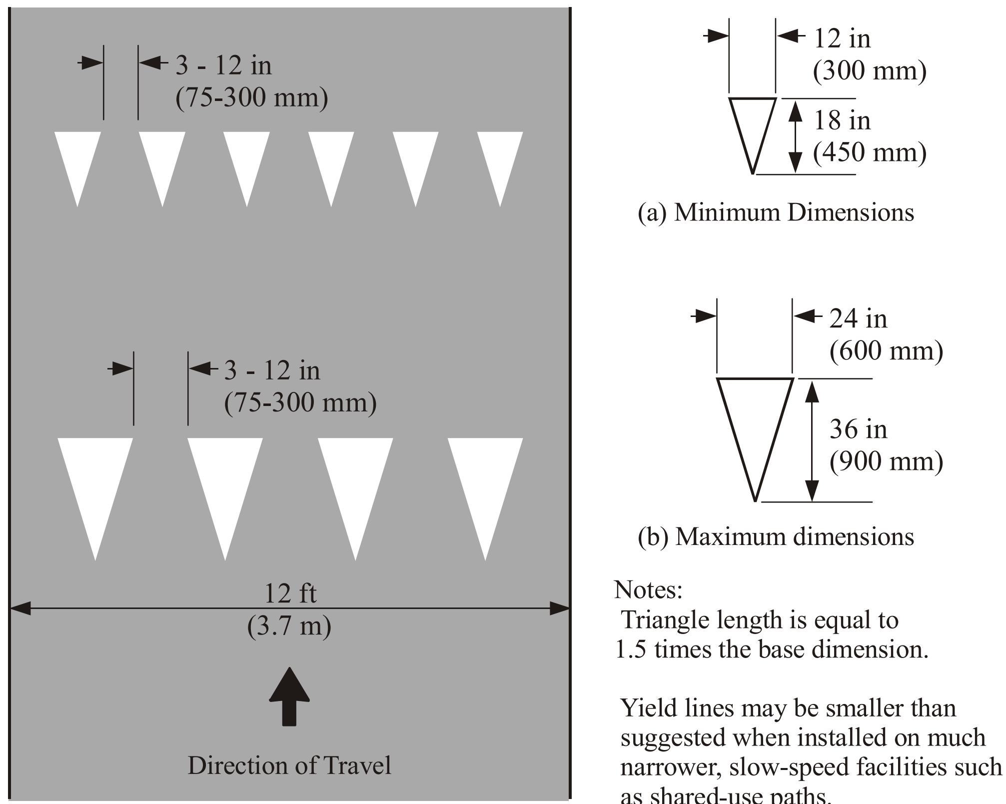


Figure 9-6. Typical Yield Line Layouts.[1]

Placement of Stop and Yield Lines

Stop and yield lines should be placed at the desired stopping or yielding point but should be placed no more than 30 ft [9 m] and no less than 4 ft [1.2 m] from the nearest edge of the intersecting traveled way or a marked crosswalk.

Motorists should be discouraged from stopping in or too close to crosswalks. Stop or yield lines:

- May be used as a guide to indicate the optimal stopping location for motorists.
- May be used in advance of marked crosswalks to help encourage motorists to stop further back from the crosswalk. This helps reduce the potential for pedestrian-related collisions that occur on streets with multiple lanes of traffic when one driver stops to

let a pedestrian cross in the crosswalk and the pedestrian is struck by a trailing vehicle in the adjacent lane.

- Are intended to be used at locations where motorists are required to stop.
- May be used on approaches to traffic signals, Stop signs (with or without marked crosswalks), or uncontrolled marked crosswalks.

Crosswalk Width

The width for marked crosswalks should not be less than 6 ft [1.8 m].[1] *The Draft Guidelines for Accessible Public Rights-of-Way* proposes a minimum width of 8 ft [2.4 m].[7] If no markings are present, per the *TMUTCD*, the width of the sidewalk or path extended between the curbs (or, in the absence of curbs, from the edge of the traversable roadway) defines a legal crosswalk. Where markings are present, the legal crosswalk is defined by such markings.

Crosswalk Markings

Crosswalk markings provide guidance for pedestrians who are crossing roadways by defining and delineating paths on approaches to and within signalized intersections and on approaches to other intersections where traffic stops. Crosswalk markings also serve to alert road users of a pedestrian crossing point across roadways not controlled by traffic signals or Stop signs. At non-intersecting locations, crosswalk markings legally establish the crosswalk.[1]

When crosswalk lines are used, they consist of solid white markings that extend across the full length of the crossing. The standard line markings are not to be less that 6 inches [152 mm] nor greater than 24 inches [610 mm] in width.[1] The approach on the left side of the figure in Figure 9-7 illustrates standard crosswalk lines.

For added visibility, the area of the crosswalk may be marked with white diagonal lines at a 45-degree angle to the line of the crosswalk (commonly called diagonal markings) or with white longitudinal lines parallel to traffic flow (commonly called zebra markings). When diagonal or longitudinal lines are used to mark a crosswalk, the transverse crosswalk lines may be omitted. Figure 9-7 illustrates diagonal and zebra marking styles.

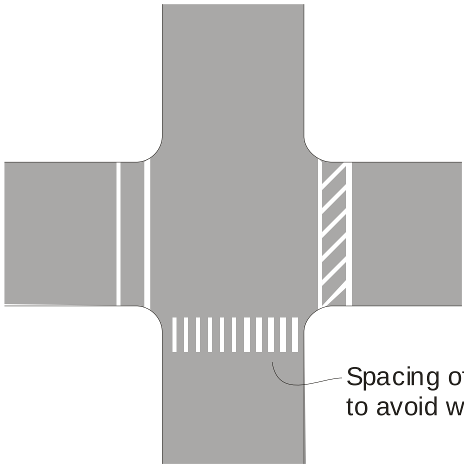


Figure 9-7. Crosswalk Marking Options.[1]

High visibility markings may be most beneficial at locations where:

- substantial numbers of pedestrians cross without any other traffic control device,
- physical conditions are such that added visibility of the crosswalk is desired, or
- a pedestrian crosswalk might not be expected.

If used, the diagonal or longitudinal lines should be 12 to 24 inches [305 to 610 mm] wide and spaced 12 to 24 inches [305 to 610 mm] apart. The spacing design should avoid the wheel paths.

At unsignalized or uncontrolled crossings, or areas such as school zones or areas where there is a substantial pedestrian presence, special emphasis markings should be used to increase visibility (i.e., zebra, diagonal). High contrast markings can also aid people with low vision. Additional discussion on crosswalk markings is in Chapter 7, Section 2 <link>.

When an exclusive pedestrian phase that permits diagonal crossing is provided at a traffic control signal, markings as shown in Figure 9-8 may be used for the crosswalk.

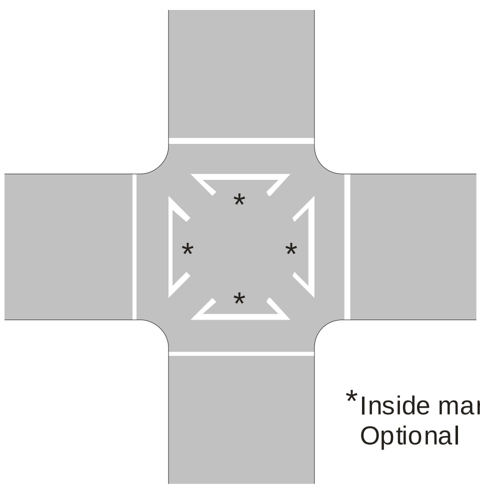


Figure 9-8. Diagonal Crossing.[1]

Crosswalk Marking Materials

It is important to ensure that crosswalk markings are visible to motorists, particularly at night. Crosswalks should not be slippery or create tripping hazards. Even though granite or cobblestones are aesthetically appealing materials, they are generally not appropriate for crosswalks. One of the best materials for marking crosswalks is inlay tape, which is installed on new or repaved streets. It is highly reflective, long-lasting, slip-resistant, and does not require a high level of maintenance. Although initially more costly than paint, both inlay tape and thermoplastic are more cost-effective in the long run. Inlay tape is recommended for new and resurfaced pavement, while thermoplastic may be a better option on rougher pavement surfaces. Both inlay tape and thermoplastic are more visible and less slippery than paint when wet.[8]

Parking Space Markings

Parking space markings are white. No parking zones should be provided at a minimum of 20 ft [6.1 m] from the crosswalk line farthest from the intersection or at 30 ft [9 m] for signalized intersections. Parking space markings are illustrated in Figure 9-9. They are also discussed in Chapter 4, Section 7 (Shoulders and Parking) <link>.

Parking space markings for the purpose of designating spaces for use by persons with disabilities are required by ADAAG/TAS and are discussed in the *TMUTCD.*[1] Additionally, TxDOT Standard PM (AP) provides details of accessible parking markings and required signing. The International Symbol of Accessibility parking space markings may be placed in each parking space designated for use by persons with disabilities. A blue background with white border may supplement the wheelchair symbol.

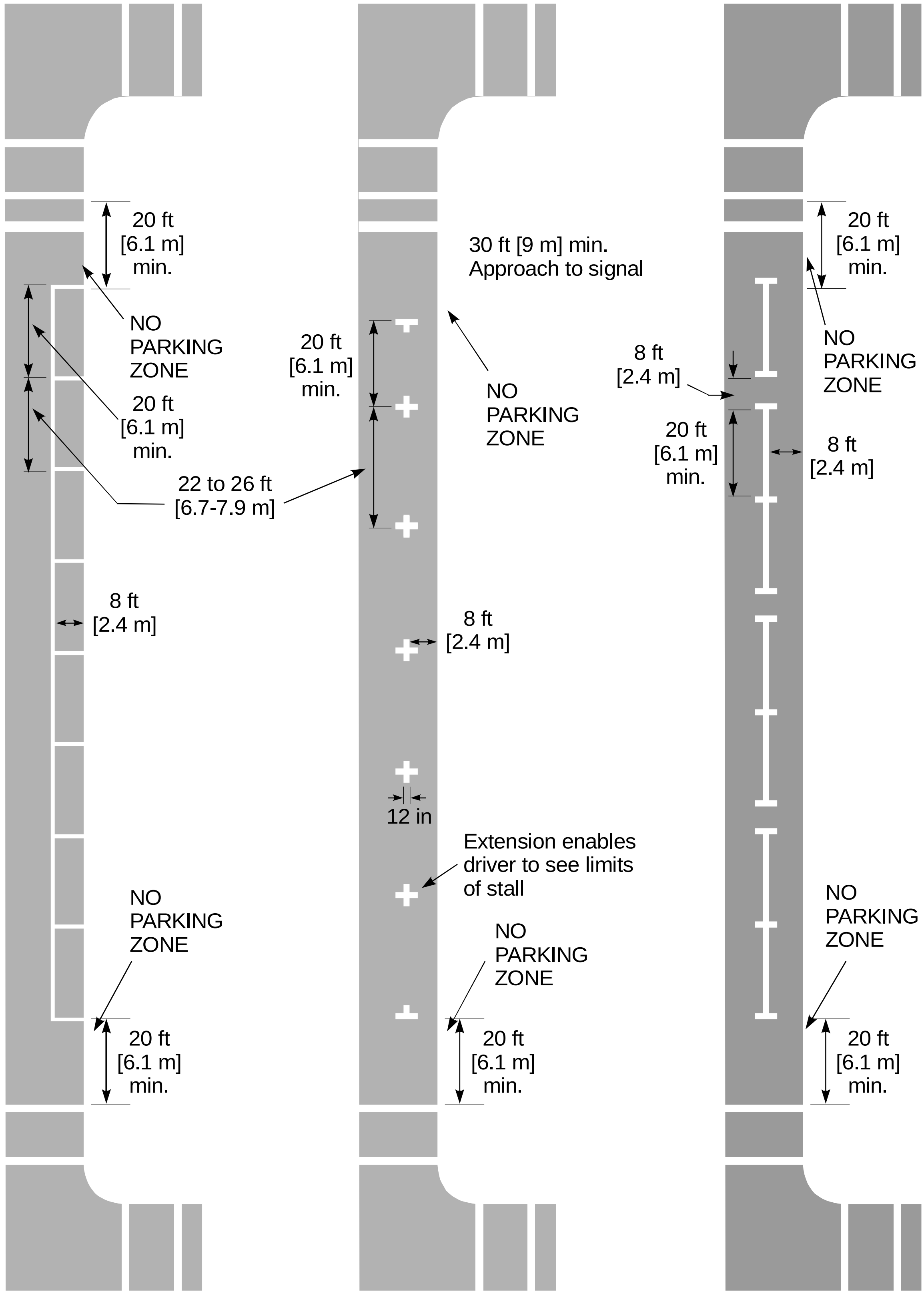


Figure 9-9. Typical Parking Space Markings.[1]

Section 4

Transverse Markings: Words and Other Symbols

Overview

Word and symbol markings on the pavement are used for the purposes of:

- guiding,
- warning, or
- regulating traffic.

Symbol messages are preferable to word messages.

Examples of typical lane use control word and symbol pavement markings are shown in Figure 9-10.

Word and symbol markings may include, but are not limited to:

- Regulatory:
  - STOP (The word STOP on the pavement is to be accompanied by a stop line and Stop sign. Do not place the word Stop on the pavement in advance of a stop line unless every vehicle is required to stop at all times.)
  - RIGHT (LEFT) TURN ONLY (see example in Figure 9-11)
  - 25 MPH (40 KPH)
  - Arrow symbols
- Warning:
  - STOP AHEAD
  - YIELD AHEAD (The YIELD AHEAD work pavement marking or Yield Ahead Triangle Symbol is not to be used unless a YIELD sign is in place at the intersection.)
  - Yield Ahead Triangle Symbol
  - SCHOOL X-ING
  - SIGNAL AHEAD
  - PED X-ING
  - SCHOOL
  - R X R
  - BUMP
  - HUMP

- Guide:
  - US 40
  - STATE 135
  - ROUTE 40

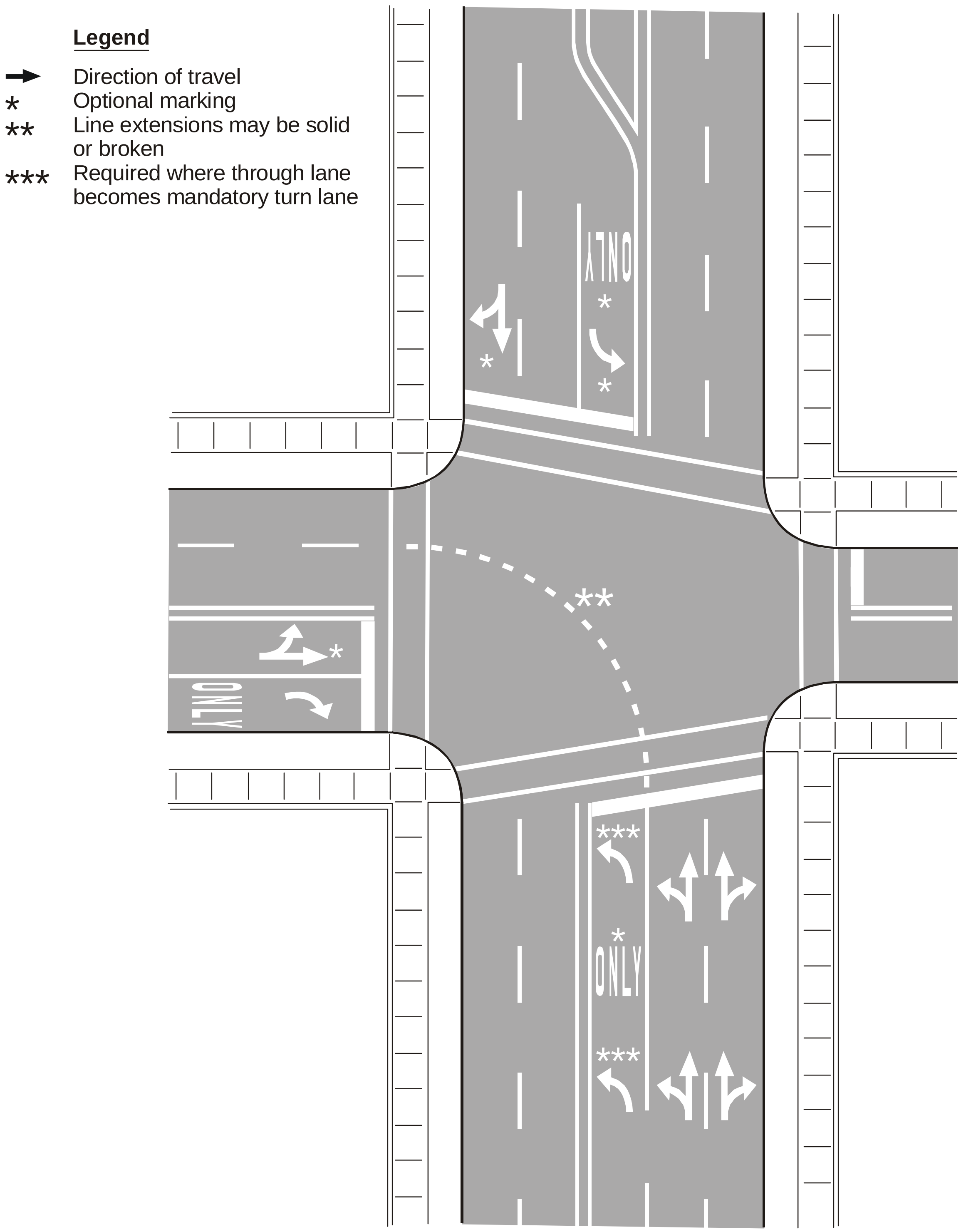


Figure 9-10. Typical Lane Use Control Word and Symbol Markings.

Figure 9-11. Example of Right Turn Only Word Pavement Markings.

Color and Size of Word and Symbol Markings

Word and symbol markings are white, except as otherwise noted in this section. Letters and numerals should be at least 6 ft [1.8 m] in height.

Other words or symbols may also be used under certain conditions.

Word and symbol markings:

- should not exceed three lines of information;
- should read in the direction of travel if the word message consists of more than one line of information;
- should be installed so that the first word of the message is nearest to the road user;
- should have a longitudinal space between word or symbol message markings, including arrow markings, of at least four times the height of the characters for low-speed roads, but not more than ten times the height of the characters under any conditions;
- should provide effective guidance and avoid misunderstandings through the minimization of the number of different word and symbol markings;
- should be no more than one lane in width, except for the option for the SCHOOL word marking (the SCHOOL word marking may extend to the width of two lanes, in which case the characters should be 10 ft [3.1 m] or more in height);
- should be proportionally scaled to fit within the width of the facility upon which they are applied; and

- may be smaller than suggested but to the relative scale on narrow, low-speed bicycle paths.

Markings Where through Lanes Become Mandatory Turn Lanes

Where through traffic lanes approaching an intersection become mandatory turn lanes, lane-use arrow markings are used and accompanied by standard signs (see Figure 9-10). Signs or markings should be repeated as necessary to prevent vehicle entrapment and to help the road user select the appropriate lane in advance of reaching a queue of waiting vehicles.

Lane use, lane reduction, and wrong-way arrow markings are discussed in the *TMUTCD*.[1] <link>. Lane-use arrow markings may be used to convey either guidance or mandatory messages. Lane-use arrow markings are often used to provide guidance:

- in turn bays,
- where turns may or may not be mandatory, and
- in two-way left-turn lanes.

The ONLY word marking may be used to supplement lane-use arrow markings (see Figure 9-10 and Figure 9-12).

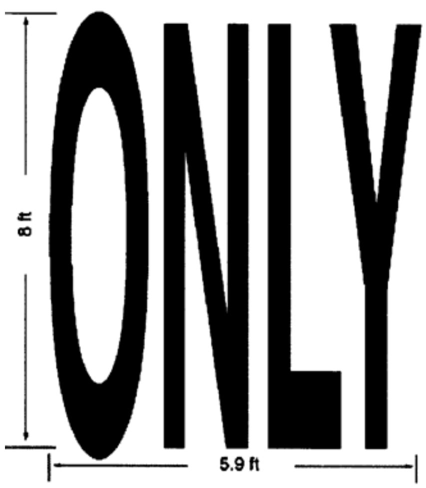


Figure 9-12. Typical Elongated Letters for Word Pavement Markings.

Preferential Lane Word and Symbol Markings

Preferential lanes may be designated to identify a wide variety of special uses that includes, but is not limited to:

- bicycle lanes,
- high-occupancy vehicle (HOV) lanes,
- bus-only lanes, and
- taxi-only lanes.

Information for preferential markings for HOV lanes, bus-only lanes, and taxi-only lanes are included in the *TMUTCD*[1] <link>.

Bicycle Lanes

Where a bicycle lane is established, the preferential lane use marking consists of a bicycle symbol or the word marking BIKE LANE as shown in Figure 9-13. Further discussion regarding bicycle lanes is provided in Chapter 4, Section 6 <link> and the *TMUTCD*.[1] An example of traffic control devices for a bicycle lane is presented in ***Application 9-1*** <link>.

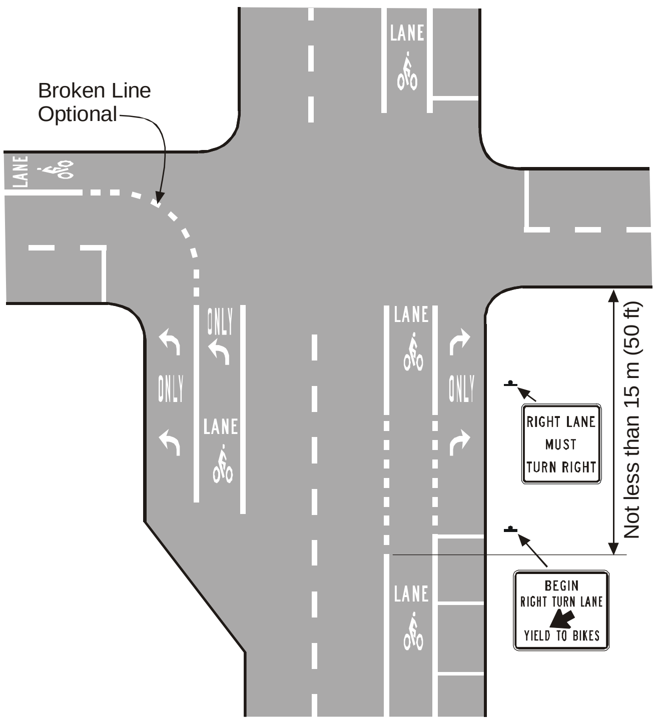


Figure 9-13. Typical Intersection Pavement Markings with Designated Bicycle Lane with Left-Turn Area, Heavy Turn Volumes, Parking, One-Way Traffic, or Divided Highway.[1]

Other Symbol Markings

Information on Markings for Roundabouts, Markings for Other Circular Intersections, Speed Hump Markings, and Advance Speed Hump Markings is included in the *TMUTCD*[1] <link>.

Section 5
Raised Pavement Markers

Overview

A raised pavement marker (RPM) is a device that:

- has a height of at least 0.4 inches [10 mm],
- is mounted on or in a road surface, and
- is intended to be used as a positioning guide or to supplement or substitute for pavement markings.[1]

Raised pavement markers are highly effective when used in addition to pavement markings. As shown in Figure 9-14, raised pavement markers provide excellent night visibility. Raised pavement markers can be used to:

- show roadway alignment,
- replace pavement markings, or
- supplement other pavement markings.[9]

Color

The color of RPMs is to conform to the color of the markings for which they serve as a positioning guide, or for which they supplement or substitute, under both daylight and nighttime conditions. White, yellow, red, and blue RPMs are currently in use. White and yellow RPMs have the same meaning as pavement markings of the same color. Red retroreflective RPMs convey the message “wrong way.” Blue retroreflective RPMs are used by towns and cities to indicate the location of a nearby fire hydrant.

Retroreflectivity or Illumination

Retroreflective RPMs consist of one or more retroreflective lenses and a base. The lens may be made of cube-cornered acrylic, tempered glass, or glass beads. Bases are made of plastic, ceramic, or metal. The lenses and bases are available in yellow, white, red, or a combination of two colors.[3]

Retroreflective and internally illuminated raised pavement markers are available in mono-directional and bi-directional configurations. The bi-directional marker is capable of displaying the applicable color for each direction of travel. Nonretroreflective raised pavement markers should not be used alone (without supplemental retroreflective or internally illuminated markers) or as a substitute for other types of pavement markings.

Directional configurations should be used to:

- maximize correct information,
- minimize confusing information provided to the road user, and
- avoid confusion resulting from visibility of markers that do not apply to the road user.

Retroreflective RPMs provide excellent visibility at night and in the rain, and they also provide motorists with an auditory warning. Snowplowable versions can be used in cold weather climates. Nonreflective RPMs are typically used along with other types of marking material to provide additional guidance.[3]

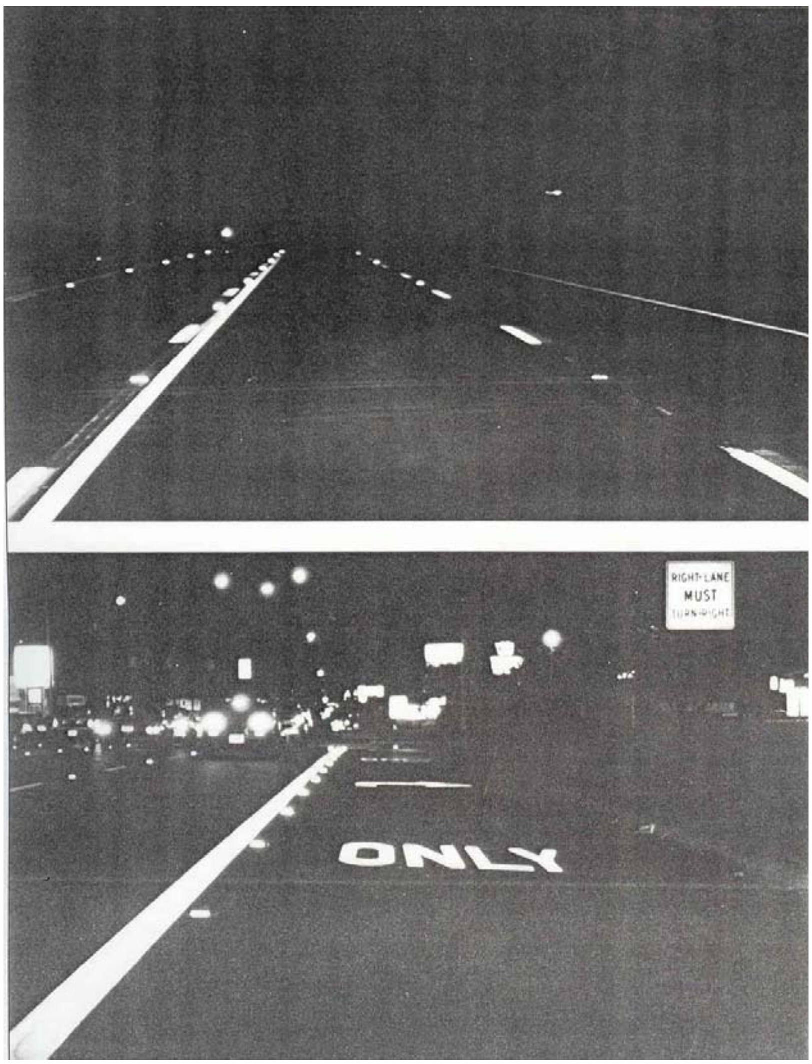


Figure 9-14. Nighttime Visibility with Raised Pavement Markers.[9]

Spacing

The spacing of RPMs used to supplement or substitute for other types of longitudinal markings should correspond with the pattern of broken lines for which the markers supplement or substitute.

Sections on Raised Pavement Markers as Vehicle Positioning Guides with Other Longitudinal Markings (Section 3B.12), Raised Pavement Markers Supplementing Other Markings (Section 3B.13), and Raised Pavement Markers Substituting for Pavement Markings (Section 3B.14) are included in the *TMUTCD.*

Application

Guidelines for materials and applications are included in the *Roadway Delineation Practices Handbook.*[9]

Advantages and Disadvantages

RPMs have the following advantages over standard painted markings:

- Retroreflective RPMs provide increased retroreflectivity under wet weather conditions.
- The vehicle vibration and audible tone produced by vehicles crossing over the RPMs creates a secondary warning.
- The capability of providing directional control of retroreflected color permits their use in conveying a wrong way message.
- Nonretroreflective RPMs can be used as transverse rumble strips.

Disadvantages of RPMs are:

- Their initial cost is high, which tends to limit application only to roadways where additional delineation is needed and where the surface will not soon be subject to major repair, replacement, or excavation.
- RPMs are also vulnerable to snowplows, although snowplow markers have been developed.[9]

Section 6

References

[1] *Texas Manual on Uniform Traffic Control Devices for Streets and Highways.* Texas Department of Transportation. 2003. http://www.dot.state.tx.us/TRF/mutcd.htm. Accessed January 2004.

[2] Gates, T.J., H.G. Hawkins, and E.R. Rose. *Pavement Marking Handbook.* FHWA/TX-04/4150-Pl, Draft Report. Texas Transportation Institute, College Station, Texas, 2003.

[3] Institute of Transportation Engineers. *Traffic Control Devices Handbook.* J.L. Pline, editor. IR-112. Washington, D.C., 2001.

[4] *Standard Alphabets for Highway Signs and Pavement Markings Reference Guide.* Department of Transportation, Federal Highway Administration, Washington D.C., 2000.

[5] Hawkins Jr. H., and H. Parham. *Feasibility Study of an All-White Pavement Marking System.* National Cooperative Highway Research Project, July 2002.

[6] Staplin, L., K. Lococo, S. Byington, and D. Harkey. *Highway Design Handbook for Older Drivers and Pedestrians*. FHWA-RD-01-103. Federal Highway Administration, May 2001.

[7] U.S. Access Board. *Draft Guidelines for Accessible Public Rights-of-Way*. June 17, 2002. http://www.access-board.gov/Rowdraft.htm. Accessed September 2003.

[8] American Association of State Highway and Transportation Officials. *Guide for the Planning, Design, and Operation of Pedestrian Facilities*. AASHTO, Washington, D.C., 2004.

[9] *Roadway Delineation Practices Handbook.* FHWA-SA-93-001, U.S. Department of Transportation, 2003.

Chapter 10
Signs

Contents:

Section 1
General

Overview

The *TMUTCD*[1] sets certain design features according to the functional category of signs:

- Regulatory signs inform the road user of a law, regulation, or legal requirement.
- Warning signs alert the road user of a condition that may be hazardous on or adjacent to the roadway.
- Guide signs provide directional or navigational information to the road user.
- Information signs provide the road user with information about facilities, services, businesses, and attractions on or near the roadway.

Properties of a sign's design include its shape, size, color, symbol, or message. Adherence to these principles as described in the *TMUTCD*[1] will provide the road user with consistency in reading and understanding traffic signs.[2] Sign placement and position are described in detail in Part 2 of the *TMUTCD*[1] <link>. Additional information regarding signs and sign installation is included in the *Traffic Control Devices Handbook.*[3] The TxDOT *Sign Crew Field Book*[4] also provides information on sign placement; however, it is for rural conditions.

Signs should be used only where justified by engineering judgment or studies. Roadway geometric design and sign application should be coordinated so that signing can be effectively placed to give the road user necessary regulatory warning, guidance, and other information.

Placement of Signs in Urban Areas

The road user in urban areas is faced with numerous traffic control devices, ranging from a variety of speed limits and parking controls to turning prohibitions. As a result, there is a delicate balance with providing the road user with sufficient information but not overwhelming the user with too much information. The need to provide information in a timely manner is critical since the road user may have to negotiate heavy traffic volumes and may not be able to change lanes or decide quickly on when and where to make turns. Additional concerns in urban areas include:

- Traffic control devices must compete with advertising signs for the attention of the road user.
- The placement of traffic control becomes a challenge because of narrow rights of way.
- The presence of sidewalks adjacent to the curb makes sign and signal placement difficult.
- The vertical clearance to the bottom of signs becomes a critical concern: the required 7 ft [2.1 m] minimum above the surface on which the sign is mounted is necessary to provide visibility above parked vehicles and for pedestrians. However, vans or similar vehicles may still block the visibility of the devices.

- Devices must be installed sufficiently far from the curb to prevent the devices from being damaged or from damaging vehicles.
- The spacing of signs is a concern due to the amount of information being conveyed to the urban road user. A common problem is the placement of a sign near an intersection as it may block the approach visibility to a Stop sign.
- Overhead sign installations should be considered because of the complexity of problems as noted above. However, overhead signs may cause some concerns about clutter and negative aesthetic impacts.[2]
- Signs should be located so that they do not protrude into the pedestrian area (Figure 10-1).
- Signs need to be placed so that they are not obstructed by signal poles, illumination poles, or other signs.
- The curb and sidewalk adjacent to disabled parking spaces should be kept free of signs or other obstacles to allow room for lift deployment from a vehicle.

Figure 10-1. Sidewalk Free of Protruding Objects.[5]

Dimensions

The standard sign dimensions in the *TMUTCD*[1] and in the *Standard Highway Sign Designs for Texas*[6] book are to be used unless engineering judgment determines that other sizes are appropriate. Where engineering judgment determines that sizes smaller than the standard dimensions are appropriate for use, the sign dimensions are to not be less than the minimum dimensions specified in the *TMUTCD*[1] and in the *Standard Highway Sign Designs for Texas*[6] book. Where engineering judgment determines that sizes larger than the standard dimensions are appropriate for use, standard shapes and colors are to be used and standard proportions are to be retained as much as practical.

Increases above standard sizes should be used where greater legibility or emphasis is needed. Wherever practical, the overall sign dimensions should be increased in 6 inch [152 mm] increments.

Symbols

In recent years, the use of symbols has become popular for certain types of signs, particularly warning signs. Figure 10-2 shows examples of symbol signs. The major advantages to symbols are greater overall readability, increased glance readability, and the ability to transcend language barriers. The effective use of symbols is preferable over word message signs in most situations. Two basic types of symbols are used:

- lines and arrows and
- pictographs.

Figure 10-2. Symbol Sign Examples.[1]

The *TMUTCD*[1] specifies that only the symbols shown in that document, or their mirror image, can be used for traffic signs. When considering devices not included in the *TMUTCD*, a request for experimentation is to be submitted and approved before installation of the device.

Word Messages

All word messages are to use standard wording and letters as shown in the *TMUTCD,*[1] the *Standard Highway Sign Designs for Texas*[6] book, and the *Standard Alphabets for Highway Signs and Pavement Markings*[7] except as noted in section 2A.06 in the *TMUTCD.*[1] Guidance for word messages includes:

- Word messages should be as brief as possible.
- Lettering should be large enough to provide the necessary legibility distance. A specific ratio, such as 1 inch [25 mm] of letter height per 40 ft [12 m] of legibility distance, should be used.
- Abbreviations (see Section 1A.14 of the *TMUTCD*[1]) should be kept to a minimum and should include only those that are commonly recognized and understood, such as AVE (for Avenue), BLVD (for Boulevard), N (for North), or JCT (for Junction).
- All sign lettering is to be in capital letters as provided in the *Standard Alphabets for Highway Signs and Pavement Markings Reference Guide*,[7] except for word messages on street name signs and destinations on guide signs which may be composed of a combination of lowercase letters with initial uppercase letters.

Section 2
Street Name Signs

Overview

Street name signs should be installed in urban areas at all street intersections regardless of other route signs that may be present and should be installed in rural areas to identify important roads that are not otherwise signed.

Street name signs provide critical guidance information to the motorists. Generally, through-traffic road users utilize route markings for guidance until they are required to leave the route to reach their destination. At that point street name signs become critical. Proper placement of street name signs along with the inclusion of block numbers also assists with wayfinding and timely response by police, fire, and emergency medical services.

Advance Street Name Signs

As a supplement to the street signs, advance street name signs provide information to the road user in time to safely position the vehicle in the proper lane to make a turn. Advance street name signs should use white letters on a green background and show the name of the upcoming street, the distance to the street, or a message such as NEXT SIGNAL or NEXT INTERSECTION. Figure 10-3 is an example of an advance street name sign. The *Traffic Control Devices Handbook*[3] recommends the use of advance street signs at:

- signalized intersections where spacing allows,
- other major highways and arterial streets, and
- where there are exclusive turn lanes.

Figure 10-3. Example of an Advance Street Name Sign.

Lettering for Street Name Signs

The *TMUTCD* provides the following guidance for lettering:[1]

- Lettering on street name signs should be at least 6 inches [152 mm] in height in capital letters, or 6 inch [152 mm] uppercase letters with 4.5 inch [114 mm] lowercase letters. Larger letter heights should be used for street name signs mounted overhead.
- For local roads with speed limits of 25 mph [40 km/h] or less, the lettering height may be a minimum of 4 inches [102 mm].
- Supplementary lettering to indicate the type of street (such as Street, Avenue, or Road) or the section of a city (such as NW) may be in smaller lettering, at least 3 inches [76 mm] high. Conventional abbreviations (see Section 1A.14 of the *TMUTCD*) may be used except for the street name itself.
- A symbol or letter designation may be used to identify the governmental jurisdiction.
- If a symbol or letter designation is used, the width of the symbol or letter designation is not to exceed the letter height of the sign.
- The symbol or letter designation should be positioned to the left of the street name.

Color, Retroreflectivity, and Illumination for Street Name Signs

Guidance for color and retroreflectivity includes:[1]

- The street name sign is to be retroreflective or illuminated to show the same shape and similar color both day and night. The legend and background are to be of contrasting colors.
- Street name signs should have a white legend on a green background. A border, if used, should be the same color as the legend.
- Street name signs may also be internally illuminated to provide additional visibility.

Placement of Street Name Signs

Guidance for placement includes:[1]

- In business districts and on principal arterials, street name signs should be placed at least on diagonally opposite corners so that they will be on the far right side of the intersection for traffic on the major street.
- In residential areas, at least one street name sign per street should be mounted at each intersection. They should be mounted with their faces parallel to the streets they name.
- When combined with a warning sign, the color of the supplemental street name sign should be a black message and border on a yellow background.
- Street name signs may be installed at both midblock and intersection locations.
- To optimize visibility, street name signs may be mounted overhead (see examples in Figure 10-4 and Figure 10-5). On intersection approaches, a supplemental street name

sign (see Section 2C.45 of the *TMUTCD*) may be installed separately or below an intersection-related warning sign.

- Street name signs may also be placed above a regulatory or Stop sign with no required vertical separation (see Figure 10-6).

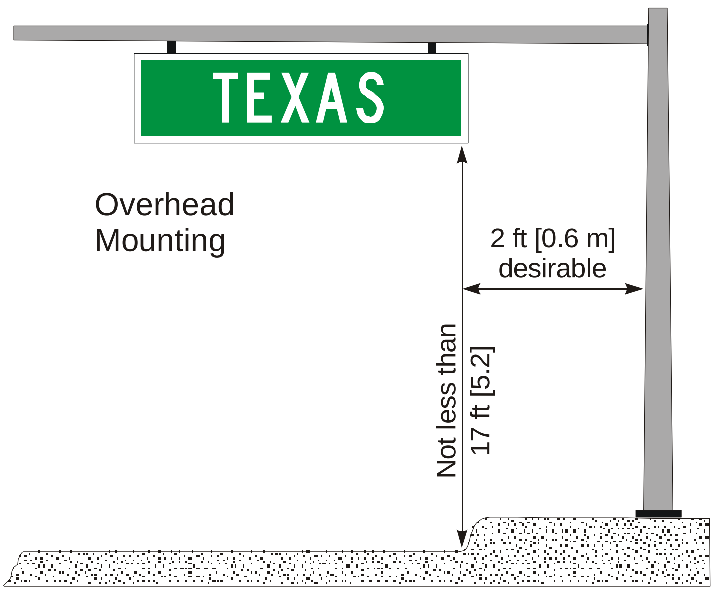


Figure 10-4. Overhead Street Name Sign on Mast Arm Post.

Figure 10-5. Example of Overhead Street Name Sign.

Figure 10-6. Example of Street Name Sign on Stop Sign.

Additional Recommendations for Older Drivers

The following recommendations on street name signs are included in the *Highway Design Handbook for Older Drivers and Pedestrians:*[8]

- To accommodate the reduction in visual acuity associated with increasing age, a minimum letter height of 6 inches [152 mm] is recommended for use on post mounted street name signs (D3).
- The use of overhead-mounted street name signs with minimum letter heights of 8 inches [203 mm] is recommended at major intersections.
- Wherever an advance intersection warning sign is erected (e.g., W2-1, W2-2, W2-3, W2-4), it is recommended that a supplemental street name sign accompany it.
- The use of redundant street-name signing for major intersections is recommended, with an advance street name sign placed upstream of the intersection at a midblock location, and an overhead-mounted street name sign posted at the intersection. Wherever practical, the midblock sign should be mounted overhead.
- When different street names are used for different directions of travel on a crossroad, the *Highway Design Handbook for Older Drivers and Pedestrians*[8] states names should be separated and accompanied by directional arrows on both midblock and intersection street name signs, as shown in Figure 10-7.

Figure 10-7. Signing for Different Street Names for Different Directions of Travel, Two Examples.

Section 3
Pedestrian Signs

Overview

Pedestrian signing is used in an attempt to reduce the potential for vehicle-pedestrian conflicts and to facilitate enforcement. A variety of signs are used to give direction to pedestrians and to provide information to drivers about pedestrians.

Sign Colors

Colors for pedestrian signs include the following:

- Pedestrian regulatory signs are white with black wording with red added for additional emphasis.
- Pedestrian warning signs are yellow or fluorescent yellow-green.
- Fluorescent yellow-green signing has been reserved as an option for pedestrian, bicycle, and school crossings to give them greater emphasis. TxDOT has chosen to further reserve the color for only school zones in order to give the most emphasis to areas where young children cross.

Comprehension of Pedestrian Laws and Traffic Control Devices

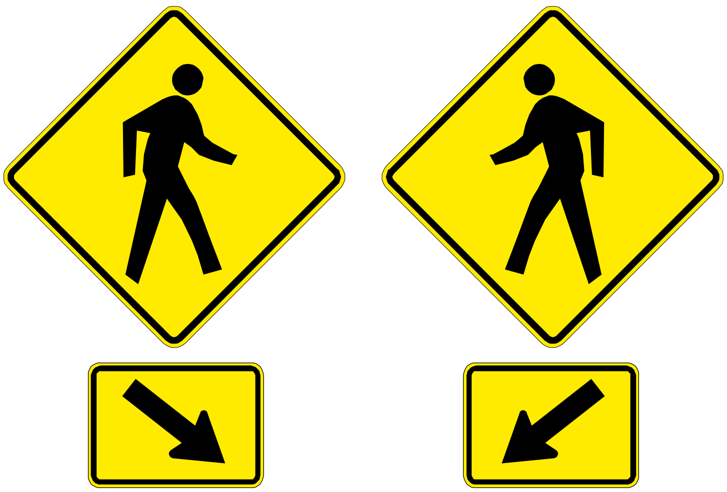
A questionnaire survey of over 4700 people for the American Automobile Association indicated that pedestrian laws and traffic control devices are poorly understood. For example, 83 percent of the drivers did not know the difference between an advance pedestrian crossing and a pedestrian crossing symbol sign. The study also found that pedestrians did not know many of the basic rules of the road: only 64 percent of drivers knew that they should walk on the left side of the road, facing traffic, when there are no sidewalks.[9]

Pedestrian Crossing Signs (Warning Signs)

Crossing signs may be used to alert road users to locations where unexpected entries into the roadway might occur. The *TMUTCD* includes the following comments on crossing signs:[1]

- Crossing signs are used adjacent to the crossing location.
- If the crossing location is not delineated by crosswalk pavement markings, the Crossing signs are to be supplemented with a diagonal downward pointing arrow plaque (W16-7P) showing the location of the crossing. If the crossing location is delineated by crosswalk pavement markings, the diagonal downward pointing arrow plaque is not required. (See Figure 10-8.)
- Crossing signs may be supplemented with supplemental plaques with the legend AHEAD, XX FEET [XX METERS], or NEXT XX MILES [NEXT XX KILOMETERS] to provide advance notice of crossing activity to road users.

- When a fluorescent yellow-green background is used, a systematic approach featuring one background color within a zone or area should be used. Mixing of standard yellow and fluorescent yellow-green backgrounds within a selected site area should be avoided.
- Crossing signs should be used only at locations where the crossing activity is unexpected or at locations not readily apparent.



Left Side Installation

Right Side Installation

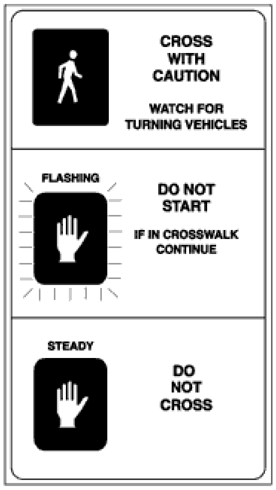
The sign and plaque may be yellow or fluorescent yellow-green. The sign and plaque shall be the same color.

Figure 10-8. Example of Crossing Signs (W11-2) with Supplemental Plaques (W16-7P).[3]

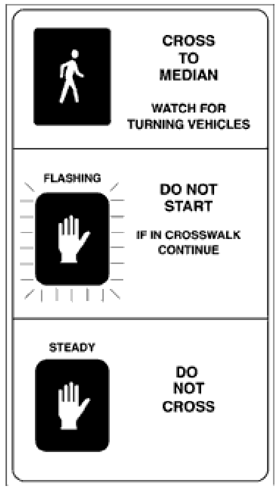
Additional Recommendations for Older Drivers

The *Highway Design Handbook for Older Drivers and Pedestrians*[8] makes the following recommendations regarding pedestrian signage at signalized intersections:

- To accommodate the shorter stride and slower gait of older pedestrians and their exaggerated "start-up" time before leaving the curb, pedestrian control signal timing based on a lower assumed walking speed is recommended. Information on walking speed is discussed in Chapter 2, Section 2 <link>.
- It is recommended that a placard explaining pedestrian control signal operations and presenting a warning to watch for turning vehicles be posted at the near corner of all intersections with a pedestrian crosswalk, using the design shown in Figure 10-9.
- It is recommended that at intersections where pedestrians cross in two stages using a median refuge island, the placard depicted in Figure 10-9a be placed on the median refuge island and that a placard modified as shown in Figure 10-9b be placed on the near corner of the crosswalk.[8]



a. Placard Sign for Intersections



b. Modified Placard for Use With Median Refuge Islands.

Figure 10-9. Placards Explaining Signal Operations.[8]

Section 4
Regulatory Signs for Intersections

Overview

Regulatory signs inform users of traffic laws, regulations, or restrictions applicable to a given roadway location, over a length of roadway, during specific time periods, or under specific circumstances. Some of the regulatory signs in the *TMUTCD*[1] do not actually describe a law, regulation, or restriction but describe controls related to the operation of a facility.[3]

The *TMUTCD* states that regulatory signs are to:

- be installed at or near where the regulations apply;
- clearly indicate the requirements imposed by the regulations;
- be designed and installed to provide adequate visibility and legibility in order to obtain compliance; and
- be retroreflective or illuminated to show the same shape and similar color by both day and night (unless otherwise specifically stated in the *TMUTCD*[1]), when the illumination requirement is not satisfied by street, highway, or strobe lighting.

The *TMUTCD* also specifies the shapes, colors, and sizes for regulatory signs in the following sections:[1]

- Design of Regulatory Signs (Section 2B.02) and
- Size of Regulatory Signs (Section 2B.03).

Regulatory signs should be used conservatively; if used to excess, the signs tend to lose their effectiveness.

Types of Regulatory Signs

Regulatory signs can be classified into several different types and categories according to the purpose of the sign. Regulatory signs related to intersections are discussed briefly in the following sections.

Stop Sign Applications

A Stop sign (R1-1) is used to indicate that traffic is always required to stop. At intersections where all approaches are controlled by Stop signs, a supplemental plaque (R1-3 or R1-4) is to be mounted below each Stop sign. The *TMUTCD*[1] (Section 2B.04) provides the description and size for Stop signs and supplemental plaques, and the design and application of stop beacons are described in Section 4K.05.

Stop signs should not be used unless engineering judgment indicates that one or more of the following conditions exist:

- at the intersection of a less important road with a main road where application of the normal right-of-way rule would not be expected to provide reasonably safe operation;
- at a street entering through a highway or street;
- at an unsignalized intersection in a signalized area; and/or
- where high speeds, restricted view, or crash records indicate a need for control by the Stop sign.

Additional information regarding Stop signs is included in Sections 2B.04, 2B.05, and 2B.06 of the *TMUTCD*.[1] Figure 10-10 illustrates some typical placements of Stop signs.

Multiway Stop Applications

Multiway stop control can be useful as a safety measure at intersections if certain traffic conditions exist, including approximately equal approach volumes or restricted sight distance. Multiway stops require all entering traffic to stop regardless of the situation. Stopping all vehicles obviously has an adverse impact on fuel consumption and efficiency. Additionally, excessive use of multiway stops can also lead to poor compliance. Information on the use of multiway stops is included in Section 2B.07 of the *TMUTCD*.[1]

Yield Sign Applications

The Yield sign assigns right of way at intersections where it may not be necessary to stop before proceeding into the intersection. Vehicles controlled by a Yield sign need to slow down or stop when necessary to avoid interference with conflicting traffic. Yield signs work well at T-intersections and ramp locations. However, their use at four-legged neighborhood intersections is diminishing.[3]

The *TMUTCD*[1] contains new yield line markings, which are distinguishably different from stop lines (see Chapter 9, Section 3 <link>). The *TMUTCD*[1] provides additional information on Yield signs and yield lines in Sections 2B.08, 2B.09, 2B.10, and 3B.16.

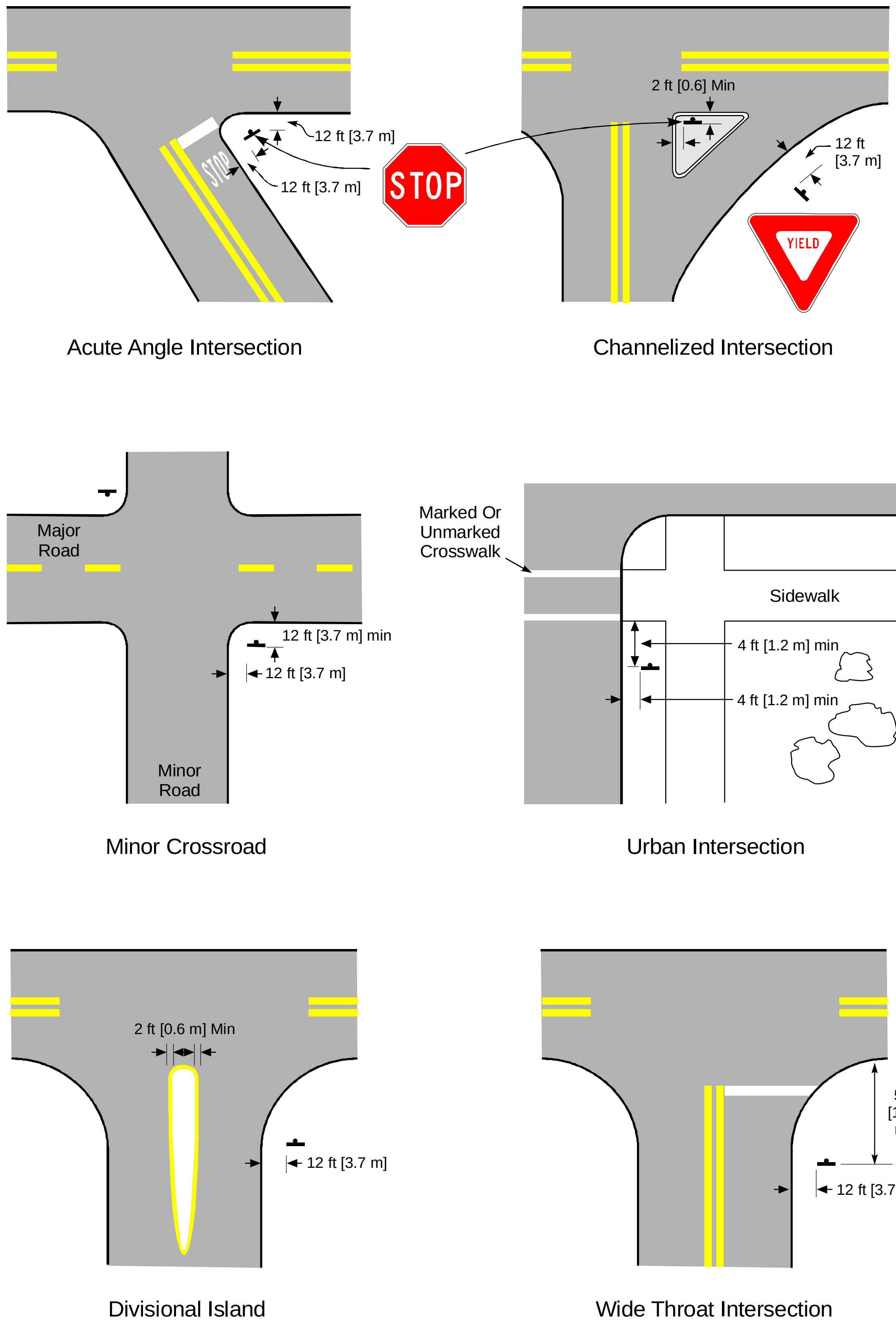


Figure 10-10. Typical Locations for Stop Signs at Intersections.[1]

Turn Prohibition Signs (R3-1 through R3-4)

Turn prohibition signs are installed where turns are prohibited except as noted below. Further guidelines include:

- Turn prohibition signs (see example in Figure 10-11) should be placed where they will be most easily seen by road users who might be intending to turn.
- If No Right Turn signs (R3-1) are used, at least one should be placed either over the roadway or at a right corner of the intersection.
- If No Left Turn signs (R3-2) are used, at least one should be placed either over the roadway, at a left corner of the intersection, on a median, or in conjunction with the Stop sign or Yield sign located on the near right corner.
- If No Turns (R3-3) signs are used, two signs should be used, one at a location specified for a No Right Turn sign and one at a location specified for a No Left Turn sign.
- If No U-Turn signs (R3-4) are used, at least one should be used at a location specified for No Left Turn signs.
- If advance signing is used, care must be taken so that no alley or public driveway exists between them and the intersection where the turning movement is prohibited.

However, if signals are present:

- The No Right Turn sign may be installed adjacent to a signal face viewed by road users in the right lane.
- The No Left Turn (or No U-Turn) sign may be installed adjacent to a signal face viewed by road users in the left lane.
- A No Turns sign may be placed adjacent to a signal face viewed by all road users on that approach, or two signs may be used.

Figure 10-11. Turn Prohibition Example from TMUTCD.[1]

Intersection Lane Control Signs (R3-5 through R3-8)

If used, intersection lane control signs:

- require road users in certain lanes to turn (see Figure 10-12),
- permit turns from a lane where such turns would otherwise not be permitted,

- require a road user to stay in the same lane and proceed straight through an intersection, or
- indicate permitted movements from a lane.

Intersection lane control signs have three applications:

- Mandatory Movement Lane Control signs (R3-5, R3-5a, and R3-7),
- Optional Movement Lane Control signs (R3-6), and
- Advance Intersection Lane Control signs (R3-8 series).

When used, intersection lane control signs should be:

- mounted overhead (with an option for ground mounting if the number of through lanes on an approach is two or less),
- placed over a projection of the lane to which it applies, and/or
- placed in advance of expected queues to allow time to move into the correct lane.

Use of an overhead sign for one approach lane does not require installation of overhead signs for the other lanes of that approach.

Intersection lane control signs may be omitted where:

- turning bays have been provided by physical construction or pavement markings, and
- only the road users using such turn bays are permitted to make a similar turn.

More specific information on Mandatory Movement Lane Control signs (R3-5, R3-5a, and R3-7), Optional Movement Lane Control signs (R3-6), and Advance Intersection Lane Control signs (R3-8 series) is provided in Sections 2B.18, 2B.19, 2B.20, and 2D.21 of the *TMUTCD.*[1]

Application 10-1 <link> includes an example of the lane control signs that could be used for dual left-turn lanes.

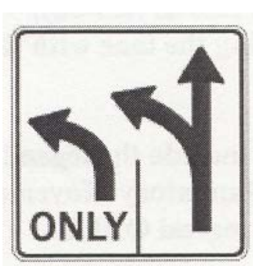


Figure 10-12. Intersection Lane Control Sign Example from the TMUTCD.[1]

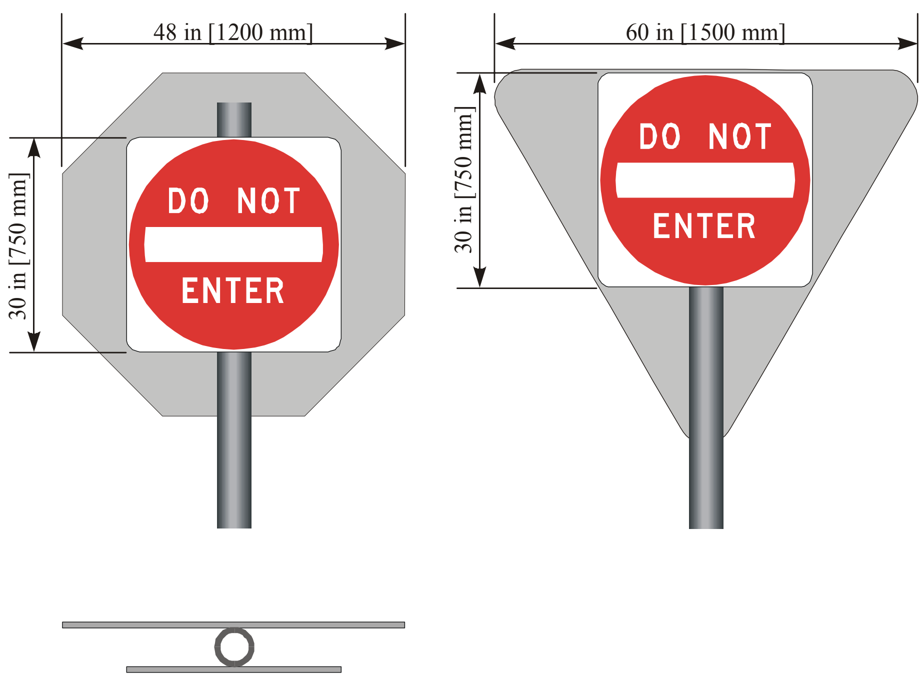
One Way Signs

One Way signs are primarily intended to inform unfamiliar drivers of the one-way direction of the traffic on the intersecting roadway but also to remind familiar drivers. They are generally placed near right and far left of the roadway. The *TMUTCD* contains information on their placement.

Do Not Enter and Wrong Way Signs

The Do Not Enter sign is intended to prohibit traffic from entering a restricted roadway. It is commonly used on ramps to controlled access facilities and one-way roadways. The Wrong Way sign is intended to supplement Do Not Enter signs. It should be used where there is no physical discouragement to prevent the wrong way travel. Such conditions include crossroads of divided highways and exit ramps that have intersecting crossroads.

Do Not Enter signs are typically placed back-to-back with Stop and Yield signs when limited right-of-way conditions exist (see Figure 10-13). The Do Not Enter signs should be placed so that they do not obscure the shape of the Stop or Yield sign as in the example shown in Figure 10-13. Otherwise, the driver on the cross street may not realize whether the approach is stop controlled. Figure 10-14 is an example location where the Stop sign is obscured by the Do Not Enter Sign.



(A) Back of Stop Sign and Do Not Enter Sign

(B) Back of Yield Sign and Do Not Enter Sign.

Figure 10-13. Back-to-Back Mounting of Do Not Enter Signs on Stop and Yield Signs.[3]

(A) Stop Sign and Back of Do Not Enter Sign (B) Do Not Enter Sign
Figure 10-14. An Example of a Do Not Enter Sign Obscuring the Shape of a Stop Sign.

Divided Highway Crossing Signs

The Divided Highway Crossing sign may be used to advise roadway users that they are approaching an intersection with a divided highway. Additional guidance includes:[1]

- When used at a four-legged intersection, the R6-3 sign is used.
- When used at a T-intersection, the R6-3a sign is used.
- The Divided Highway Crossing sign may be located on the near right corner of the intersection and may be mounted beneath a Stop or Yield sign or on a separate support.

Parking, Standing, and Stopping Signs (R7 and R8 Series)

Signs governing the parking, stopping, and standing of vehicles cover a wide variety of regulations. Typical examples of parking, stopping, and standing signs are shown in Figure 10-15, and additional guidance is provided in Sections 2B.35 through 2B.37 of the *TMUTCD.*[1]

Figure 10-15. Parking and Bus Sign Examples from TMUTCD.

Preferential Lane Signs

Preferential lanes in urban areas are lanes designated for special traffic uses such as light rail, buses, taxis, or bicycles. Preferential lane treatments might be as simple as restricting a turning lane to a certain class of vehicle during peak periods or as sophisticated as providing a separate roadway system within a highway corridor for certain vehicles. Guidance for preferential lanes follows:

- Preferential lane assignments may be made on a full-time or part-time basis.
- Preferential lane sign spacing should be determined by engineering judgment based on prevailing speed, block length, distances from adjacent intersections, and other considerations.
- The symbol and word message that appear on a particular Preferential Lane sign will vary based on the specific type of allowed traffic and on other related operational constraints that have been established for a particular lane.
- At the end of a preferential lane, a Lane Ends sign (R3-12a, R3-15a, or R3-16a) is used.

The R3-11b (ground mounted) or R3-14a (overhead) word message signs should be used in situations where a preferential lane is designated exclusively for bus and/or taxi use. The R3-11b sign should be located adjacent to the preferential lane, and the R3-14a sign should be mounted directly over the lane.

Additional Recommendations for Older Drivers

The *Highway Design Handbook for Older Drivers and Pedestrians*[8] (referred to as the *Older Driver Handbook*) includes several recommendations regarding signing for older drivers. Following are recommendations related to signing at intersections.

Traffic Control for Left-Turn Movements at Signalized Intersections. The *Older Driver Handbook* recommends:

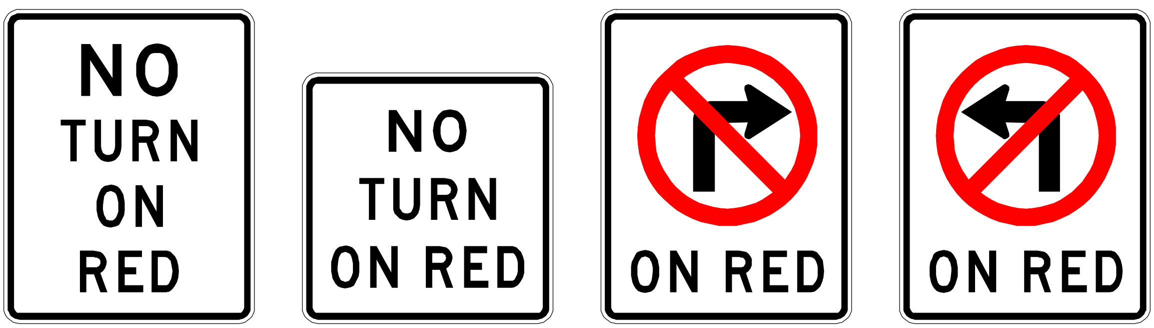
- The use of redundant upstream signing (R10-12) is recommended to advise left-turning drivers of permitted signal operation.

- It is also recommended that the signing afford at least a 3 second preview (at operating speeds in the left-turn lane) before the intersection, using either overhead or median sign placement.

Traffic Control for Right-Turn/RTOR Movements at Signalized Intersections. The *Older Driver Handbook* recommends:

- The signing of prohibited RTOR movements is recommended, with sign placement on the overhead mast arm and on the opposite corner of the intersection. Figure 10-16 shows appropriate signs in the *TMUTCD*.

- Where RTOR is permitted and a pedestrian crosswalk is marked on the intersecting roadway, the word message TURNING TRAFFIC MUST YIELD TO PEDESTRIANS should be used per section 2B.40 of the *TMUTCD*. An overhead or roadside location that is easily visible to the motorist prior to initiating the turning maneuver should be considered.



R10-11a R10-11b R10-11c R10-11d

Figure 10-16. Signing for Prohibited Right Turn on Red (TMUTCD).

One-Way/Wrong-Way Signage. The *TMUTCD* includes typical signing arrangements for one-way signing for divided highways (less than and greater than 30 ft [9.1 m] medians and at intersections) in Section 2A.16. The *Older Driver Handbook* recommends:

- Approaches to divided highways should be consistently signed. Use of the Divided Highway Crossing sign (R6-3) is the recommended current practice, but this sign may be replaced or supplemented with new treatments when they are demonstrated through research to provide improved comprehensibility to motorists.

- For divided highways with medians of 30 ft [9.1 m] and under, use four One Way signs (the *TMUTCD* shows typical locations in Figure 2A-3[1]).

- For medians over 30 ft [9.1 m], use eight One Way signs (the *TMUTCD* shows typical locations in Figure 2A-4[1]).

- For T-intersections, use a near-right side One Way sign and a far-side One Way sign. The preferred placement for the far-side sign is opposite the extended centerline of the approach leg as shown in *TMUTCD* Figure 2A-6.[1] Where the preferred far-side location is not feasible because of blockage, distracting far-side land use, or an excessively wide approach leg, etc., engineering judgment should be applied to select the most conspicuous alternate location for a driver who has not yet initiated the wrong-way turning maneuver.

- For intersections of a one-way street with a two-way street, place One Way signs at the near-right/far-left locations, regardless of whether there is left-to-right or right-to-left traffic.
- As a general practice, use Do Not Enter and Wrong Way signs at locations where the median width is 20 ft [6 m] and greater; consideration should also be given to the use of these signs for median widths narrower than 20 ft [6 m], where engineering judgment indicates a special need.

Stop- and Yield-Controlled Intersection Signage. System-wide recommendations to improve the safe use of intersections by older drivers, where the need for stop control or yield control has already been determined, include the following:

- Use standard size 30 inch [762 mm] Stop (R1-1) and standard size 36 inch [914 mm] Yield (R1-2) signs, as a minimum.
- For Stop (R1-1) and Yield (R1-2) signs, use a minimum in-service sign background (red area) retroreflectivity level of 12 cd/m^2/lux for roads with operating speeds under 40 mph [64 km/h], and 24 cd/m^2/lux for roads with operating speeds of 40 mph [64 km/h] or higher.
- Use a supplemental warning sign panel mounted below the Stop (R1-1) sign, as illustrated in Figure 10-17, for two-way stop-controlled intersections selected on the basis of accident experience; where the sight triangle is restricted; or wherever a conversion from four-way stop to two-way stop operations is implemented. (Note: The *TMUTCD*[1] considers this application of the Cross Traffic Does Not Stop sign to be a regulatory use.)

Figure 10-17. Supplemental Panel to Mount below Stop Sign.

- Use a Stop Ahead sign (W3-1a) where the distance at which the Stop sign is visible is less than the AASHTO stopping sight distance (SSD) at the operating speed, plus an added preview distance of at least 2.5 seconds. (Stopping sight distance dimensions are available in the TxDOT *Roadway Design Manual*[10] <link>.) Consideration should also be given to the use of transverse pavement striping or rumble strips upstream of stop-controlled intersections where engineering judgment indicates a special need due to sight restrictions, high approach speeds, or other geometric or operational characteristics likely to violate driver expectancy.

Devices for Lane Assignment on Intersection Approach. The *Older Driver Handbook* recommends:

- The consistent placement of lane-use control signs (R3-5, R3-6) overhead on the signal mast arm at intersections as a supplement to pavement markings and shoulder- and/or median-mounted signage. (See Figure 10-18.)
- The consistent posting of lane-use control signs plus application of lane-use arrow pavement markings at a preview distance of at least 5 seconds (at operating speed) in

advance of a signalized intersection, regardless of the specific lighting, channelization, or delineation treatments implemented at the intersection. Signs should be mounted overhead wherever practical, but they may be shoulder- and/or median-mounted in other cases.

Figure 10-18. Placement of Overhead Lane-Use Control Signs.[8]

Section 5
Warning Signs for Intersections

Overview

Warning signs are intended to improve the overall safety of the roadway environment by providing the driver with a warning of conditions that might not be apparent or expected. Such conditions, known as potential hazards, do not indicate a defective condition or unsafe situation; they are merely used to describe a condition that may be unfamiliar or unknown to the driver and may present the potential for injury or damage if the proper response is not performed.[3]

Guidelines for the design and use of warning signs are contained in Chapter 2C of the 2003 Edition of the *TMUTCD.*[1] The new version includes many changes in the chapter on warning signs, and one of the most significant changes is a more thorough treatment of supplemental plaques. Another significant change is the introduction of signs with metric measurements.

The *TMUTCD* states that the use of warning signs is to be based on an engineering study or on engineering judgment. Additionally, the use of warning signs should be kept to a minimum as the unnecessary use of warning signs tends to breed disrespect for all signs.[1] Warning signs should be removed or covered for seasonal or temporary activities at times when the activities do not exist.[1]

Signs related to intersections are discussed in the following sections. Part 2 of the *TMUTCD*[1] provides additional information on warning signs along with guidelines for their installation.

Intersection Control Warning Signs

Intersection control devices are commonly used to provide orderly assignment of right of way at intersections. The four types of intersection control are: Yield signs, Stop signs, intersection control beacons, and traffic control signals. In some cases, these control devices may not be visible far enough in advance to allow a vehicle to take the appropriate action at the intersection. Most of the advance traffic control signs are intended to improve this situation by providing the driver with advance warning so that the vehicle can be stopped before entering the intersection (if a stop is necessary). The signs used to warn of the type of intersection control include:

- Stop Ahead (W3-3 or W3-1a),
- Yield Ahead (W3-2 or W3-2a),
- Signal Ahead (W3-3 or W3-3a),
- Be Prepared To Stop (W4-3), and
- Cross Street Traffic Does Not Stop (W4-4).

The Cross Traffic Does Not Stop sign is intended to provide drivers with an indication of the difference between two-way and multiway stop-controlled intersections. It is a new sign in the 2003 *TMUTCD*, and it can be used as a regulatory or a warning sign. As a warning sign, it can be used below a Stop Ahead sign in advance of a stop-controlled intersection (either a two-way stop controlled or a T-intersection) to warn drivers that intersecting traffic will not stop. When used in this manner, the plaque should be black on yellow. The sign may also be used below the Stop sign as a regulatory sign in which case it would be black on white.[1]

The *TMUTCD* requires the use of intersection control warning signs when the control devices (Stop signs, Yield signs, or signals) are not visible for a sufficient distance to permit the road user to respond to the device. The visibility obstructions may be permanent or intermittent (such as foliage). If intermittent, engineering judgment should be used to determine if an advance warning sign is needed. The *TMUTCD* also allows these warning signs to be used to provide additional advance emphasis of the primary traffic control device, even if visibility is adequate.

Merge, Added Lane, Lane Ends Signs

A Merge sign (W4-1) may be used to warn road users on the major roadway that merging movement might be encountered in advance of a point where lanes from two separate roadways converge as a single traffic lane and no turning conflict occurs.

The Added Lane sign (W4-3) should be installed in advance of a point where two roadways converge and merging movements are not required. When possible, the Added Lane sign (W4-3) should be placed such that it is visible from both roadways; if this is not possible, an Added Lane sign should be placed on the side of each roadway.

The Lane Ends Merge Left (Right) sign (W9-2) should be used to warn of the reduction in the number of traffic lanes in the direction of travel on a multilane highway.

Intersection Warning Signs

A Cross Road (W2-1), Side Road (W2-2 or W2-3), T-Symbol (W2-4), or Y-Symbol (W2-5) sign may be used on a roadway, street, or shared-use path in advance of an intersection to indicate the presence of an intersection and the possibility of turning or entering traffic. The Circular Intersection sign (W2-6) accompanied by an educational word message plaque may be installed in advance of a circular intersection.

Crossing Signs

Entry or Crossing signs are used to provide advance notice of an entry or cross or to indicate the location of a crossing. Warning signs for pedestrian crossings are discussed in Section 3 of this chapter <link>. A Fire Station warning sign (W11-8) may be necessary where a fire station is located in close proximity to an intersection. Section 2C.37 of the *TMUTCD*[1] provides additional information.

Section 6
Guide Signs for Intersections

Overview

Guide signs are essential to:

- Direct road users along streets and highways.
- Inform road users of intersecting routes.
- Direct road users to cities, towns, villages, or other important destinations.
- Identify nearby rivers and streams, parks, forests, and historical sites.
- Give road users information that will help them in the most simple, direct manner possible.

The major emphasis of conventional guide signing is on highway class, number, and cardinal direction. This information is provided at the intersection where the maneuver is performed. Destination information (for cities) is provided in advance of the intersection and is not repeated at the intersection. However, drivers have become accustomed to using destination information to navigate on freeways and have carried that preference onto conventional highways. Therefore, while the emphasis of conventional guide signing remains on class, number, and direction, destination information is a critical element of the signing system and must be given equal consideration.[4]

Types of Guide Signs

The *TMUTCD*[1] provides detailed information on the following guide signs in Part 2, Chapter 2D:

- Route Sign Assembly,
- Junction Assembly,
- Advance Route Turn Assembly,
- Directional Assembly,
- Confirming or Reassurance Assemblies,
- Trailblazer Assembly,
- Destination and Distance,
- Street Name (discussed in Chapter 10, Section 2 <link>), and
- Traffic Signal Speed signs.

Section 7

References

[1] *Texas Manual on Uniform Traffic Control Devices for Streets and Highways.* Texas Department of Transportation, 2003. http://www.dot.state.tx.us/TRF/mutcd.htm. Accessed January 2004.

[2] Institute of Transportation Engineers. *Traffic Engineering Handbook.* 5th Edition. J.L. Pline, editor. ITE. Washington, D.C., 1999.

[3] Institute of Transportation Engineers. *Traffic Control Devices Handbook.* J.L. Pline, editor. IR-112. Washington, D.C., 2001.

[4] Texas Department of Transportation. *Sign Crew Field Book. A Guide to Proper Location and Installation of Signs and Other Devices.* 2nd Edition. TxDOT, Traffic Operations Division, April 1998.

[5] Federal Highway Administration. *Designing Sidewalks and Trails for Access, Part 2.* Best Practice Design Guide. FHWA-EP-01-027. September 2001.

[6] *Standard Highway Sign Designs for Texas.* Texas Department of Transportation. ftp://ftp.dot.state.tx.us/pub/txdot-info/trf/shsd/Navigate.pdf. Accessed January 2004.

[7] *Standard Alphabets for Highway Signs and Pavement Markings Reference Guide.* Department of Transportation, Federal Highway Administration, Washington, D.C., 2000.

[8] Staplin, L., K. Lococo, S. Byington, and D. Harkey. *Highway Design Handbook for Older Drivers and Pedestrians*. FHWA-RD-01-103. Federal Highway Administration, May 2001.

[9] Tidwell, J.E. and D. Doyle. “Driver and Pedestrian Comprehension of Pedestrian Laws and Traffic Control Devices.” AAA Foundation for Traffic Safety, Washington D.C., 1993.

[10] Texas Department of Transportation. *Roadway Design Manual*. Revised April 2002. http://manuals.dot.state.tx.us/dynaweb/coldesig/forms/rdw.pdf. Accessed August 30, 2002.

Chapter 11
Influences from Other Intersections

Contents:

Section 1
Influences from Other Intersections

Overview

The presence of nearby intersections can influence intersection design and traffic operations significantly. Queuing, crossing movements, and signal coordination may all be adversely impacted, depending primarily on the traffic control present and distance separating the intersections.

Queuing

Intersections that are closely spaced and have significant queuing can easily exceed the amount of available storage space. As shown in the text of the TxDOT *Roadway Design Manual*[1] Chapter 3, Section 2, Speed Change Lane <link> and Sections 4-2 <link> and 4-3 <link> of these guidelines, the required length of a turn lane consists of a taper, deceleration length, and storage length. These lengths are found in Table 3-3 of the TxDOT *Roadway Design Manual* <link>.

If left- or right-turn lanes are provided, spacing between intersections may reduce the effectiveness of those turn lanes by requiring a reduced length that may not accommodate the queues. If the queues exceed the available storage space, vehicles may block through lanes or nearby intersections. Consideration may be given to the use of dual left-turn lanes if the left-turn queue exceeds the available space between intersections.

Crossing Movements

It is desirable that opposing intersections are either directly aligned or separated by an adequate distance to require two separate movements in a crossing maneuver, thus eliminating "jog" crossing movements. Intersections that are offset by only a minimal amount encourage undesirable driver behavior when drivers proceed from one street to the other in one maneuver (see Figure 11-1). Minimum separation distances of 200 to 400 ft [61 to 122 m] have been recommended.[2,3] If those separation distances cannot be attained, realignment should be investigated to see if the crossroads can be aligned. ***Application 11-1*** <link> provides an example of the realignment of a jog intersection to form a single intersection.

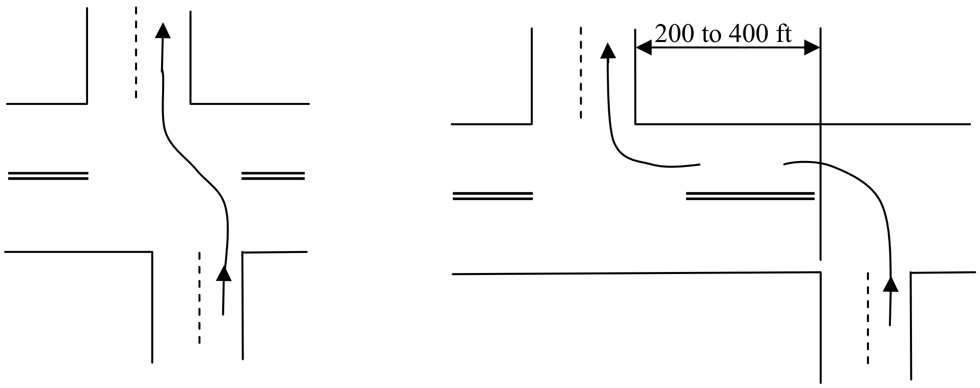


Figure 11-1. Elimination of Jog Crossing Movements by Increasing Separation.

Signal Coordination

Motor Vehicles. Signal coordination helps reduce motorist delay by keeping platoons moving through adjacent traffic signals <insert link to *Traffic Signals Manual*, Chapter 4, Section 2>.[4] The spacing of signalized intersections along a corridor directly affects the possibility of providing signal coordination. If signals are too close or their spacing is not regular, they can eliminate the possibility of providing coordination in both directions along the corridor.

Progression can sometimes be obtained if the intersections are not located at the optimum points. However, reductions in available green time to the crossing roadway may be required (resulting in increased delay at the intersection) or progression may be provided in only one direction. Further information on signal interconnection can be found in Signal Interconnection in this chapter.

Bicyclists. Traffic signals are timed to accommodate smooth motor vehicle flows at a desired operational speed. In urban areas, this ranges from 15 to 45 mph [24 to 72 km/h]. These speeds are higher than typical bicycling speeds (10 to 20 mph [16 to 32 km/h]). Signal timing can create difficulties for bicyclists who are using their momentum to maintain a constant speed with the existing signal timing. They may be able to maintain their speed through two or three signals and then have to stop, wait, and start over again at the next signal. This can tempt bicyclists to “jump” or to “run” red signal indications. Figure 8-14 illustrates a signalized intersection sensitive to bicycles.

Where bicycle use is high, signal timing can account for the convenience of bicyclists. For example, the traffic signals in downtown Portland, Oregon, are timed for speeds of 12 to 16 mph [19 to 26 km/h], allowing bicyclists to ride with traffic.

Section 2
Highway Railroad Grade Crossing

Overview

Intersections near highway railroad grade crossings present a number of challenges to designers. Successful designs require consideration of:

- appropriate grades,
- clearance between the intersection and the grade crossing,
- channelization, and
- illumination.

TxDOT and local policies regarding the use of four-quadrant gates and quiet zoning should be reviewed.

Grades

The close proximity of an intersection to a highway railroad grade crossing complicates the process of selecting appropriate grades that may serve both the intersection and the grade crossing. Compromises in grades may have to be made because of conflicts between the intersection and the grade crossing, although the designer should strive to provide the best design possible.

When roadways are widened toward railroad tracks, frequently the effect is to make any grades present more severe (see Figure 11-2). The problem is compounded because railroad track elevations tend to rise over time due to re-ballasting operations.

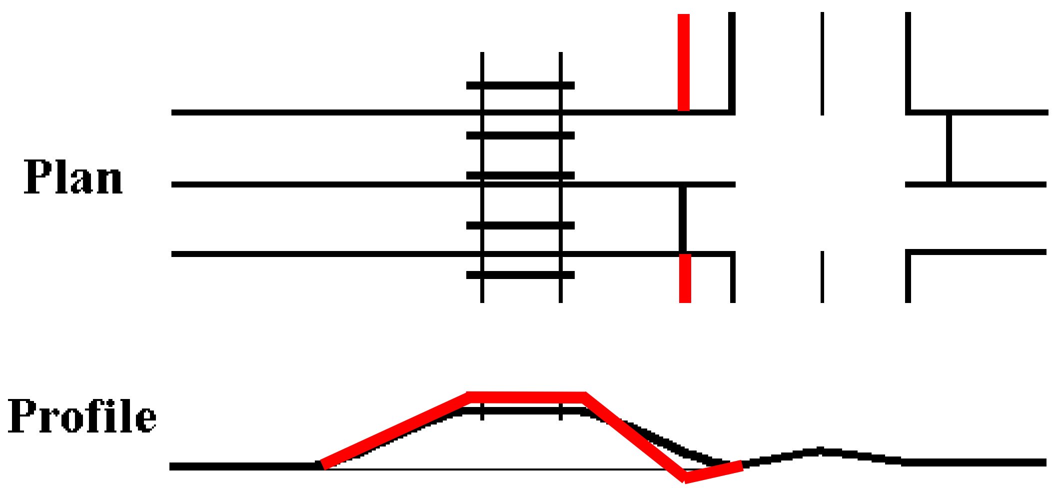


Figure 11-2. Effect of Widening Roadway and Raising Railroad on Grades.

If a high-profile or "hump" crossing is present, it should be reviewed to determine whether a problem could result from vehicles striking the crossing with their undercarriage. According to the *Green Book,*[5] it is desirable that the crossing surface be as level as possible. If low-clearance vehicles are used as a design vehicle and if the vertical alignment cannot practically be made level, the *Green Book* provides a suggested alignment.

Potential for Vehicles to Strike Railroad Tracks

If the crossing cannot reasonably be made to meet these guidelines, it should be evaluated further to determine whether a design vehicle can cross without hanging up. Software programs have been developed and are available to simulate the movement of trucks over grade crossings. Users enter roadway profile data and graphically review vehicle movement over the roadway to determine where hang-up problems can occur.

The selection of a specific design vehicle depends upon local conditions, but one design vehicle that has been suggested has:

- a wheelbase of 36 ft [11 m],
- a clearance of 5 inches [127 mm], and
- an overhang of 0 ft [0 m] front and rear.[6]

Typical dimensions for other selected type-specific design vehicles are shown in Table 11-1, although the dimensions may vary somewhat depending on the manufacturer. The HANGUP[7] software may be obtained from the Federal Highway Administration.

Table 11-1. Potential Low-Clearance Design Vehicles.[8]

Vehicle Type	Overall Length (ft) [m]	Overhang (ft) [m]		Wheelbase (ft) [m]	Clearance (ft) [mm]
		Front	Rear		
Double Bottom/ Low-Boy Semitrailer[A,B]	35 [10.7]	0	0	30 [9.1]	10 [254]
	48 [14.6]	0	0	29 [8.8]	6 [152.4]
Grain Trailer[C]	48 [14.6]	0	3 [0.9]	39 [11.9]	17 [431.8]
Livestock Trailer[C]	48 [14.6]	0	5 [1.5]	39 [11.9]	14 [355.6]

[A] Based on design vehicle used by TxDOT Pharr District for design of typical railroad crossings.
[B] Based on specifications for BlackHawk 5000p Series Trailer, Etnyre Trailer Company, Oregon, Il.
[C] Based on specifications provided by Wilson Trailer Company, Sioux City, Ia.

For existing crossings that have a high potential for problems with low-clearance vehicles, guidelines for low ground clearance in the *TMUTCD*[9] should be followed:

- Whenever conditions are sufficiently abrupt to create a hang-up for long wheelbase vehicles or trailers with low ground clearance, the Low Ground Clearance (W10-5) warning symbol sign shall be installed in advance of the crossing (Figure 11-3).
- Because the new warning symbol may not be readily recognizable by the public, the *TMUTCD* states that it shall be accompanied by an educational plaque, LOW GROUND CLEARANCE, which is to remain in place for at least three years after initial installation.

The sign should be placed on each approach to the crossing far enough in advance that low-clearance vehicles can turn around before reaching the crossing. The *TMUTCD* guidelines state that a supplemental message such as “Ahead,” “Next Crossing,” or “Use Next

Crossing" (with appropriate arrows) should be placed at the nearest intersecting road where a vehicle can detour or at a point on the roadway wide enough to permit a U-turn.

Figure 11-3. Low Ground Clearance Highway-Rail Grade Crossing Sign (W10-5).[9]

Clearance Distance

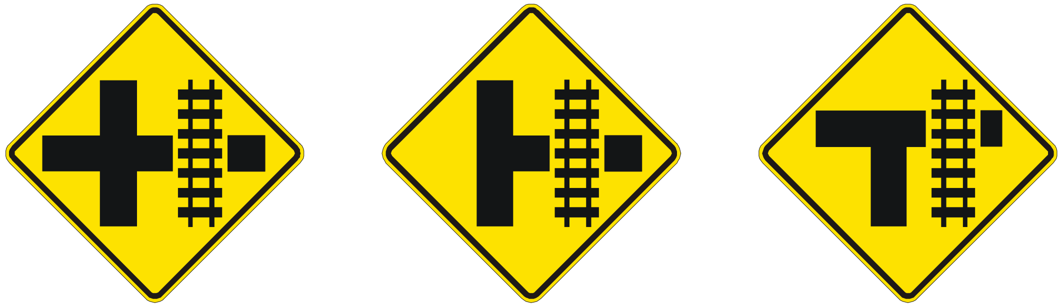
The separation distance between a railroad grade crossing and an intersection affects both passive devices (i.e., signs and pavement markings) and active devices (i.e., gates and traffic signals). The need for additional signs warning drivers of their proximity to the railroad grade crossing and for consideration of traffic signal preemption are controlled by the clearance distance between the railroad grade crossing and the intersection.

Although it may appear cheaper or easier to widen a highway toward parallel railroad tracks because of ROW availability, this can result in significant operational problems if inadequate room is available for vehicle storage between the highway and the railroad.

Signs

The *TMUTCD*[9] requires a number of signs and devices for highway railroad grade crossings. Designers should consult Part 8 of the *TMUTCD,*[9] Traffic Controls for Highway-Rail Grade Crossings, to determine the overall signing recommendations for the grade crossing. A review of those elements affected by the presence of a nearby intersection is provided here.

Signing to alert drivers on the parallel roadway to the nearby presence of the grade crossing shall be provided if a separation distance is less than 100 ft [30 m] (see Figure 11-4).[9] The signs should be placed in accordance with standard distance and viewing recommendations in the *TMUTCD*.



W10-2   W10-3   W10-4

Figure 11-4. Alternative Warning Signs for Use on Roadways Parallel to Railroad Tracks.[9]

If traffic signals are preempted by approaching trains (required if train tracks are within 200 ft [61 m] of a signalized intersection), all turning movements toward the tracks should be prohibited during the preemption. Standard traffic signs or active signs can be used (see Figure 11-5) (i.e., changeable message signs, appropriate traffic signal displays, etc.).

R10-11a

Figure 11-5. Turn Prohibition Sign.[9]

If engineering judgment determines a likelihood for vehicles stopping on the tracks, the Do Not Stop On Tracks sign should be used (Figure 11-6). If the design vehicle cannot be stored between the intersection and the railroad tracks, a storage space sign should be used (Figure 11-7).

Figure 11-6. Stop on Tracks Prohibition Sign.[9]

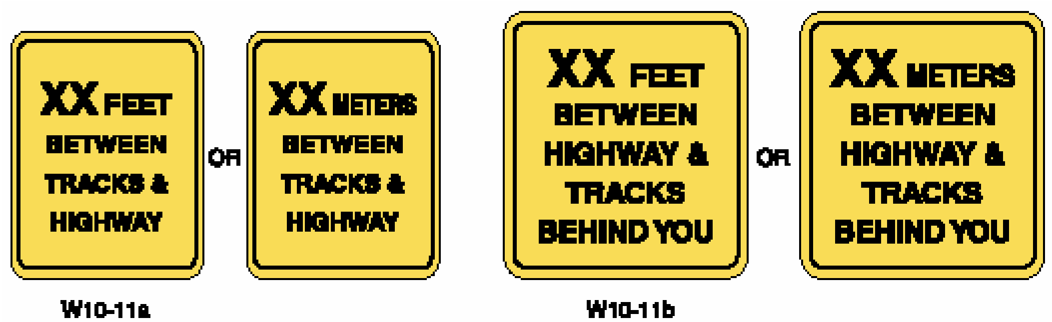


Figure 11-7. Storage Space Signing (U.S. Customary,[9] Metric[10]).

Signal Preemption

Intersections with traffic signals near highway railroad grade crossings with active railroad grade crossing devices (i.e., flashing lights or gates) should be reviewed to determine whether the signals and active devices should be interconnected. Conflicts between the traffic control signals and the highway-rail grade crossing flashing-light signals could result in the entrapment of vehicles on the highway-rail grade crossing.

If less than 200 ft [61 m] separates a traffic signal from an active railroad grade crossing device, interconnections between the devices should be provided to allow signal preemption. Under certain circumstances, traffic queues may develop that are longer than 200 ft [61 m]; in these situations signal preemption may be warranted even though the *TMUTCD* may not require it. Prediction methods for this circumstance can be found in *Design Guidelines for At-Grade Intersections Near Highway-Railroad Grade Crossings*.[8] Signal preemption is used to prevent trapping motorists by coordinating the messages provided by the traffic signal and grade crossing devices. The ITE Recommended Practice on signal preemption[11] and the *TMUTCD*[9] should be consulted to determine an appropriate design for the intersection. The Traffic Operations Division has developed worksheets that may be used to assist signal preemption design.

Channelization

Channelization at highway railroad grade crossings can help to restrict vehicles from leaving their lane and driving around lowered gates, as well as providing a mounting point for traffic control devices. A design developed to facilitate these goals is shown in Figure 11-8.

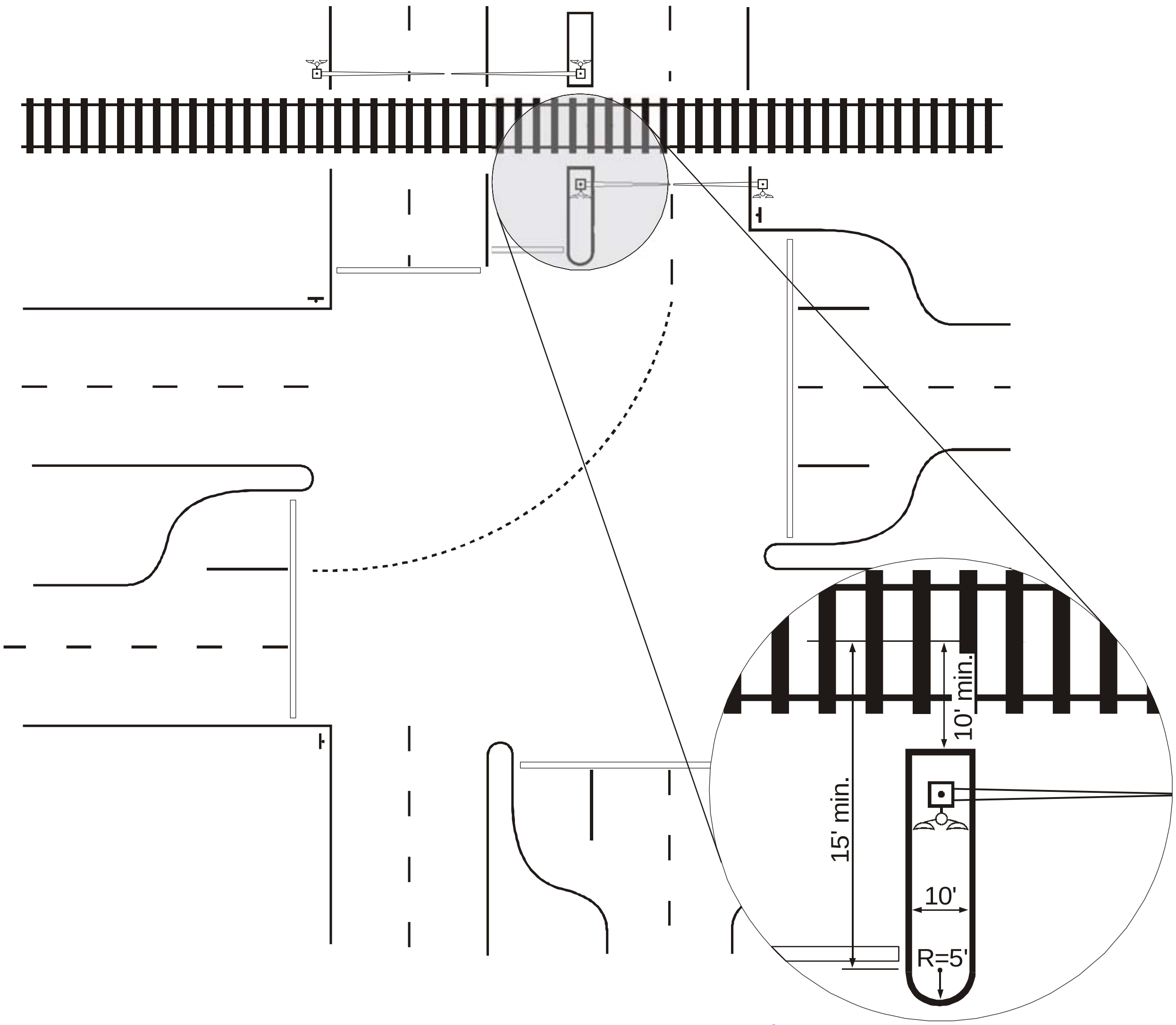


Figure 11-8. Channelizing Island at Railroad Grade Crossing.[8]

Illumination

Consideration for illuminating railroad grade crossings should be given when an engineering study determines that:

- Better nighttime visibility of the train and the highway-rail grade crossing is needed (for example, where a substantial amount of railroad operation is conducted at night).
- Where train speeds are low and highway-rail grade crossings are blocked for long periods.
- Crash history indicates that drivers experience difficulty in seeing trains or traffic control devices during hours of darkness.

Recommended lighting design details are contained in the American National Standards Institute's (ANSI) "Roadway Lighting"[12] available from the Illuminating Engineering Society.

Pedestrians

Railroad track crossings must be defined by detectable warnings when sidewalks cross or adjoin the tracks unless curbs, railings, or other elements separate the pedestrian areas and the train.[13] The detectable warnings should be placed outside the dynamic envelope of the train (the clearance required for the train and its cargo overhang).[9]

Because train tracks may present gaps in the sidewalk that are difficult to cross, sidewalk crossings of the tracks should be minimized as much as practical.

Bicyclists

Railroad crossings can be problematic for bicyclists if they are not at right angles to the rails.[14] The greater the crossing deviates from a 90 degree angle to the rails, the greater is the potential for trapping the bicyclist's front wheel beside the rail. When crossing angles are less than 45 degrees, additional paved shoulder width or path should be provided to allow bicyclists to cross at a safer angle (further information is provided in AASHTO's *Guide for the Development of Bicycle Facilities*[14]).

Other Issues

Quiet Zoning. Some communities have enacted "quiet zoning" ordinances that restrict the use of train whistles at highway-railroad grade crossings. According to the Federal Railroad Administration's proposed rule[15] each crossing in a quiet zone must be equipped with automatic gates and flashing lights that conform to the standards contained in the *TMUTCD*.[9] Further, the *TMUTCD* requires that a No Train Horn sign (W10-9) shall be installed at each highway-rail grade crossing where there is a Federal Railroad Administration authorization for trains to not sound a horn. The sign should be mounted as a supplemental plaque below the Advance Warning (W10-1) sign. For more information contact the Traffic Operations Division Railroad Coordinator.

Four-Quadrant Gates. According to Part 8 of the *TMUTCD*,[9] four-quadrant gate systems may be installed to improve safety at highway-rail grade crossings based on an engineering study when less restrictive measures, such as automatic gates and median islands, are not effective. A four-quadrant gate system consists of automatic gates used as an adjunct to flashing-light signals to control all lanes at the highway-rail grade crossing. For more information consult the *TMUTCD* or contact the Traffic Operations Division Railroad Coordinator.

Section 3
Driveways

Overview

Driveways provide necessary access to adjacent land and are an integral part of the roadway. Their design and location should be carefully considered for impacts on roadway and intersection safety and operations. Given the large number of potential conflict points present in most intersections (see Figure 11-9), the addition of driveways close to those intersections is frequently undesirable. Functionally, driveways *are* intersections and may be evaluated as such.

The regulation of driveways through access management principles can benefit:[16]

- safety:
  - as access density increases, crash rates increase;
  - roadways with nontraversable medians are safer at higher speeds and at higher traffic volumes than undivided roadways or those with continuous two-way left-turn lanes;
- operations:
  - as access points increase, free flow speeds are reduced;
  - capacity can be reduced;
- economics:
  - increased travel times reduce market area for businesses;
  - poor quality of access can adversely affect property values and investment.

TxDOT's access management policies are contained in the *Access Management Manual.*[16] Local agencies that choose to handle access permitting for state highway system roadways within their jurisdiction can either develop or use their own access management guidelines or use the guidelines in TxDOT's manual.

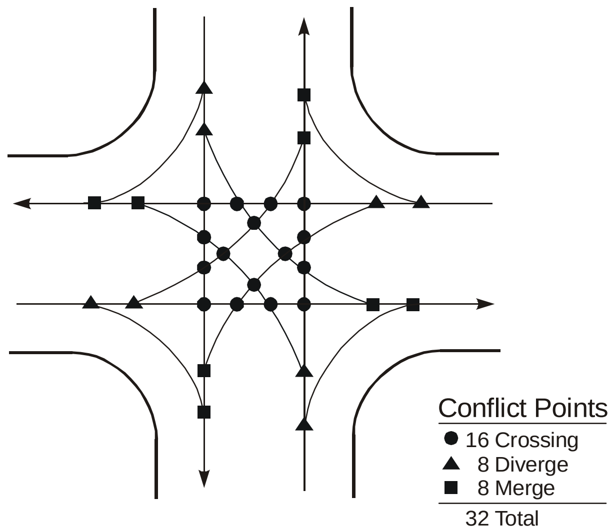


Figure 11-9. Intersection Conflict Points.

Adverse Impacts

Driveways that are too close to the operational area of an intersection contribute adversely to its safety and operation. Increases in the number of conflict points can complicate the operation of the intersection such that safety is compromised.

Driveways on side streets that are too close to the primary roadway (see Figure 11-10) function poorly because of the high probability that they will be blocked by vehicles stopping at the intersection.[2] The presence of additional lanes can greatly complicate the problems illustrated in Figure 11-10, as vehicles attempt to weave through multiple lanes of traffic to access driveways.

A number of possible treatments or improvements may be provided to alleviate the impacts of driveways on intersections, including (but not limited to):

- Convert driveways to right in, right out.
- Provide adequate spacing between ramps and downstream intersections.
- Purchase access rights.
- Encourage the use of shared driveways.
- Encourage the use of rear access.

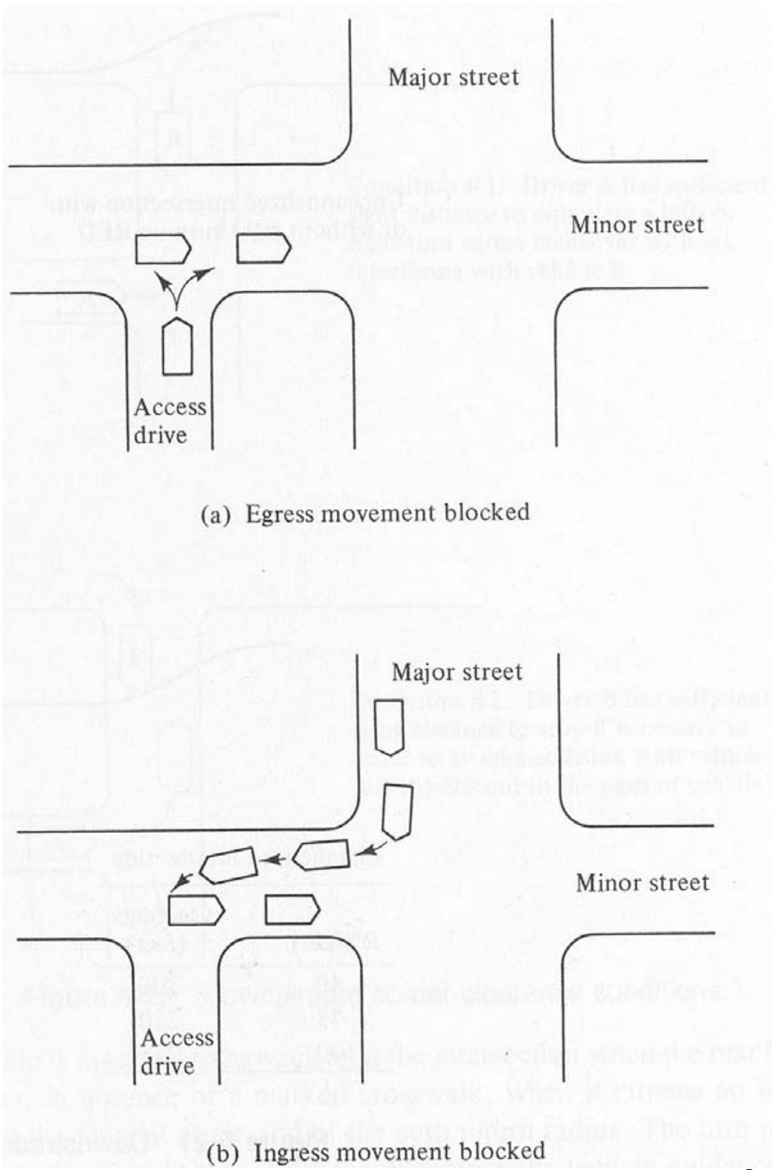


Figure 11-10. Driveways Blocked by Intersection Queue.[2]

Vehicles turning onto a side street from the primary roadway can experience problems if they encounter vehicles entering the side street from a driveway that is too close to the roadway. Vehicles engaged in the turning movement are more concerned with clearing potential traffic on the primary roadway and in the guidance of the vehicle, limiting available attention for vehicles entering from close driveways.[2]

Access Spacing Criteria

Access points that are too closely spaced can have adverse safety, operational, and economic impacts. The *Access Management Manual*[16] provides minimum connection spacing guidance. These spacing guidelines range from 200 to 510 ft [61 m to 155 m], depending on the type of roadway and the posted speed. TxDOT's *Access Management Manual* should be reviewed for more information regarding access spacing criteria.

If clearance between driveways cannot be obtained through joint access with a neighboring property, consideration may be given for alternative locations with TxDOT approval. Reduced spacings can be used to keep from land-locking a property, or to replace or re-establish access to on-system roadways under construction or rehabilitation. Conditions such as limiting the traffic volumes using the driveway may be included in the driveway permit.

Section 4
Midblock Median Treatment

Overview

Medians offer opportunities to restrict movements and control access. Although raised or depressed medians are typically installed to restrict crossings, additional crossing points may need to be installed if major intersections are too widely spaced. Designs that provide access for specific movements are available if necessary.

U-Turns

Median openings may be constructed specifically for U-turns. Because U-turns may be more common on roadways with raised medians, this type of treatment may enhance traffic operations at signalized intersections if used judiciously. Uses include:[5]

- Prior to intersection: accommodate U-turns to reduce interference with turn- and through-movements.
- Downstream of minor crossing points: allow access to minor roadways and driveways through U-turns. Acceptable performance is attained with low traffic volumes only due to the necessary weaving movements.
- Gap in area of long, unbroken median: provide access for highway maintenance, emergency vehicles, tow-trucks, etc.

Median designs to accommodate U-turns should equal or exceed the characteristics shown in Exhibit 9-92 of the 2001 AASHTO *Green Book.*[5]

Left Turns

Median openings designed to permit left turns only may be used at locations where it is desirable to provide limited access. Figure 11-11 illustrates such an installation. The channelization restricts through movements, thereby limiting use of the median opening to left-turning vehicles.

Figure 11-11. Channelized Median Opening to Restrict through Movements.

Section 5

Signal Interconnection

Signal coordination, or interconnection, attempts to accommodate platoons with minimal stops and delays. The movement of platoons of traffic through a signalized area makes more efficient use of the potential capacity of the roadway network. Additionally, traffic demand can be steered from one area to another by the signal system settings. For example, requiring multiple stops or long delays on the major roadway for minor roadway traffic can discourage the use of specific routes in favor of ones which the road users perceive as being easier to travel.[17] Also, trip times are generally repeatable along the same route with signal interconnection. The success of interconnection is influenced by the following factors:

- signal spacing,
- prevailing speed of traffic,
- signal timing (cycle length and split),
- volume,
- platoon dispersion, and
- midblock storage or contributions of traffic (such as parking garages).[18]

Grouping Intersections

The decision of how to group intersections into a system is complex. The objective is to assemble those intersections requiring similar timing strategies in terms of controller cycle lengths and controller offset coordination into groups of reasonable size. A number of factors need to be considered, including:

- Geographic relationship: distance between intersections, natural and artificial boundaries such as rivers, and controlled-access facilities.
- Traffic/capacity ratio: Larger traffic volumes benefit more from coordination. While saturated flows may exist for periods of each day, the rest of the day may be well served by progression. Coordination should also improve the capacity of the roadway.
- Traffic flow characteristics: If traffic arrivals on the major roadway are random throughout the controller cycle, the red display on the major roadway will produce the same stops and delays regardless of its position within the controller cycle. If traffic arrivals on the major roadway are by platoon, the benefits of coordination are enhanced.[17]

Signal Spacing

Signal spacing of less than 1500 ft [457 m] should be reviewed to ensure that the following factors are addressed or are not applicable.

- Closely spaced signals with overhead indications. When a driver is nearing the upstream stop line, the downstream indications may be easier for a driver to see than the upstream indications. The driver may mistakenly continue past red indications on the upstream signal if the downstream indication is green.

- Intersections on higher speed roadways. If the upstream indications are green when the downstream indications are red, an approaching driver may not begin to slow in time to avoid colliding with a vehicle stopped in the queue of the downstream signal.
- Coordination of closely spaced signals. Obtaining effective coordination without excessive green time on a coordinated roadway becomes more problematic as the spacing decreases.[17]

Signal Coordination

Traffic control signals should be coordinated, preferably with interconnected controller units, when they are within 0.5 mi [805 m] of one another along a major route or in a network of intersecting major routes. However, signal coordination need *not* be maintained across boundaries between signal systems that operate on different cycle lengths.[9] Traffic operations modeling techniques should be used to determine whether progression can be provided for specific circumstances.

The key to efficient system operation is the predictability with which a platoon of densely spaced traffic passes along the roadway. Arriving too early requires a stop and restart, and arriving too late means that some or most of the green display is not used. When a platoon disperses and is no longer densely spaced, the platoon takes more time to pass through an intersection. The maintenance of platoon flow is contingent upon:

- traffic characteristics,
- topography,
- condition of the roadway surface and shoulders, and
- roadside friction.

Effective coordination of traffic signals can in most cases be achieved for distances in excess of 0.5 mi (805 m). The traffic will generally maintain a cohesive platoon structure under these circumstances: the roadway is a well-designed facility, without driveways, with opportunities for passing, and with the provision for left turns. While no specific rules with regard to distance between signals can be given, there are many examples of effective coordination where signals are spaced up to 1 mi [1.6 km] apart, although if the following conditions are not met then effective coordination may not be achieved:

- Roadside frictions are minimal.
- Speeds are fairly high.
- The traffic control signals are visible for some distance in advance of the intersection.

Conversely, if the design of a facility is such that traffic cannot flow in an unimpeded manner, it may not be possible to identify a platoon at the downstream intersection and coordination may not be effective.

Where undesirable platoon dispersion takes place, the operational characteristics of an area should be field reviewed to determine if traffic signals, not otherwise needed, would prove beneficial in keeping the platoons together between existing signals. The *TMUTCD*[9] provides that the spacing of such signals should not be less than 1000 ft [305 m].

Methods of Interconnection

There are two basic ways to interconnect the signals: direct means and indirect means. Direct methods employ a physical connection between controller assemblies, while indirect methods rely on an air path or time-based approach. These methods include:

- electrical cables (wires),
- telephone-type cables,
- coaxial cables,
- fiber-optic cables,
- microwave, and
- radio.

Preemption and Priority Control

Traffic control signals may be designed and operated to respond to certain classes of approaching vehicles by altering the normal signal timing and phasing plan(s) during the approach and passage of those vehicles. The alternative plan may be as simple as extending a currently displayed green interval or as complex as replacing the entire set of signal phases and timing. Examples include:

- preemption control, typically given to emergency vehicles and to vehicles such as boats and trains; and
- priority control, typically given to certain non-emergency vehicles such as buses and light-rail vehicles.[9]

Refer to Chapter 11, Section 2 <link> for discussion on signal preemption at highway-rail grade crossings.

Section 6

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16. Abstract

Intersections are an important part of a highway facility because the efficiency, safety, speed, cost of operation, and capacity of the facility depend on their design to a great extent. Each intersection involves through- or cross-traffic movements on one or more of the highways and may involve turning movements between these highways. Such movements may be facilitated by various geometric designs and traffic controls, depending on the type of intersection. The main objective of intersection design is to facilitate the convenience, comfort, and safety of people traversing the intersection while enhancing the efficient movement of motor vehicles, buses, trucks, bicycles, and pedestrians. In order to design intersections that are both functional and effective, designers need current information regarding intersection design that is easily accessible and in a user-friendly format. The prime objective of the Texas Department of Transportation Project 0-4365 is to produce this reference document, the *Urban Intersection Design Guide*, to provide this information.

This document is presented in two volumes:

- Volume 1 – Guidelines and
- Volume 2 – Applications.

This project is designed to provide TxDOT and other interested parties with useful and practical information on operations and design for intersections.

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Texas Department of Transportation
and the
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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation. The engineer in charge was Kay Fitzpatrick, P.E. (TX-86762).

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Overview

The following application discusses ultimate design considerations. The *Urban Intersection Design Guide*, Chapter 1, Section 1 <link> presents additional discussion on intersection planning and development.

Background

A city of approximately 100,000 is experiencing rapid growth to the south of the city. A two-lane state highway (with shoulders) (referred to as McCullum Road) currently exists that extends from the city's central business district (CBD) (where it is wider) southward for many miles beyond the city's extraterritorial jurisdiction. The state has planned to widen this arterial south of the city in the future and expects to let the widening project in about 10 years. The new cross section of the arterial will be consistent with the city's typical cross section for its major arterial streets, which consists of two 28-ft-wide [8.5 m] roadway sections (measured face-to-face) with an 18-ft-wide [5.5 m] median.

A major developer has decided to plan and construct a large residential/golf course development, called Twin Oaks Estates, south of town and adjacent to the east side of McCullum Road where the arterial currently has a two-lane cross section. Figure 1-1 illustrates the current cross section of McCullum Road, which consists of two 12-ft-wide [3.7 m] travel lanes and two 10-ft-wide [3.0 m] shoulders. The developer desires to work with the city and the state to plan the entrance to the proposed subdivision so that the ultimate McCullum Road cross section can be constructed without affecting the subdivision's entrance. In addition, the developer plans to open the subdivision to development within 2 years, long before the McCullum Road widening project will be completed.

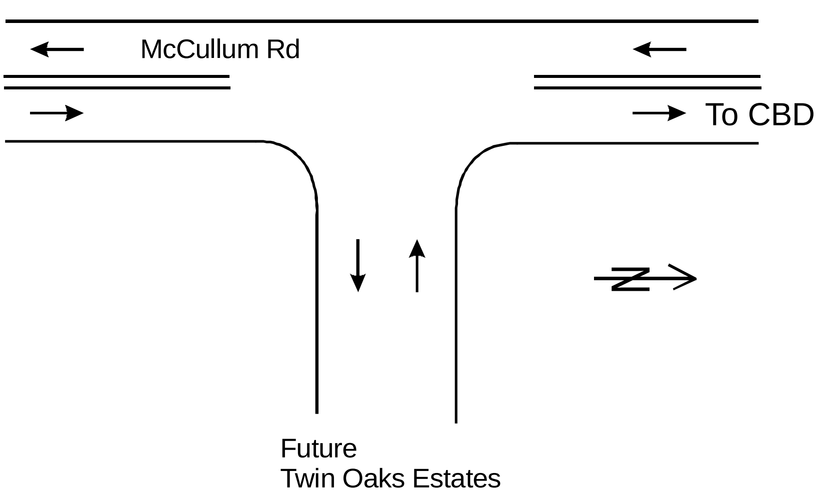


Figure 1-1. Location of McCullum Road and Twin Oaks Intersection.

Issues Considered

Although the final construction plans for the McCullum Road widening project have not been completed, sufficient planning had been done to provide a reasonable estimate of the elevation of McCullum Road where Twin Oaks Boulevard will intersect the arterial. The intersection would be located where sight distance will not be an issue so the location of the intersection would be approved by the state. Also, a preliminary drainage design for McCullum Road had been conducted so the developer's engineer would be able to plan the entrance road in a manner consistent with the proposed drainage plan and optimum placement of curb ramps. The developer also requested the state to provide a median opening on McCullum Road to access Twin Oaks Boulevard, and a separated left-turn lane on southbound McCullum Road to serve the entrance. The state was able to grant the request because the location of the median opening would be relatively consistent with the state's planned spacings of median openings.

The subdivision entrance road was to be designed with the assumption that the planned ultimate cross section of McCullum Road would be constructed, so the intent was to place the subdivision entrance signs, landscaping, and lighting at a location where they would remain permanent. Hence, the subdivision entrance would be placed some distance east of the existing location of McCullum Road, and a temporary extension of Twin Oaks Boulevard from the subdivision entrance to McCullum Road had to be designed and constructed.

Because of the isolated location of the intersection, the numbers of pedestrians and bicyclists expected in the interim were almost non-existent. Hence, the designers did not consider temporary bicycle facilities necessary or cost-effective. Temporary pedestrian facilities to connect the subdivision entrance to McCullum Road were considered appropriate. However, permanent bicycle and pedestrian facilities were considered and planned for the ultimate design of both Twin Oaks Boulevard and McCullum Road.

Lighting of the intersection was considered important because of the intersection's isolated location along a high-speed, rural highway. The city anticipated that the intersection would be signalized at some point in time because of the number of vehicles that would be expected to be generated by the large development and the expectations of high volumes on McCullum Road that would exist in the future. Signals may be warranted at the interim intersection (and considered necessary for safety and operational considerations) before McCullum Road is widened. Utilities need to be located away from pedestrian routes, curb ramps, and landings.

Design Selected

The design selected for the intersection of McCullum Road and Twin Oaks Boulevard is shown in Figure 1-2. The state's plan to widen McCullum Road included using the existing section as the location of the southbound travel lanes and widening the highway on the east side. Hence, the ultimate entrance to Twin Oaks Estates would be positioned about 50 ft [15 m] east of McCullum Road. Twin Oaks Boulevard was constructed to its ultimate cross section (with portland cement concrete) to the edge of the entrance where the curb return of the future intersection would begin. Bicycle lanes on Twin Oaks Boulevard ended at the same location. Temporary sidewalks were extended from the permanent sidewalks at the subdivision entrance to McCullum Road.

Twin Oaks Boulevard was extended westward from the end of the concrete surface to McCullum Road with a compacted base and asphaltic concrete surface consistent with city specifications. Intersection returns were constructed with 25-ft [7.6 m] radii, because the existing shoulders and a relatively flat area adjacent to the shoulders provided additional space for turning movements. A culvert had to be constructed beneath Twin Oaks Boulevard to accommodate roadside drainage.

In anticipation of a future traffic signal installation, a 4-inch [10.2 cm] conduit was placed below Twin Oaks Boulevard extending from the north to the south sides of the roadway. Ground boxes also were installed on both sides of Twin Oaks Boulevard at the terminals of the conduit. Anticipating that temporary traffic signals would be installed at the intersection before McCullum Road is widened, utility poles were installed on both the northeast and southeast corners of the intersection outside of the clear zone for McCullum Road. Luminaire arms and luminaires were installed on both utility poles to provide nighttime illumination.

A wide pavement area existed between the subdivision entrance and the existing McCullum Road. In order to provide delineation of this area and help to keep motorists from traveling on the wrong side of Twin Oaks Boulevard, large buttons and reflectorized pavement markers were installed west of the subdivision entrance essentially to extend the median to the intersection.

Because traffic on McCullum Road currently travels at high speed, the state decided to restripe the McCullum Road approaches to Twin Oaks Boulevard so that a separated left-turn lane could be provided. The restriping required narrowing the shoulders from 10 to 4 ft [3.0 to 1.2 m] in width; however, experience with similar rural intersections in this section of the state revealed that rear-end accidents at intersections on high-speed rural highways where left turns were frequent were reduced when separated left-turn lanes were provided.

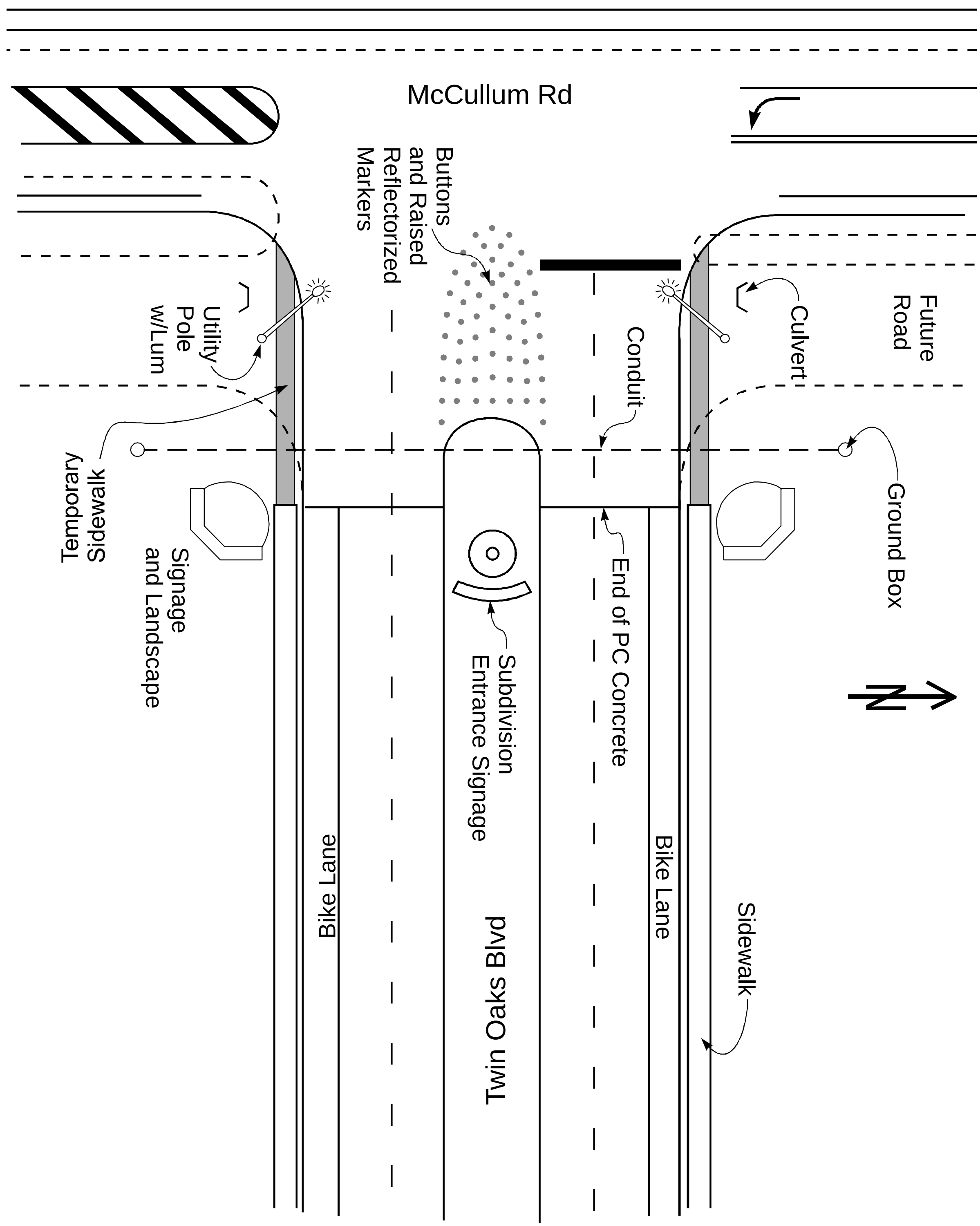


Figure 1-2. McCullum Road and Twin Oaks Intersection.

Application 2
Roundabouts

Overview

Interest in roundabouts as a form of traffic control in North America has been growing. (Discussion on other intersection types are included in the *Urban Intersection Design Guide,* Chapter 1, Section 2 <link>.) Roundabouts guide traffic flow with a raised island constructed in the center of an intersection to create a one-way circular flow of traffic. Figure 1-3 shows the basic geometric elements of a roundabout. They have been used to lower travel speeds, to reduce crash frequency by reducing the number of conflict points, and to provide an alternative to traffic signal installation. Current research is investigating how best to accommodate pedestrians at this type of intersection. The decision to use a roundabout should be based on an engineering analysis that considers the needs of all modes of travel. Discussions with the TxDOT Design Division should occur early in the decision process when considering a roundabout in a project.

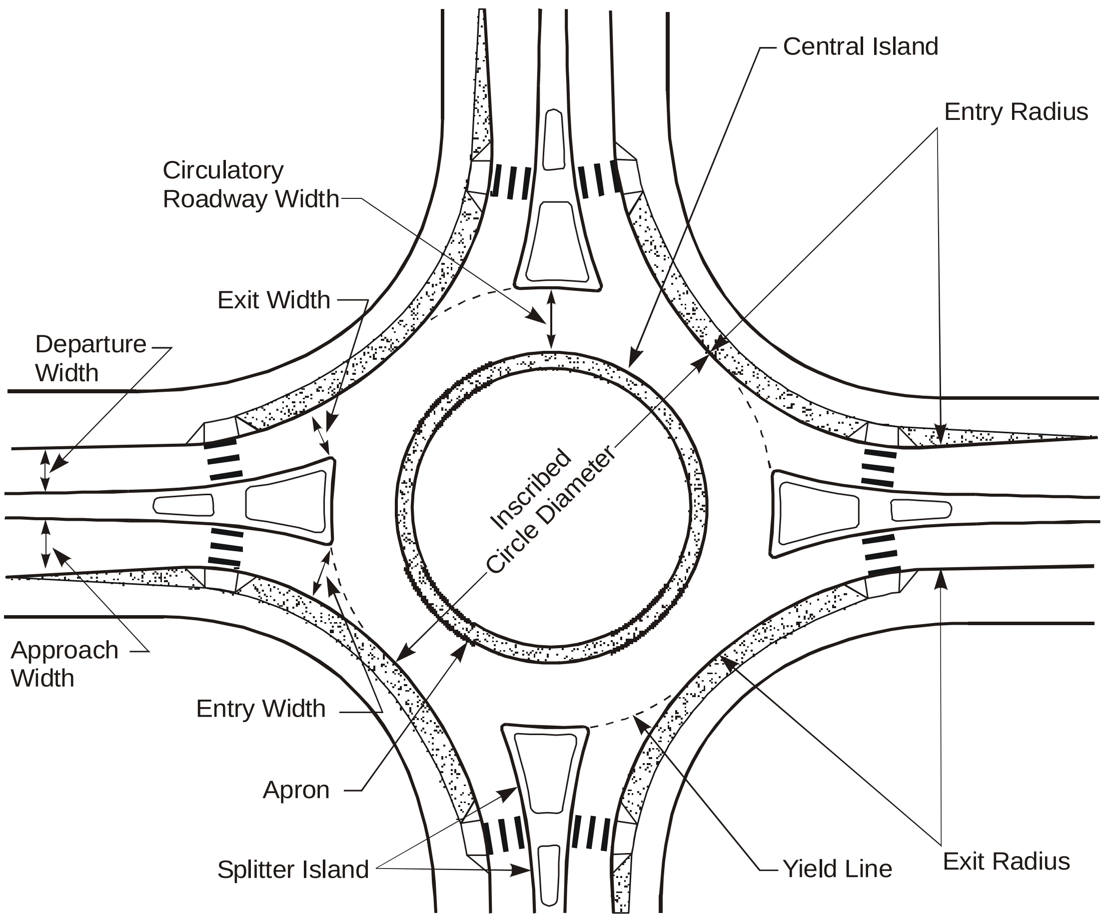


Figure 1-3. Example of Roundabout.[1]

[1] Roundabouts: An Informational Guide. Federal Highway Administration, McLean, Virg., January 1998.

Characteristics

Roundabouts perform best at intersections with similar traffic volumes on each approach leg and at intersections with heavy left-turning volumes. Roundabouts reduce the severity and frequency of intersection crashes by the nature of their design. Roundabouts resolve vehicle conflicts by means of priority control; the key operational feature of roundabouts is that entering vehicles yield to the circulating traffic. Traffic interactions are based on gap acceptance; entering traffic must wait for a gap in the traffic stream to enter.

Modern roundabouts range in size from mini-roundabouts with inscribed circle diameters as small as 50 ft [15.2 m], to compact roundabouts with inscribed circle diameters between 100 and 115 ft [30.5 and 35.1 m], to large roundabouts, often with multilane circulating roadways and more than four entries up to 500 ft [152.4 m] in diameter. The greater speeds permitted by larger roundabouts, with inscribed circle diameters greater than 250 ft [76.2 m], may reduce their benefits to some degree.[2]

Roundabouts eliminate left turns at intersections, which reduces the opportunity for crashes. Roundabouts contain only four merging conflict points, compared with 24 merging/crossing conflict points at intersections controlled by STOP signs or traffic signals (see Figure 1-4). The driver needs to decide when to enter the circulating stream, when to leave the circulating stream, and how fast to travel while circulating so that other drivers may enter the circulating stream without causing a conflict or crash.

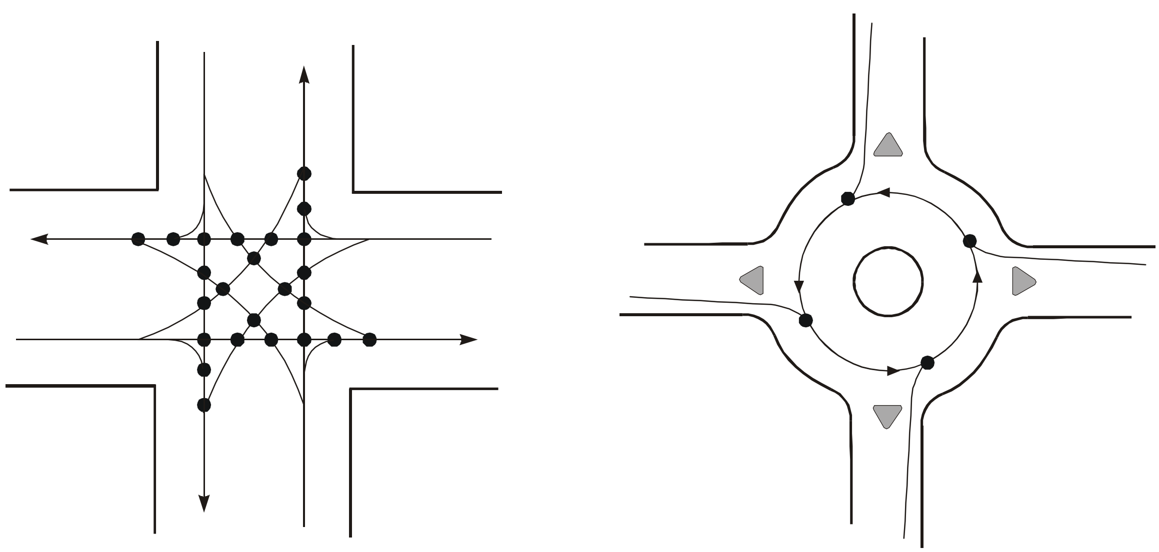


Figure 1-4. Comparison of Conflict Points at a Traditional Four-Leg Intersection and a Roundabout.[3]

[2] American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets.* AASHTO, Washington, D.C., 2001.

[3] Parham, A., and K. Fitzpatrick. "Handbook of Speed Management Techniques." Report FHWA/TX-99/1770-2. Texas Department of Transportation, Austin, Tex., September 1998.

Figure 1-5 shows examples of roundabouts. Additional photographs are available at the Center for Transportation Research and Training Web site.[4] Figure 1-6 illustrates a roundabout warning sign approaching a roundabout. The *TMUTCD*[5] states that the Circular Intersection (W2-6) sign accompanied by an educational word message plaque may be installed in advance of a circular intersection.

Roundabouts at interchange ramp termini may result in fewer delays and crashes and may be less costly when compared to other conventional interchange designs. A modern roundabout interchange is a freeway-to-street interchange or a street-to-street interchange that contains at least one roundabout. Unlike interchanges regulated by traffic signals, modern roundabout interchanges do not require long storage and turning lanes over or under a bridge, which is an expensive element of the interchange.

[4] Center for Transportation Research and Training. Kansas State University. February 6, 2003. http://www.ksu.edu/roundabouts/home.htm. Accessed February 2004.

[5] *Texas Manual on Uniform Traffic Control Devices for Streets and Highways.* Texas Department of Transportation. 2003. http://www.dot.state.tx.us/TRF/mutcd.htm. Accessed January 2004.

(A)

(B)

Figure 1-5. Examples of Roundabouts.[4]

Figure 1-6. Roundabout Advance Warning Sign Example.

Comparison with Traffic Circles

Roundabouts are similar to traffic circles, but they have design and operational characteristics that result in better performance. In general, traffic circles have smaller diameters than roundabouts. The typical residential traffic circle is approximately 20 ft [6.1 m] in diameter, with roadway approach widths of 30 ft [9.1 m] or more.[6] The key operational feature of roundabouts is that traffic must yield at entry to the traffic that is already within roundabouts. Roundabouts and traffic circles can be compared as follows:[7]

- Vehicles entering a roundabout on all approaches are required to yield to vehicles within the circulating roadway. Traffic circles sometimes employ stop or signal control to give priority to entering vehicles.
- The circulating vehicles are not subjected to any other right-of-way conflicts, and weaving is kept to a minimum. This provides the means by which the priority is distributed and alternated among vehicles. A vehicle entering as a subordinate vehicle immediately becomes a priority vehicle until it exits the roundabout. Some traffic circles impose control measures within the circulating roadway or are designed with weaving areas to resolve conflicts between movements.
- The speed at which a vehicle is able to negotiate the circulating roadway is controlled by the location of the central island with respect to the alignment of the right entry curb. This feature is responsible for the improved safety record of roundabouts. Some large

[6] *Neighborhood Traffic Control*. North Central Section, Institute of Transportation Engineers. December 1994.

[7] Courage, K., and L.T. Hoang. "Design and Evaluation of Modern Roundabouts in Florida." Resource Papers for the 1997 ITE International Conference, March 23-26, 1997.

traffic circles provide straight paths for major movements or are designed for higher speeds within the circulating roadway. Some small traffic circles do not achieve adequate deflection for speed control because of the small central island diameter.

- No parking is allowed on the circulating roadway of a roundabout.
- No pedestrian activities take place on the central island. Pedestrians are not expected to cross the circulating roadway. Some larger traffic circles provide for pedestrian crossing to, and activities on, the central island.
- Roundabouts are designed to properly accommodate specified design vehicles. Some smaller traffic circles are unable to accommodate large vehicles, usually because of right-of-way restraints.
- Roundabouts have raised splitter islands on all approaches. Splitter islands are an essential safety feature, required to separate traffic moving in opposite directions and to provide refuge for pedestrians. They are also an integral part of the deflection scheme.
- When pedestrian crossings are provided across the approach roads, they are placed approximately one car length back of the entry point. Some traffic circles accommodate pedestrians in other places, such as the yield point.
- The entry deflection is the result of physical features of a roundabout. Some traffic circles rely on pavement markings to promote deflection.

Roundabouts and Pedestrians

The *Green Book*[2] states that pedestrian crossing locations at roundabouts should achieve a balance among pedestrian convenience, pedestrian safety, and roundabout operations. The further a pedestrian crossing is from the roundabout, the more likely it is that pedestrians will choose a shorter route that may present unintended conflicts. Both crossing location and crossing distance are important considerations. Crossing distance should be minimized to reduce exposure to pedestrian-vehicle conflicts. Location of pedestrian crosswalks at the yield line is discouraged, as drivers may be distracted from pedestrian movements by watching for appropriate gaps in the traffic stream to merge into the circulating roadway. Crosswalks should be located to take advantage of the splitter island. The pedestrian refuge in the island should be level with the street grade to avoid the use of ramps at the refuge. Crossings should also be located at a distance from the yield line that is approximately an even increment of a vehicle length to reduce the likelihood that vehicles will be queued across the crosswalk.

Roundabouts are difficult for persons with visual disabilities to cross as a pedestrian. There are two main problems — determining where to cross and determining when it is safe to cross. Determining where to cross is made difficult by the very nature of a roundabout its circular geometry. Determining when to cross near a roundabout is made difficult because the information available at traditional intersections is not available. Specifically, there is no surge of parallel traffic movement to communicate to the visually impaired pedestrian that a gap in cross traffic is available. Therefore, to comply with the Americans With Disabilities Act (ADA), additional information needs to be provided to communicate to the pedestrian with a visual disability where and when the crossing should be made. At this time, specific requirements for how to provide this communication have not been developed, but this does not alleviate the designer's responsibility to do so.

The U.S. Access Board[8] has developed recommendations for accessible design of roundabout crossings. Some of the more general items are similar to those noted by the *Green Book,*[2] such as a street-grade pedestrian refuge. Other items of interest include aligning the crosswalk with the ramp from the sidewalk, including landscaping or small barriers to prevent pedestrians from crossing a roundabout at a non-crosswalk location, and including pedestrian signals at the crossings. Another idea is to use raised crossings at roundabouts to help ensure that traffic slows, particularly on the roundabout exit. NCHRP Project 03-78 entitled *Crossing Treatments at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities* was funded to develop some alternative treatments that would make these crossings accessible without hindering the operation of all roundabouts with a signal requirement.

Summary

Advantages of roundabouts include that they:

- can noticeably reduce vehicle speeds,
- reduce potential for vehicular crashes,
- can increase capacity,
- reduce the number of conflict points at an intersection,
- provide an orderly and continuous flow of traffic,
- provide landscaping opportunities, and
- are effective at multileg intersections.

Disadvantages of roundabouts include that they:

- may be restrictive for some larger service and emergency vehicles unless central island is mountable,
- require pedestrians and bicyclists to adjust to less traditional crossing patterns,
- may require some parking removal on approaches to accommodate vehicles' deflected paths,
- may result in drivers being unfamiliar with operation initially, and
- require additional maintenance if landscaped.

[8] United States Access Board. Draft Guidelines for Accessible Public Rights-of-Way. June 17, 2002. http://www.access-board.gov/rowdraft.htm. Accessed September 2003.

Application 3
Alternative Intersection Designs

Overview

At each particular location, selecting an intersection type is influenced by:

- functional class of intersecting streets;
- design level of traffic;
- number of intersecting legs;
- topography;
- access requirements;
- traffic volumes, patterns, and speeds;
- all modes to be accommodated;
- availability of right of way; and
- desired type of operation.

Any of the basic intersection types can vary greatly in scope, shape, and degree of channelization.[2] Basic intersection types are discussed in the *Urban Intersection Design Guide*, Chapter 1, Section 2 <link>; however, there are also a number of alternatives for intersection design. Following is overview information on a number of innovative intersection designs. Before an innovative design is pursued, the designer should coordinate with the Design and Traffic Operations Division for additional guidance.

Unconventional Left-Turn Alternative Designs

Hummer[9,10] provided information on unconventional left-turn alternatives for urban and suburban arterials. The alternatives are focused on treating left turns to and from arterials, reducing delay to through vehicles, and reducing or separating the number of conflict points. Hummer notes that by their nature as unconventional solutions and rerouting certain movements, the alternatives all have the potential to cause more driver confusion than a conventional arterial. However, this can be offset by using the alternatives on a section of the arterial and developing appropriate legible and understandable traffic control devices.

Detailed studies on the operation and safety benefits of the alternatives are not available; however, Hummer noted that the unconventional alternatives, where the number of unprotected conflicting movements has been reduced, are theoretically safer than conventional arterials. Simulation tools can be used to determine the benefits of different

[9] Hummer, J.E. "Unconventional Left-Turn Alternatives for Urban and Suburban Arterials – Part One." *ITE Journal,* September 1998.

[10] Hummer, J.E. "Unconventional Left-Turn Alternatives for Urban and Suburban Arterials – Part Two." *ITE Journal,* November 1998.

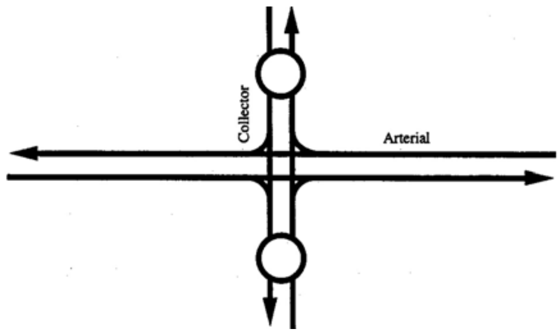
design alternatives, including unconventional alternatives, for a selected arterial. Table 1-1 summarizes characteristics of locations that may be suited for an unconventional intersection. The following figures summarize the information Hummer provided on the seven alternatives:

- Figure 1-7 Bowtie
- Figure 1-8 Superstreet
- Figure 1-9 Paired Intersection
- Figure 1-10 Jughandle
- Figure 1-11 Continuous Flow Intersection
- Figure 1-12 Continuous Green T

Table 1-1. Summary of Alternative Designs.[9,10]

Alternative	**Applicable Traffic Volume**			**Extra right of way needed**
	Left turns from arterial	**Left turns from minor street**	**Minor Street through**	
Median U-Turn	low-medium	low-medium	any	30-ft-wide [9.1 m] along arterial
Bowtie	low-medium	low-medium	low-medium	two circles up to 300 ft [91.4 m] in diameter on minor street
Superstreet	any	low-medium	low-medium	30-ft-wide [9.1 m] along arterial
Paired Intersection	any	any	low	two 80-ft-wide [24.4 m] parallel collectors
Jughandle	low-medium	low-medium	any	two 400-ft [122.0 m] by 300-ft [91.4 m] triangles at intersection
Continuous Flow	any	any	any	two 400-ft [122.0 m] by 300-ft [91.4 m] rectangles at intersection
Continuous Green T	any	low-medium	none	no extra

BOWTIE



Description. The bowtie alternative, inspired by "raindrop" interchange designs common in Great Britain, is a variation of the median U-turn alternative with the median and the directional crossovers on the cross street. To overcome the disadvantage of requiring a wide right of way on the cross street, the bowtie uses roundabouts on the cross street to accommodate left turns instead of directional crossovers across a wide median, as shown in the figure above. Left turns are prohibited at the main intersection, which therefore requires only a two-phase signal. Vehicles yield upon entry to the roundabout, but if the roundabout has only two entrances as shown above, the entry from the main intersection does not have to yield. The roundabout diameter, including the center island and circulating roadway, varies from 90 to 300 ft [27 to 91 m] depending on the speed of traffic on the approaches, the volume of traffic served, the number of approaches, and the design vehicle. The distance from the roundabout to the main intersection could vary from 200 to 600 ft [61 to 183 m], trading off spillback against extra travel distance for left-turning vehicles. The arterial may have a narrow median. Arterial U-turns are difficult, having to travel through both roundabouts and through the main intersection three times, so midblock left turns should be accommodated directly along the arterial.

Variations. A three-legged version of the bowtie is possible but would require much extra right of way. It would likely be inferior to a three-legged median U-turn or jughandle except in cases where an agency was later phasing in a fourth leg of the intersection.

History. A few agencies have installed roundabouts on cross streets in an evolutionary manner, but no agency to the author's knowledge has consciously designed a complete bowtie alternative. Raindrop interchanges, similar to diamond interchanges but with roundabouts instead of signalized or stop-controlled ramp terminals, have been in use successfully in Great Britain for years. A few raindrop interchanges have been designed and built in the United States recently, most notably in Vail, Colorado.

Advantages. The advantages of the bowtie over conventional multiphase signalized intersections include:

- reduced delay for through arterial traffic,
- reduced stops for through arterial traffic,
- easier progression for through arterial traffic,
- fewer threats to crossing pedestrians, and
- reduced and separated conflict points.

Disadvantages. The disadvantages of the alternative relative to conventional intersections include:

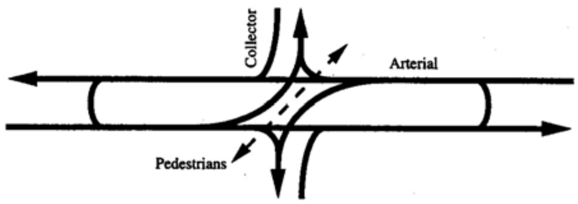
- driver confusion,
- driver disregard for the left-turn prohibition at the main intersection,
- increased delay for left-turning traffic and possibly cross-street through traffic,
- increased travel distances for left-turning traffic,
- additional right of way for the roundabouts, and
- difficult arterial U-turns.

When to Consider. Agencies should consider the bowtie alternative where there are generally high arterial through volumes and moderate to low cross-street through volumes and moderate to low left-turn volumes. If the left-turn volume is too high, the extra delay and travel distance for those drivers, and the spillback potential, will outweigh the savings for arterial through traffic. Likewise, if the cross-street through volume is too high, delays caused by the roundabout will outweigh the savings for the arterial through traffic. Arterials with narrow or nonexistent medians and no prospects of obtaining extra right of way for widening are good candidates for the bowtie. Developers may be convinced with certain incentives to build roundabouts into site plans. The distances between signals should be long so that the extra right-of-way costs for the roundabouts do not overwhelm the savings elsewhere.

Incidentally, roundabouts rarely make sense directly on multilane arterials. Roundabout capacity cannot easily be expanded by widening beyond two lanes, so roundabouts rarely work at intersections between multilane arterials. However, roundabouts are generally inappropriate for intersections between arterials and collectors or local streets because of the extra delay to larger numbers of arterial vehicles.

Figure 1-7. Alternative Designs – Bowtie.[9]

SUPERSTREET



Description. A superstreet is another extension of the median U-turn concept that provides the best conditions for through arterial movements short of interchanges. The superstreet alternative, shown above, requires cross-street through movements and left turns to and from the arterial to use the directional crossovers. Four-approach intersections become two independent three-approach intersections. This independence allows each direction of the arterial to have its own signal timing pattern, including different cycle lengths if desired, so that engineers can achieve "perfect" progression in both directions at any time with any intersection spacing. Pedestrians can make a relatively safe but slow two-stage crossing of the arterial as shown above. Other design details of the superstreet are identical to median U-turns.

Variations. One variation, at an intersection with a low-volume cross street, is to dispense with the directional crossovers for left turns from the arterial at the intersection. Another variation is to reverse the direction of the crossovers at the intersection to allow left turns to the arterial in cases where those are the heavier volume movements. However, these crossovers create difficult merges for the left on the arterial.

History. Richard Kramer, the long-time traffic engineer in Huntsville, Alaska, USA, conceived of the superstreet alternative and published a paper on it in 1987. To the author's knowledge, nobody has implemented the full superstreet, but some agencies have severed cross-street through movements and built directional crossovers on arterials in a piecemeal fashion.

Advantages. The advantages of the superstreet over a conventional multiphase signalized intersection include:

- reduced delay for through arterial traffic and for one pair of left turns (usually left turns from the arterial),
- reduced stops for through arterial traffic,
- "perfect" two-way progression at all times with any signal spacing for through arterial traffic,
- fewer threats to crossing pedestrians, and
- reduced and separated conflict points.

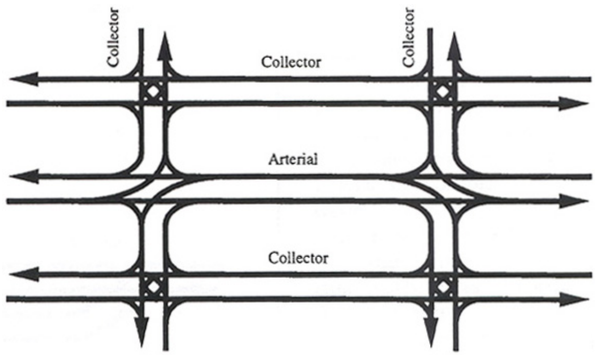
Disadvantages. The disadvantages of the alternative relative to conventional intersections include:

- driver and pedestrian confusion,
- increased delay for cross-street through traffic and for one pair of left turns (usually left turns to the arterial),
- increased travel distances for cross-street through traffic and for one pair of left turns,
- increased stops for cross-street through traffic and for one pair of left turns,
- a slow two-stage crossing of the arterial for pedestrians, and
- additional right of way along the arterial.

When to Consider. Consider a superstreet where high-arterial through volumes conflict with moderate to low cross-street through volumes. This will be the case for many suburban arterials where roadside development generates most of the conflicting traffic. One should also consider a superstreet where close to 50/50 arterial through-traffic splits exists for most of the day, but uneven street spacings remove any chance of establishing two-way progression. As for median U-turns, arterials with narrow medians and no prospects for obtaining extra rights of way for widening are poor candidates for the superstreet.

Figure 1-8. Alternative Designs – Superstreet.[9]

PAIRED INTERSECTION



Descriptions. The paired intersection alternative uses directional crossovers (see above). The alternative employs directional crossovers for left turns from the arterial at one intersection of the pair and directional crossovers for left turns to the arterial at the second member of the pair. Complete circulation throughout the corridor requires that continuous two-way collector roads are parallel to the arterial, are set back at least several hundred feet from the arterial to avoid spillback, and provide developable parcels fronting the arterial. The intersections between the cross streets and the parallel collector roads may be stop-controlled or signal-controlled depending on the traffic volumes and other usual factors. If developments along the arterial have access from the parallel collector roads, then the arterial median does not have to be wide enough to accommodate U-turns by all vehicles. Like in a superstreet, pedestrians in the paired intersection alternative can make a relatively safe but slow two-stage crossing of the arterial.

Variations. Directional crossovers accommodating left turns to the arterial can operate with a signal controlling both directions of the arterial, but this could make two-way progression suboptimal with poor signal spacing. A variation that preserves perfect two-way progression as in the superstreet is to have the crossover end in a merge onto the arterial, which requires several hundred feet for an acceleration lane and a median that is at least 30 ft or so wide.

History. Agencies have been prohibiting turns from or onto arterials while relying on parallel streets for circulation for years, especially in downtown areas. Designers also have been channeling left turns into a development through one driveway and left turns out of the development through another driveway for years. However, Edison Johnson, a traffic engineer with the City of Raleigh, North Carolina, USA, was the first to conceive of the complete paired intersection alternative (with directional crossovers and parallel collector streets) in the late 1980s when asked to work on developing an arterial where complete conversion to a freeway was not politically acceptable. The design, which appeared in a consultant's report in 1992, is slowly being phased in by the city as the area develops.

Advantages. The advantages of the paired intersection alternative over an arterial with conventional multiphase signalized intersections include:

- reduced delay for through arterial traffic and for some left turns;
- reduced stops for through arterial traffic;
- easier progression for through arterial traffic, and with the left merge variation "perfect" two-way progression at all times with any signal spacing;
- fewer threats to crossing pedestrians; and
- reduced and separate conflict points on the arterial.

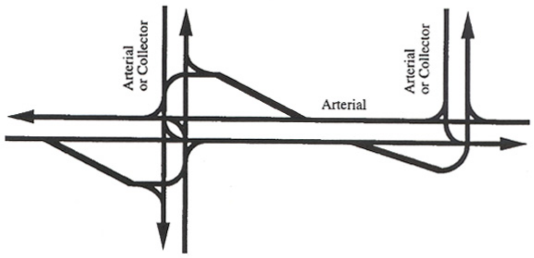
Disadvantages. The disadvantages of the alternative relative to conventional intersections include:

- driver and pedestrian confusion,
- increased delay for cross-street through traffic and for some left-turning traffic,
- increased travel distances for cross-street through traffic and for some left-turning traffic,
- a slow two-stage crossing of the arterial for pedestrians,
- additional right of way for the parallel collector roads, and
- additional construction, maintenance, and operation costs for the parallel collector roads.

When to Consider. The paired intersection alternative is worth considering for arterials with high through-traffic volumes and low cross-street through volumes. In addition, the means to build and operate the parallel collector roads must be available. In developed corridors, good parallel streets must exist and the environment on them must allow increased traffic. In such circumstances, a one-way pair may be a superior alternative anyway. In developing corridors, agencies may be able to convince developers to pay for a portion of the cost of the collectors, and the agencies should ensure that parcels access the collectors.

Figure 1-9. Alternative Designs – Paired Intersection.[9]

JUGHANDLE



Description. The jughandle alternative uses ramps diverging from the right side of the arterial to accommodate all turns from the arterial. In the four-approach jughandle intersection shown above, the ramps are prior to the intersection. Left turns from the arterial use the ramp, then turn left on the cross street at the ramp terminal. Ramp terminals are typically stop-controlled for left turns and yield-controlled for channelized right turns. In modern jughandles ramp terminals are several hundred feet from the main intersection to ensure that queues from the signal on the cross street do not block the terminal. Since no U-turns or left turns are allowed directly from the arterial, the median may be narrow. The signal at the main intersection may need a third phase, for left turns from the cross street, if the volume is heavy.

If agencies use jughandles as the only way drivers can make left turns and U-turns along a section of arterial, all turns will be made from the right lane. This could decrease driver confusion, decrease lane changes, and increase travel speeds in the left lane.

Variations. If left turns from the ramp terminal are difficult, agencies can use loop ramps beyond the main intersection to accommodate left turns from the arterial. The travel distances for the left-turning vehicles are longer with a loop ramp, but loop ramps allow an easier right turn onto the cross street at the ramp terminal. Agencies also can employ loop ramps beyond the intersection for left turns from the cross street to avoid the third-signal phase. Jughandles for three-approach intersections and jughandles exclusively for U-turning traffic use ramps which curve back to meet the arterial as shown above.

History. The New Jersey Department of Transportation has used jughandles for years on hundreds of miles of heavy-volume arterials and continues to build new jughandle intersections.

Advantages. The advantages of the jughandle alternative over conventional multiphase signalized intersections include:

- reduced delay for through arterial traffic,
- reduced stops for through arterial traffic,
- easier progression for through arterial traffic,
- narrower right of way needed along the arterial, and
- reduced and separated conflict points.

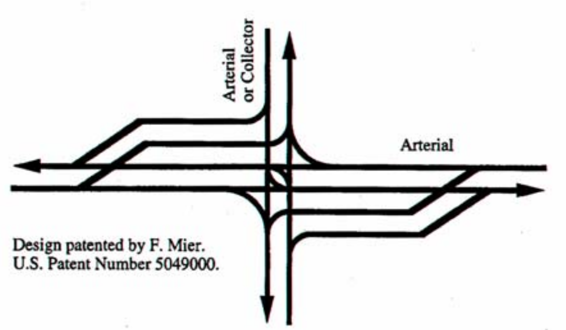
Disadvantages. The disadvantages of the alternative relative to conventional intersections include:

- driver confusion;
- driver disregard for left-turn prohibitions at the main intersection;
- increased delay for left turns from the arterial, especially if queues of cross-street vehicles block the ramp terminal;
- increased travel distances for left turns from the arterial;
- increased stops for left turns from the arterial;
- pedestrians must cross ramps and the main intersection;
- additional right of way for ramps;
- additional construction and maintenance costs for ramps; and
- lack of access to arterial for parcels next to ramps.

When to Consider. Designers should consider jughandles on arterials with high through volumes, moderate to low left-turn volumes, and narrow rights of way. The distances between signals should be long so that the extra right of way and other costs for the ramps do not overwhelm the savings elsewhere.

Figure 1-10. Alternative Designs – Jughandle.[9]

CONTINUOUS FLOW INTERSECTION



Description. The continuous flow intersection features a ramp to the left of the arterial upstream of the main intersection to handle traffic turning left from the arterial, as shown above. Usually, high volumes will justify a signal at the crossover where the ramp begins. Engineers can easily coordinate this two-phase signal with the signal at the main intersection. A single signal controls the main intersection and the left-turn ramp/minor-street intersection. The major breakthrough with this design is that arterial through traffic and traffic from this left-turn ramp can move during the same signal phase without conflicting. This allows, in effect, protected left turns with a two-phase signal. The cross-street stop bar must be set back beyond the left-turn ramp, which probably means more lost time and longer clearance intervals for the cross-street signal phase(s). Right turns are removed from conflicts near the intersection with ramps. U-turns on the arterial are possible at the left-turn crossover if the median is wide enough. Without provisions for U-turns the arterial median may be narrow. The left-turn ramp usually crosses the opposing traffic 300 ft [92 m] or so from the cross street to balance the various higher costs of a longer ramp against the chance of spillback from the main intersection blocking the signal at the crossover.

Franciso Mier of El Cajon, Calif., USA, holds the U.S. patent, #5049000, for the continuous flow intersection. Agencies wishing to implement the design must contact Mier to obtain the rights.

Variations. If left turns to the arterial are heavy at the continuous flow intersection as shown above, a third signal phase may be needed at the main intersection. To avoid the third phase, designers can use left-turn ramps in three or all four quadrants of the intersection.

History. Mier obtained his patent in 1987. With co-authors, he has published articles evaluating the concept in general and has written several reports evaluating the concept in particular locations. The first continuous flow intersection in the United States, with ramps in a single quadrant at a T-intersection, was opened in 1994 in Long Island, N.Y., USA, at an entrance to Dowling College. Several others have opened recently in Mexico. Early reports on the operation of these intersections are favorable.

Advantages. The advantages of the continuous flow intersection over a conventional multiphase signalized intersection include:

- reduced delay for through arterial traffic,
- reduced stops for through arterial traffic,
- easier progression for through arterial traffic,
- narrower right of way needed along the arterial, and
- reduced and separated conflict points.

With ramps in three or four quadrants these advantages may extend to the cross street as well.

Disadvantages. The disadvantages of the alternative relative to conventional intersections include:

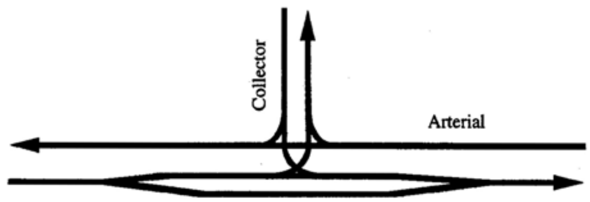
- driver and pedestrian confusion;
- increased stops for left turns from the arterial;
- restricted U-turn possibilities;
- pedestrians must cross ramps and the main intersection (and pedestrians must cross the four-quadrant design in a slow two-stage maneuver);
- additional right of way for ramps;
- additional construction, maintenance, and operation costs for ramps and extra signals;
- lack of access to the arterial for parcels next to ramps; and
- the costs of obtaining the rights to use the design.

If left turns from the arterial experience more delay than at comparable conventional intersections, the extra delay is likely to be small in magnitude.

When to Consider. Agencies should consider the continuous flow intersection on arterials with high through volumes and little demand for U-turns. The designer must have some right of way available along the arterial near the intersection and must be able to restrict access to the arterial for parcels near the intersection. Like the bowtie and jughandle alternatives, the extra right of way and other costs will be hard to justify if installations are too close together.

Figure 1-11. Alternative Designs – Continuous Flow Intersection.[10]

CONTINUOUS GREEN T



Description. While the other unconventional alternatives discussed worked for both three-approach and four-approach intersections, the continuous green T alternative only works for three-approach intersections (see above). The two through lanes on the top of the T are controlled differently. The median lane is subject to the standard two-phase or (more likely) three-phase signal, which also controls opposing through traffic; left turns from the arterial; and turns from the cross street. However, the shoulder lane receives a steady green signal. Pavement marking directs traffic turning left from the cross street into the median lane. Pedestrians must seek signal protection between the two through lanes. This area can be narrow and should not present a hazardous fixed object. Agencies should make the separation visible and tactile with raised reflectors or rumble strips. The separation should extend several hundred feet upstream and downstream from the intersection to minimize last-minute weaves. Agencies can use more than one continuous through lane, but dual left-turn lanes from the cross street would mean dual signal-controlled through lanes on the top of the T and would put great pressure on the remaining continuous through lane(s). The arterial should have a raised median of some type, at least for the length of the through-lane separation, to stop vehicles from turning left or from driveways and thereby crossing the through-lane separation.

Variations. The main variation to the continuous green T as shown above is to have all through lanes on the top of the T get a steady green signal while left turns from the cross street are channelized into a merging lane in the median. The merging lane must be lengthy to minimize conflicts. This variation requires a slightly wider median than the minimal 16-ft [4.9 m] median (i.e., one exclusive turn-lane wide) required for the continuous green T-intersection as shown above. The island channelizing the left turns should be very positive; some agencies use curbs with pavement markings and reflectors. A merge from the left is a difficult driving maneuver, so while this variation rewards higher volumes of arterial through traffic, it will break down with higher left-turn volumes.

History. Several districts of the Florida Department of Transportation have used the continuous green T alternative shown with no major apparent problems. A large number of agencies use the variation described above.

Advantages. The advantages of the continuous green T-intersection over a conventional multiphase signalized T-intersection include:

- reduced delay for through arterial traffic in one direction, and
- reduced stops for through arterial traffic in one direction.

It is very unlikely that the through movement at the top of the T is a critical movement that controls signal timing. If that movement should happen to be critical, however, removing it from the domain of the signal would lead to reduced delay for all other movements at the intersection.

Disadvantages. The disadvantages of the alternative relative to conventional intersections include:

- driver and pedestrian confusion,
- driver disregard of the separation between the through lanes,
- no signal protection for pedestrians to cross the arterial,
- increased lane changing conflicts before and after the separation of the through lanes, and
- restricted access to parcels adjacent to the continuous green through lane(s).

Driveways along the continuous green through lanes(s) pose two potential problems. First, through drivers in the continuous green lanes may not expect to slow for anything in those lanes, even a right-turning vehicle. Second, drivers turning left onto the arterial from the minor street may try to merge into the continuous green through lane or pass through the lane separation to get to a driveway.

When to Consider. Of the unconventional alternatives discussed in these features, the continuous green T has the most restrictive niche. Engineers should consider it at signalized three-approach intersections with moderate to low left-turn volumes from the minor-street and high arterial through volumes, where there are no crossing pedestrians and few drivers choose one of the two continuous green lanes.

Figure 1-12. Alternative Designs – Continuous Green T.[10]

Quadrant Roadway Intersection

Reid[11] also proposed another unconventional intersection design alternative B the "quadrant roadway intersection" (QRI) design. The QRI design removes left-turn movements from main arterial/cross-street intersections through use of an additional roadway in one intersection quadrant. Figure 1-13 shows a typical QRI design and Figure 1-14 shows the left-turn patterns. By routing all left-turn movements from the arterial and cross street to the quadrant roadway, the main arterial and cross-street intersection can operate with a simple two-phase signal. The spacing of the QRIs from the main intersection is a trade-off between left-turn travel distance and time versus available storage for the westbound left-turn movement. In the analysis of the QRI, a 91.8-ft [28 m] spacing was selected for both QRIs from the main intersection. Other considerations for QRI include:

- potential uses of the land within the quadrant roadway such as service station or convenience store served by right-in/right-out driveways,
- additional advance signing needs,
- design modifications for missed left-turn opportunities (consider additional median U-turns beyond the main intersection),
- preservation of signal operation at each intersection (a fourth intersection leg cannot be developed at either end of the quadrant roadway because these signals must function as T-intersections), and
- restriction of driveways between intersections to preserve left-turn storage for the main intersection approaches.

[11] Reid, J.D. "Using Quadrant Roadways to Improve Arterial Intersection Operations," *ITE Journal*, June 2000.

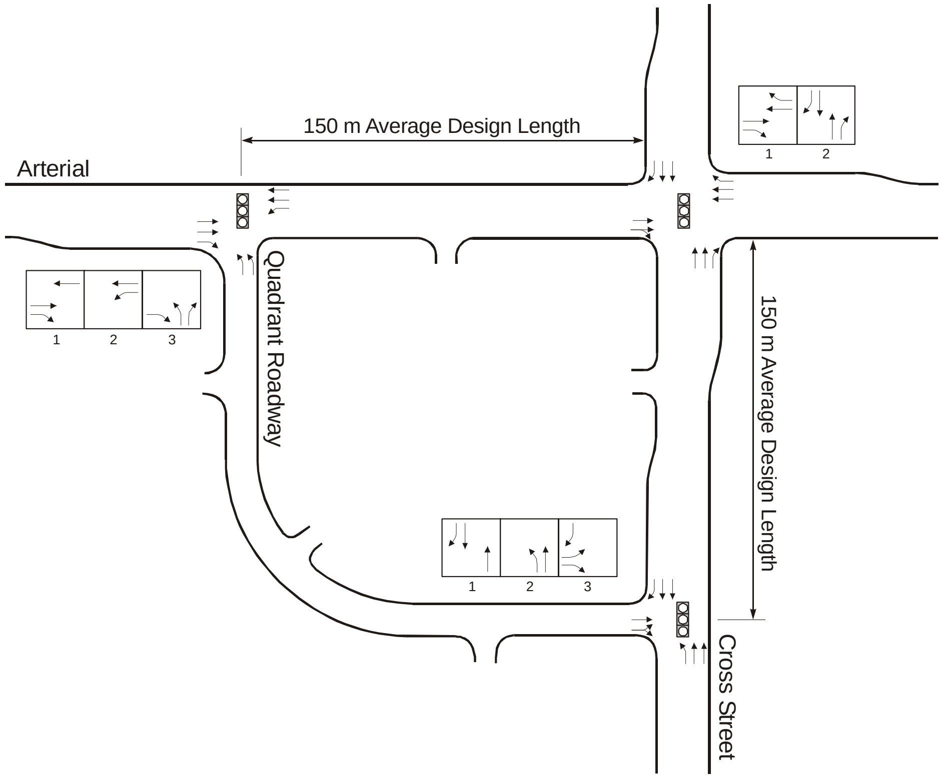


Figure 1-13. QRI Design.[11]

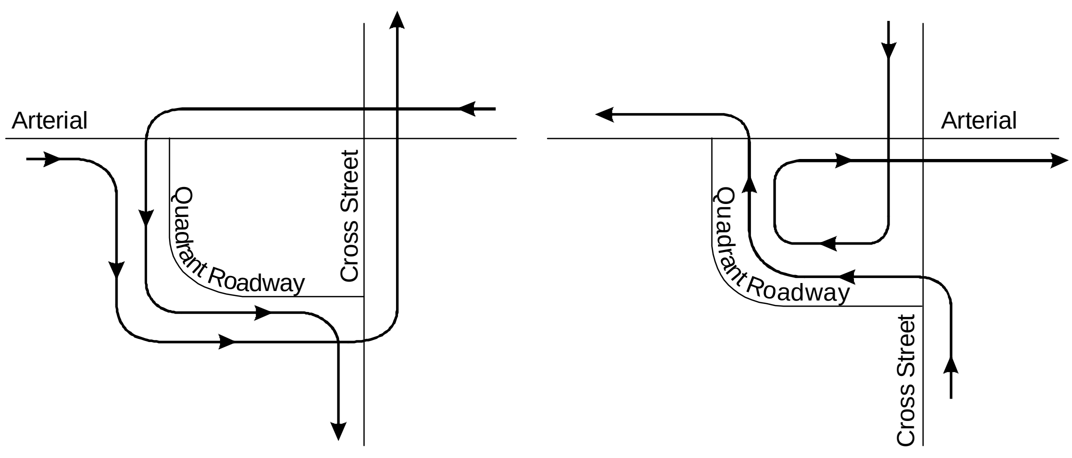


Figure 1-14. QRI Left-Turn Pattern.[11]

A CORSIM experiment was conducted that showed improved stopped-delay and system travel time for QRIs as compared to typical arterial intersections. The author noted that while driver expectations may be violated at QRIs, designs similar to QRI have been successfully implemented in the field. Based on his analysis, the advantages and disadvantages listed below were identified.

Advantages were:

- creates more progression opportunities by allowing a larger progression bandwidth due to two-phase signal operation at the main intersection;

- reduces total intersection system delay;
- reduces queuing, especially for the worst approach movements, by greater than 120 percent in level of service conditions;
- fewer vehicle conflict points at the main intersection and a probable reduction in left-turn or head-on collisions; and
- narrower intersection widths (by eliminating dual turn lanes) reduce vehicle clearance and pedestrian crossing times.

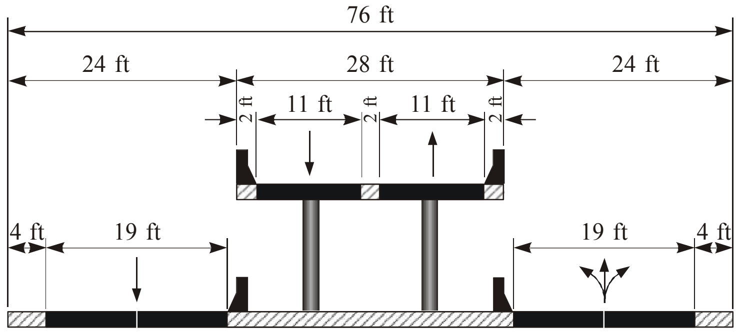
Disadvantages were:

- increased left-turn travel distance and the potential for increased left-turn travel times and stops;
- greater possibility of driver confusion, error at critical (intersection) locations, and missed left-turn opportunities;
- nonconformity of left-turn patterns for each approach of the same intersection;
- additional advance signing requirements; and
- additional right of way required for the quadrant roadway.

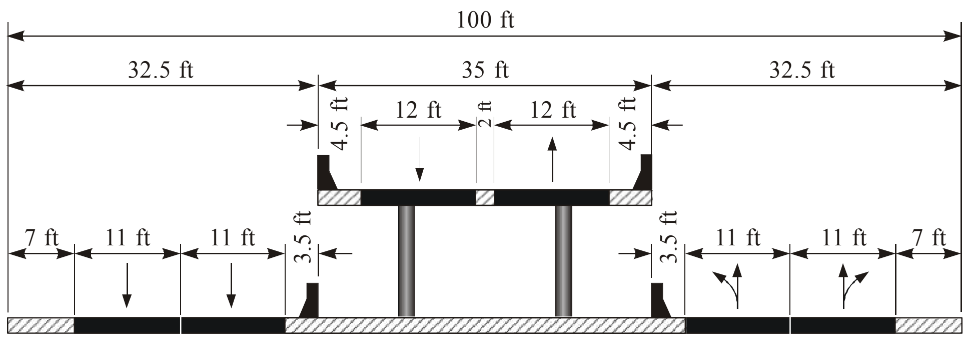
Flyovers

Bonilla[12] examined the benefits of the flyover, which is defined as a grade-separated structure that allows arterial through traffic to go over a crossing arterial or collector without slowing down or stopping for an at-grade signal. He states that capacity per lane is generally that of arterial through lanes, about 1750 vph. His economic evaluation showed that congested intersections with an approach volume averaged over 20 years of 50,000 vehicles per day or more would justify a simple arterial flyover. The minimum right of way for urban arterial flyovers is listed in Table 1-2, and Figure 1-15 shows minimum cross sections. Safety considerations for flyovers require a smooth transition from at-grade arterial lanes to the flyover. The physical split between exiting intersection-bound traffic and the through traffic must be logical, simple, and anticipated.

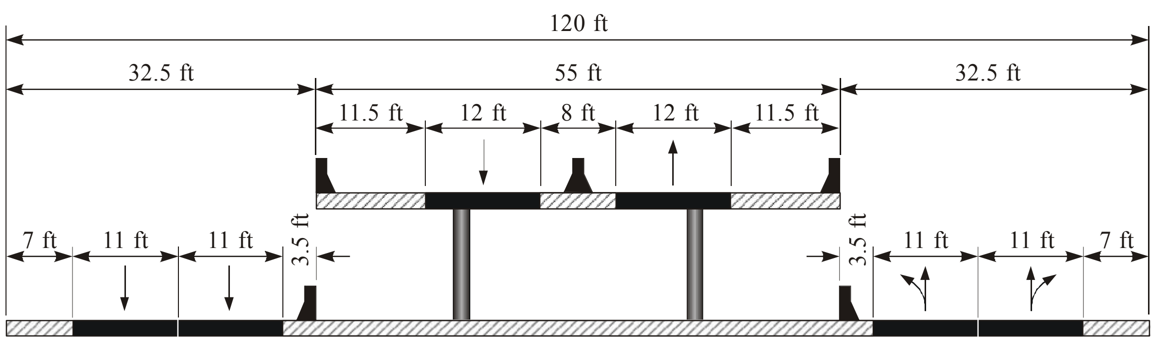
[12] Bonilla, C.R. Physical Characteristics and Cost-Effectiveness of Arterial Flyovers, *Transportation Research Record* 1122, Transportation Research Board, Washington, D.C., 1987.



(A) Marginal



(B) Low Type



(C) High Type

Figure 1-15. Minimum Cross Section and Right of Way for a Two-Lane Flyover.[11]

Table 1-2. Minimum Right of Way for Urban Arterial Flyovers.[12]

	Right of Way by Number of Lanes, ft [m]		
	Two Lanes	Four Lanes	Six Lanes
Marginal	76 [23.2]	98 [29.9]	
Low Type	100 [30.5]	120 [36.6]	140 [42.7]
High Type	120 [36.6]	144 [43.9]	168 [51.2]

Merging traffic from the at-grade intersection with traffic from the flyover may require somewhat longer tapers, similar to those used for arterial lane drops. Another challenge with the design is tying the vertical alignment with existing grade before reaching the next cross street. Bonilla proposed the following warrants for flyovers:

- The intersection is a bottleneck and conventional traffic engineering measures cannot resolve the capacity problem.
- A minimum of four through lanes already exists and maximum use of the intersection right of way has been made. The sum of critical lane volumes approaches or exceeds 1200 vph.
- It is time-consuming, expensive, or contrary to public objectives to obtain additional right of way. A minimum right of way of 100 ft [30 m] is available.
- Impact to adjacent properties and minor streets limited to right turn only is not severe.
- The accident rate is significantly larger than for nearby intersections on the same arterial.

Echelon

Another concept for an uncontrolled access urban arterial interchange is the echelon interchange.[13] The echelon interchange elevates one-half of a divided highway as it approaches the point of intersection, resulting in two grade-separated intersections. The two grade-separated intersections operate in the same manner as two one-way pair intersections (see Figure 1-16). Miller and Vargas[13] concluded that the echelon interchange will sometimes, but not always, out-perform traditional grade separation designs in signalized networks. It offers two important possible advantages: (a) it will not overpower the adjacent signalized intersection to the extent free-flow movements might; and (b) it offers the planner/designer significant flexibility and more discretionary options relative to its layout and its attendant land use.

[13] Miller, N.C., and J.E. Vargas. "The Echelon Interchange," 1997 *ITE Compendium*. (1997).

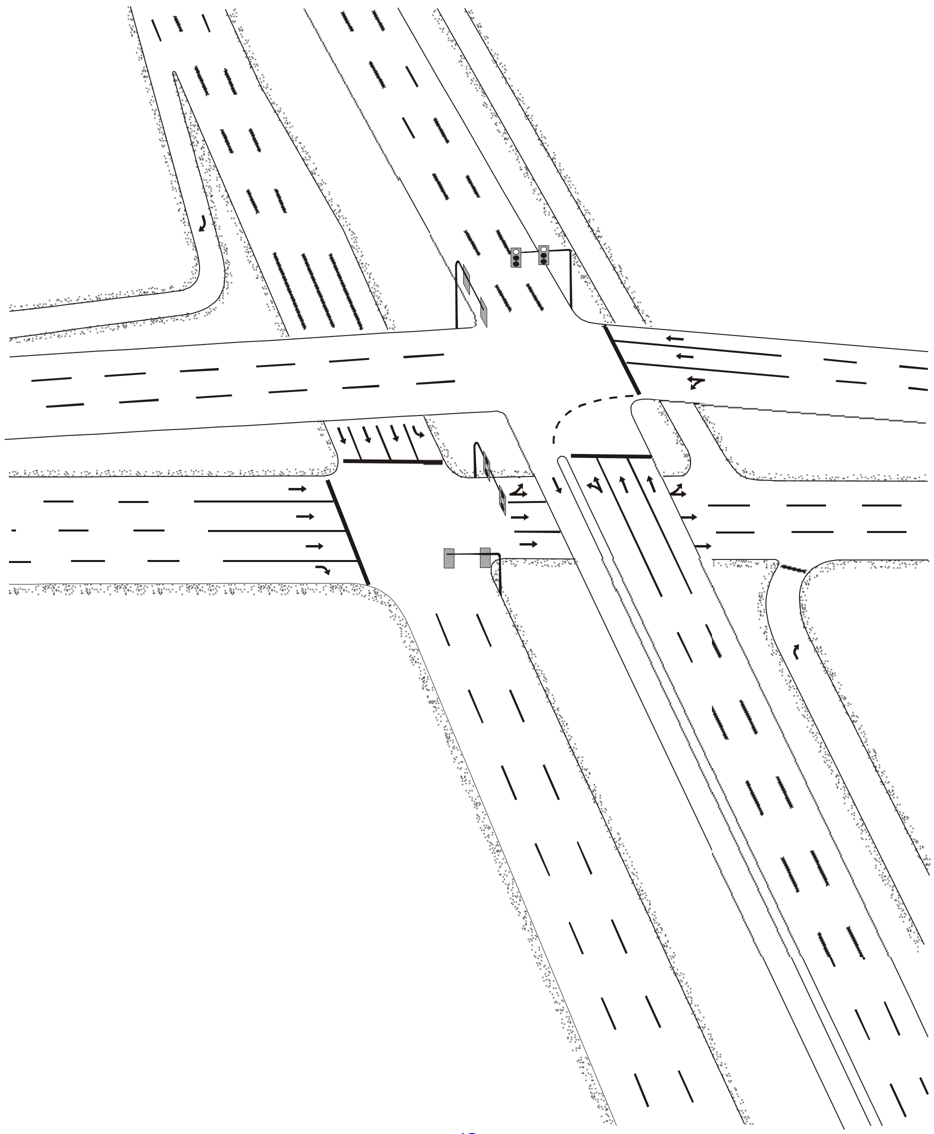


Figure 1-16. Echelon Interchange.[13]

Chapter 2
Design Control and Criteria

Contents:

Application 1

Pedestrian Features Checklist

Overview

The following presents a checklist on pedestrian features. The *Urban Intersection Design Guide*, Chapter 2, Section 2 presents additional information on pedestrians. Information on sidewalks and pedestrian treatments is in the *Urban Intersection Design Guide*, Chapter 5, Section 1 and Chapter 7, respectively.

Background

During an intersection design, several elements are competing for attention. Following is a checklist that can be used to review a design to assist in identifying whether pedestrians are adequately considered within the design. The objective of the checklist is to encourage consideration of pedestrians throughout the design. It is easier to incorporate pedestrian-friendly features early in the design rather than trying to retrofit after the design is nearly complete or after the intersection is constructed.

Checklist

Checklist For Pedestrian Features At An Urban Intersection

***Checklist Key**

Y = Yes or Acceptable N = No or Needs Improvement I = Irrelevant to Site

*Y	N	I	**SIDEWALKS**
			Is a sidewalk present on at least one side of road?
			Are sidewalks on both sides of road?
			Is sidewalk continuous (e.g., no gaps)?
			Is sidewalk wide enough to meet current accessibility requirements?
			Is sidewalk wide enough to meet current demand?
			Is sidewalk wide enough to meet future demand?
			Is cross slope on sidewalk < 2 percent (required by *Americans with Disabilities Act Accessibility Guidelines* (ADAAG))?
			Is the pedestrian path clear of obstructions, such as street lights, utility poles, newspaper stands, trash receptacles, etc.?

Checklist For Pedestrian Features At An Urban Intersection

***Checklist Key**

Y = Yes or Acceptable N = No or Needs Improvement I = Irrelevant to Site

*Y	N	I	**SIDEWALKS (Continued)**
			Is there street furniture in the pedestrian path that could affect movement (e.g., benches, etc.)?
			Is condition of sidewalks well maintained (e.g., are tree roots causing upheave)?
			Is there adequate separation between the pedestrian path and traffic (greater separation desired on higher functional class roads)?
			Is adequate information provided for the pedestrian (e.g., signs, clearly defined pedestrian route, etc.)?
			Are signs of adequate size or lighted as needed for the pedestrian population expected for the area?
			Is adequate street lighting of the sidewalk present?
			Is desirable street furniture present (e.g., benches, water fountain, etc.)?
			Are accessible driveway crossings present?
			Are pedestrians visible to drivers (and vehicles visible to pedestrians) exiting driveway?

*Y	N	I	**CROSSING**
			Can pedestrians (including children and wheelchair users) see approaching vehicles?
			Can vehicles in each lane clearly see pedestrians?
			Is waiting area paved?
			Is waiting area large enough to accommodate anticipated demand?
			Does waiting area meet accessibility requirements?
			Is waiting area clear of street furniture, fixtures, or other obstacles?

Checklist For Pedestrian Features At An Urban Intersection

***Checklist Key**

Y = Yes or Acceptable N = No or Needs Improvement I = Irrelevant to Site

*Y	N	I	**CROSSING (Continued)**
			Are relevant traffic control devices (signs, markings, signals) present? If so, are they clearly visible (or audible) to the pedestrian (e.g., pedestrian head located in-line with crosswalk, etc.)?
			Is the length of the crossing (i.e., width of cross street) appropriate for the ability or comfort of the pedestrian?
			Is the pedestrian push button in the desired location?
			Does the crossing reflect pedestrian desired lines?
			Are traffic control devices at the crossing appropriate or is a more restrictive control needed?
			Is the amount of time a pedestrian waits at an unsignalized intersection to cross the street reasonable?
			Is the pedestrian crossing interval at a signalized intersection adequate?
			Are pedestrian-oriented signal treatments (e.g., scramble phases, no right turn on red, etc.) needed?
			Are additional features (e.g., longer crossing time) that would be activated by an extended button press at a signalized intersection needed?
			Are detectable warnings present where needed (e.g., on curb ramps, at flush transitions)?
			Is curb ramp and landing present?
			Does curb ramp meet accessibility requirements?
			Is the foot of the curb ramp contained within the crosswalk markings?
			Is median refuge island large enough to accommodate anticipated demand?
			Is the median refuge island accessible?
			Does the median refuge island limit visibility for the pedestrian?

Checklist For Pedestrian Features At An Urban Intersection

***Checklist Key**

Y = Yes or Acceptable N = No or Needs Improvement I = Irrelevant to Site

*Y	N	I	**CROSSING (Continued)**
			Does the median refuge island include signal activation (e.g., pedestrian push button) if crossing is signalized?
			Do pedestrians need to be physically directed to cross in a preferred location?
			Would stormwater drainage (e.g., flow rate, ponding, snow, ice accumulating, etc.) near the crossing affect pedestrians?

*Y	N	I	**INTERACTING**
			Can drivers see waiting pedestrians?
			Can drivers see crossing pedestrians?
			Do through drivers appropriately yield the right of way to pedestrians?
			Do left-turning drivers appropriately yield the right of way to pedestrians?
			Do right-turning drivers appropriately yield the right of way to pedestrians?
			Is right turn on red an issue?
			Is the posted or operating speed on the roadway an issue?
			Is red-light running a frequent problem?
			Do drivers realize that a pedestrian may be crossing (e.g., is crosswalk clearly marked and clearly visible, are advance signs of crossing present)?
			Is transit stop located where pedestrians are likely to be walking, waiting, or crossing?
			Is the speed of the turning vehicle (which is influenced by the corner radius) incompatible with pedestrian usage in the area?
			Do features of the median refuge island limit visibility to the pedestrian?
			Does on-street parking affect pedestrian movement?

***Checklist For Pedestrian Features At An Urban Intersection**

***Checklist Key**

Y = Yes or Acceptable N = No or Needs Improvement I = Irrelevant to Site

*Y	N	I	**EXPERIENCE**
			Do landscaping, art, and/or vista enhance experience?
			Does landscaping interfere with walking/crossing (e.g., planters consume too much of available walking area, trees/bushes limit view to or from pedestrians, etc.)?
			Is the interaction between development and walking/waiting areas positive?
			Is the area maintained?
			Are amenities appropriate for types of pedestrians using the facility (e.g., school children, disabled, older, etc.)?
			Is walking route comfortable and convenient (sidewalk direct without unnecessary horizontal or vertical changes)?
			Is waiting area comfortable?
			Is alternative route available if sidewalk is blocked?
			Does the pedestrian route have good drainage (e.g., ponds are not forming near the route)?
			Would pedestrians feel secure?
			Would pedestrians feel safe?

Checklist For Pedestrian Features At An Urban Intersection

***Checklist Key**

Y = Yes or Acceptable N = No or Needs Improvement I = Irrelevant to Site

*Y	N	I	**POLICY**
			Is location part of a sidewalk plan?
			Is there support by municipality?
			Is there support by local residents or businesses?
			Is there support by community groups?
			Is there evidence of pedestrian travel (e.g., beaten down path, etc.)?

Application 2
Safety Study Example

Overview

The following application presents a safety study. The *Urban Intersection Design Guide*, Chapter 2, Section 4 presents additional information on urban intersection safety.

Background

A young engineer was assigned the task of developing suggestions for improvements to an intersection reported as having a crash problem. The intersection of interest is in a rapidly developing area of the district. Two two-lane state highways intersect at a 90-deg angle with one highway having an Average Daily Traffic (ADT) of 11,000 and the other having an ADT of 6000. The intersection has a signal and no turn lanes on any of the approaches. A sketch of the intersection is shown in Figure 2-1.

The engineer identified two resources that could assist in the evaluation:

- ITE's *Manual of Transportation Engineering Studies*,[1] and
- TxDOT's *Treatments for Crashes on Rural Two-Lane Highways in Texas* (TxDOT Report 4048-2).[2]

The engineer used the procedure presented in these documents as a guide for the assignment along with several other references. While the TxDOT report had a rural focus, the steps presented were applicable to safety studies on all facility types. The following is the safety study format that was used:

- Identify Crash Characteristics,
- Gather Existing Conditions,
- Collect Additional Field Data,
- Assess Situation and Select Treatments, and
- Implement and Evaluate.

Steps undertaken within each of the above elements are discussed in the following sections.

[1] Hummer, J.E., "Traffic Accident Studies" chapter, *Manual of Transportation Engineering Studies*. Institute of Transportation Engineers. Prentice Hall, Englewood Cliffs, NJ, 2000.

[2] Fitzpatrick, K., A.H. Parham, and M.A. Brewer. *Treatments for Crashes on Rural Two-Lane Highways in Texas*. Report FHWA/TX-02/4048-2. Texas Transportation Institute, College Station, TX, April 2002.

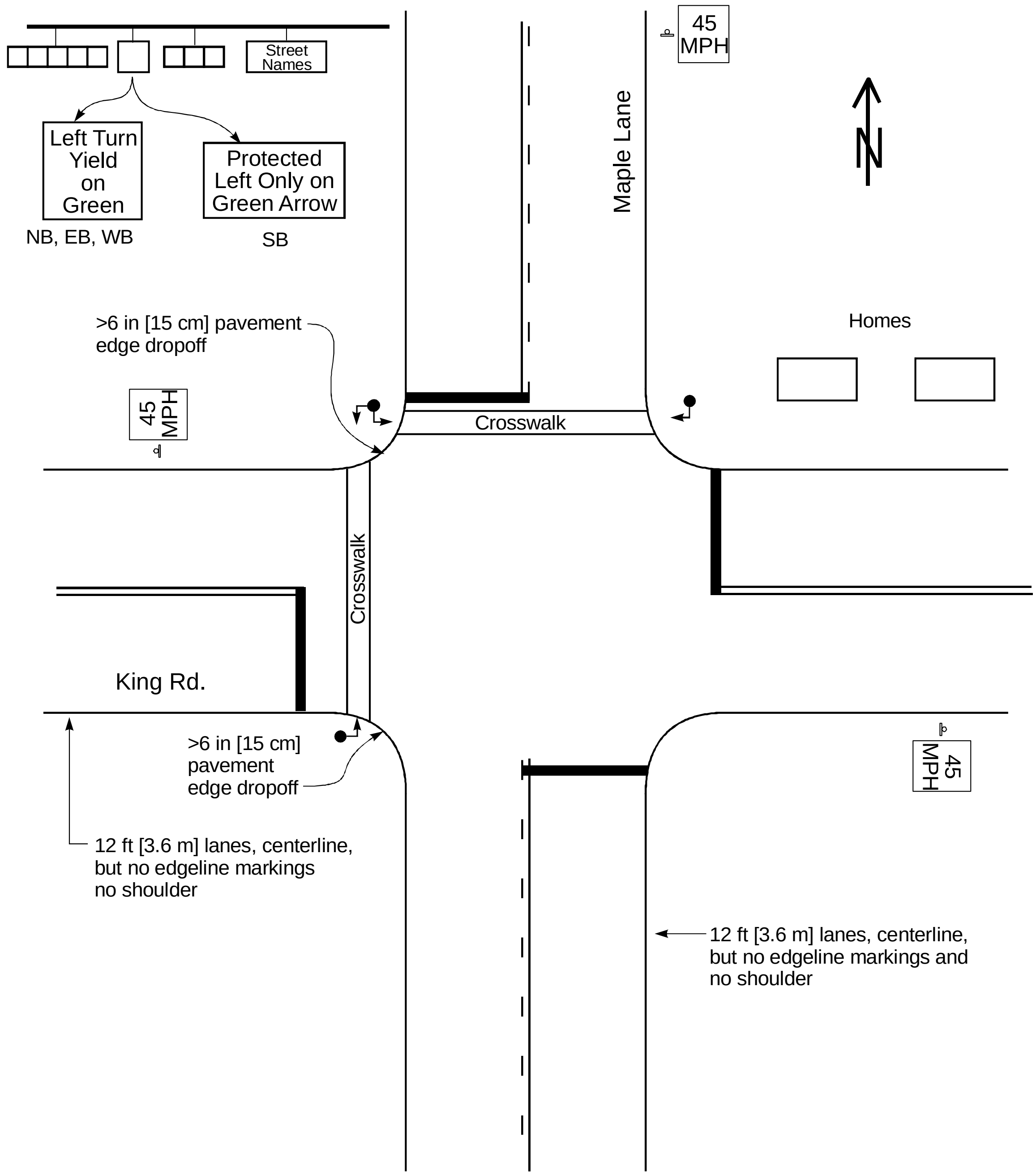


Figure 2-1. Condition Diagram.

Identify Crash Characteristics

For this location, a citizen reported that the intersection needed improvements due to the number of crashes occurring. In other situations sites may be identified by other agencies (e.g., police) or through a comprehensive review of a region's crash data. The engineer identified the following resources as being needed for the evaluation:

- Texas crash data (available from the District Traffic Section) and
- crash narratives (ordered from Department of Public Safety [DPS] after crashes are identified or may be available from local law enforcement).

Documents that could assist with the safety study include the following:

- ITE "Traffic Accident Studies" chapter of the *Manual of Transportation Engineering Studies*,[1]
- *Treatments for Crashes on Rural Two-Lane Highways in Texas*[2] (TxDOT Report 4048-2),
- *Texas Manual on Uniform Traffic Control Devices*[3] (*TMUTCD*),
- TxDOT *Roadway Design Manual*[4] (available on the web),
- AASHTO *Roadside Design Guide*,[5]
- NCHRP Synthesis 295: Statistical Methods in Highway Safety Analysis,[6] and
- NCHRP Report 440: *Accident Mitigation Guide for Congested Rural Two-Lane Highways*.[7]

The following steps were used to identify the crash characteristics at the site:

- ***Crash Data.*** An initial step in a safety study is to request the crash data for the site. The junior engineer was told to obtain 3 years of data since this is the most common time frame used in these types of studies. Time frames of less than 2 years may be necessary, but the smaller sample size may not be representative of conditions at the location and the user may need to adjust for the regression-to-the-mean condition (see NCHRP Synthesis 295[6] for additional information on regression-to-the-mean). Several

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[3] *Texas Manual on Uniform Traffic Control Devices for Streets and Highways*. Texas Department of Transportation. 2003. http://www.dot.state.tx.us/TRF/mutcd.htm. Accessed February 17, 2003.

[4] *Roadway Design Manual.* Texas Department of Transportation. 2002. http://manuals.dot.state.tx.us/dynaweb/coldesig/rdw/@Generic__BookView

[5] AASHTO. *Roadside Design Guide*. American Association of State Highway and Transportation Officials, Washington, D.C., 2002.

[6] Persaud, B.N. *Statistical Methods in Highway Safety Analysis.* NCHRP Synthesis 295. Transportation Research Board, Washington, D.C., 2001.

[7] Fitzpatrick, K., D.W. Harwood, I.B. Anderson, and K. Balke. *Accident Mitigation Guide for Congested Rural Two-Lane Highways*. National Cooperative Highway Research Program Project 440, November 1999.

factors are associated with each crash in the Texas crash database. The analyst may not be interested in all the factors and may want to limit which data fields are pulled. For example, the database includes ADT for several years, and the analyst may only be interested in the ADTs for the years under study. Examples of factors that may be of interest include: collision type, severity of injury, road surface conditions, weather, object struck, traffic control, month, day of week, time of day, light conditions, first harmful event, roadway condition, alignment, curve, number of vehicles involved, other factors, and direction of travel. The crash data for this study were obtained from the District Traffic Section. Starting in 2005, the department's new Crash Record Information System (CRIS) will replace the existing Department of Public Safety database.

- ***Summary Report.*** Once the crash data were available, a summary report of the crashes was prepared. This report, shown in Table 2-1, will assist in the evaluation.
- ***Collision Diagram.*** A collision diagram was developed to identify the patterns of crashes and is shown in Figure 2-2. Examples of collision diagrams are contained in several documents including NCHRP Report 440: *Accident Mitigation Guide for Congested Rural Two-Lane Highways*[7] and ITE "Traffic Accident Studies" chapter of the *Manual of Transportation Engineering Studies*.[1]
- ***ADT.*** The approach volumes for each roadway were identified for the intersection. The calculated crash rates for the intersection could be compared to district averages to assist in the determination of whether improvements should be programmed.
- ***Crash Narratives.*** The crash narratives from the Department of Public Safety were requested. The information from the crash database used to produce the summary and collision diagram was compared with the information contained in the narratives. The narratives provided additional information, such as conditions during the crash involving a driving while intoxicated (DWI) charge.

Table 2-1. Crashes at Maple and King.

Acc Num	Collision Type	Severity	Surface	Weather	Time of Day	Month	Day	Light Condition	No. of Veh
6019	same 1 str 2 stop	non-injury	wet	clear	6:00 AM	Jan	Mon	dawn	2
6217	opp 1 str 2 LT	possible	dry	clear	3:00 PM	Sept	Mon	daylight	2
6295	opp 1 str 2 LT	nonincap	wet	fog	8:00 PM	Dec	Mon	daylight	2
6146	opp 1 str 2 LT	possible	wet	raining	6:00 AM	July	Fri	daylight	2
6162	same 1 str 2 stop	possible	wet	clear	9:00 AM	July	Wed	daylight	2
6163	opp 1 bck 2 stop	possible	dry	clear	10:00 AM	July	Tues	daylight	2
7195	same 1 str 2 stop	non-injury	dry	clear	11:00 AM	Aug	Sun	daylight	2
7165	opp 1 str 2 LT	possible	dry	clear	7:00 PM	July	Fri	daylight	2
7262	ang both str	possible	wet	raining	11:00 AM	Nov	Wed	daylight	3
7263	same 1 str 2 stop	possible	wet	raining	11:00 AM	Nov	Wed	daylight	2
8024	opp 1 str 2 LT	possible	dry	clear	8:00 AM	Feb	Tues	daylight	2
8088	same 1 str 2 stop	nonincap	wet	raining	6:00 PM	April	Mon	daylight	3
8124	opp 1 str 2 LT	possible	dry	clear	3:00 PM	June	Wed	daylight	2
8257	same 1 str 2 stop	nonincap	wet	raining	2:00 PM	Nov	Sat	daylight	3
6245	opp both str	incap	wet	raining	1:00 PM	Oct	Tues	daylight	2
8005	opp 1 str 2 LT	non-injury	dry	clear	8:00 PM	Jan	Thurs	dark not lighted	2
8057	same 1 str 2 stop	possible	wet	raining	12:00 PM	March	Sat	daylight	2
8106	same 1 str 2 stop	nonincap	dry	clear	6:00 PM	May	Mon	daylight	3
8175	opp 1 str 2 LT	possible	dry	clear	6:00 AM	Aug	Tues	daylight	3
9277	opp both str	nonincap	dry	clear	10:00 PM	Nov	Tues	dark not lighted	2
9085	rear end	non-injury	dry	clear	5:00 PM	April	Fri	daylight	4
9200	rear end	non-injury	wet	raining	3:00 PM	Aug	Fri	daylight	2
9256	same 1 str 2 stop	non-injury	wet	raining	10:00 AM	Oct	Sat	daylight	2
9257	same 1 str 2 stop	non-injury	wet	raining	4:00 PM	Oct	Sat	daylight	2
9293	same 1 str 2 stop	possible	wet	raining	4:00 PM	Dec	Sat	daylight	4
9157	ang both sir	nonincap	wet	raining	5:00 PM	July	Wed	daylight	2
9001	opp 1 str 2 LT	possible	dry	clear	6:00 PM	Jan	Sat	dark not lighted	2
9094	opp 1 str 2 LT	nonincap	wet	clear	11:00 AM	April	Mon	daylight	2
9286	same 1 str 2 stop	possible	wet	clear	9:00 AM	Dec	Sat	daylight	4
9055	same 1 str 2 stop	possible	wet	clear	4:00 PM	March	Fri	daylight	3
9068	SIN str	non-injury	wet	raining	5:00 PM	March	Sat	daylight	1

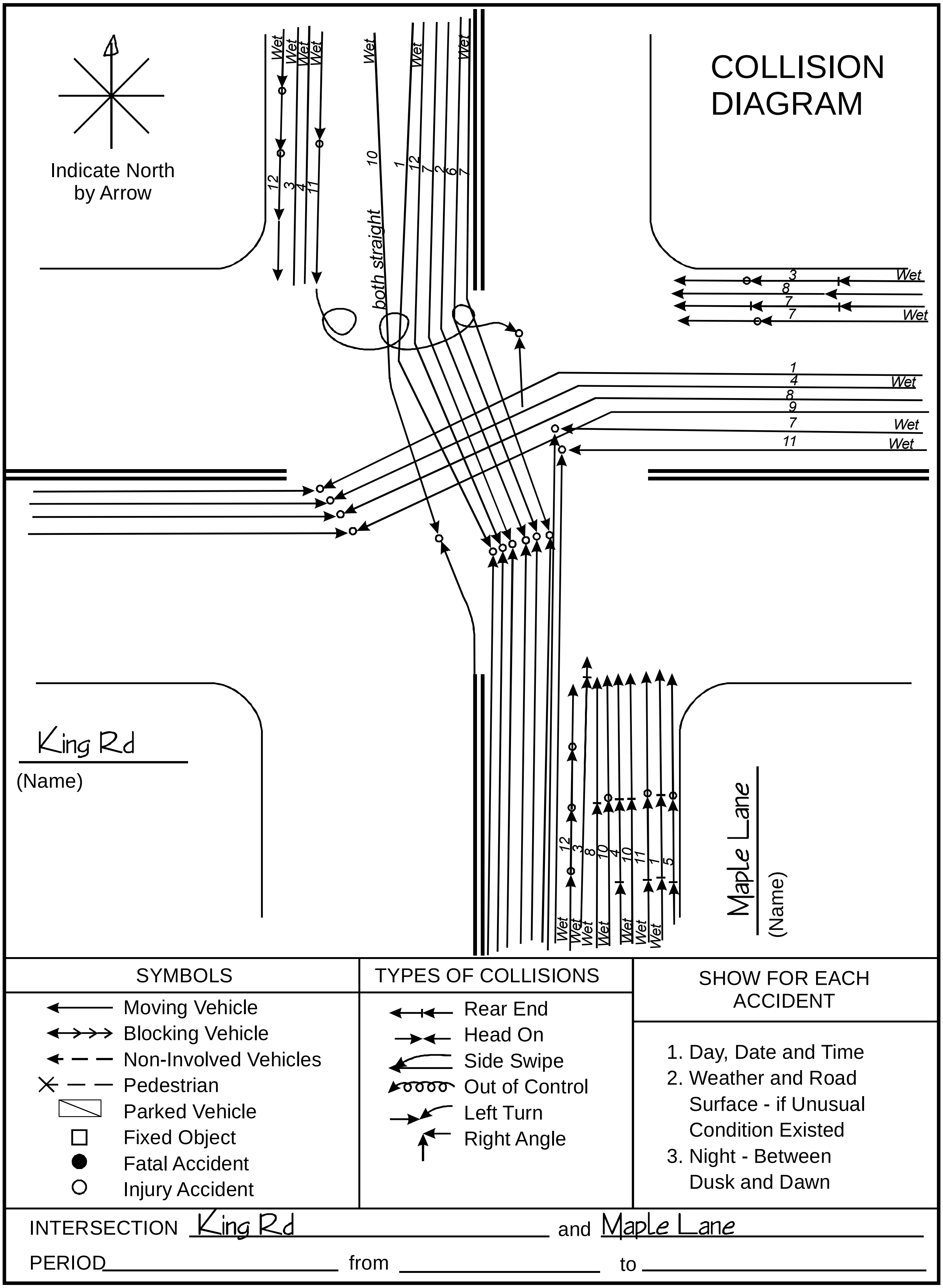


Figure 2-2. Collision Diagram.

Gather Existing Conditions

The next effort in the process was to gather information on the in-field condition of the site. Following are the steps that were followed:

- ***Field Methodology.*** At each location, the review team performed the following:
  - filmed a drive-through video of all approaches to record existing conditions from a driver's perspective,
  - drew a condition diagram (see Figure 2-1),
  - took pictures,
  - observed traffic, and
  - noted driver behavior.
- ***Checklists.*** To assist with field operations, three groups of questions or checklists were used at each site (these checklists are shown in Table 2-2, Table 2-3, and Table 2-4). Observations recorded on the checklists included the following:
  - High volumes produced queues (5 to 10 vehicles long) during red indications.
  - Queues that formed cleared during the next green indication.
  - Pavement markings were worn and needed replacing.
  - No left-turn bays were present; however a left-turn indication would appear during the cycle on the southbound approach. Is that left-turn signal pretimed or activated due to standing queue? (Need to request signal timing plan.)
  - Edge drop-offs are present, especially on the westbound approach.
  - Several large trucks were observed on the westbound approach.
  - Subdivisions are being constructed on several approaches.
- ***Findings.*** The findings from the field, information in the crash narratives obtained from the Department of Public Safety, and information from the crash database used to produce the summary and collision diagrams were compared.

Table 2-2. Basic Field Observations.[7]

Operational Problem Symptoms	Physical Inventory Parameters (Supplement Construction Plans)
♦ Length of vehicle queues	♦ Sight distance restrictions
♦ Erratic vehicle maneuvers	♦ Pavement and shoulder conditions
♦ Vehicles experiencing difficulty in making turning movements	♦ Signal visibility
♦ Vehicles experiencing difficulty in making merging or weaving movements	♦ Signs, including speed limits
♦ Evidence of unreported crashes such as damaged guardrail, skid marks, or tire tracks off of the pavement	♦ Curb radii
♦ Pedestrians on roadway	♦ Pavement markings
♦ Pedestrian-vehicle conflicts	♦ Lighting
	♦ Driveway locations
	♦ Fixed objects and roadside design

Table 2-3. Questions to Consider During the Field Observation.[7]

a. Are the crashes caused by physical conditions of the road or adjacent property, and can the condition be eliminated or corrected?
b. Is a blind corner responsible? Can it be eliminated? If not, can adequate measures be taken to warn the motorists?
c. Are the existing signs and pavement markings doing the job for which they were intended? Is it possible they are, in any way, contributing to causes of crashes, rather than contributing to crash prevention?
d. Is traffic properly channelized to minimize the occurrence of crashes?
e. Would crashes be prevented by the prohibition of any single traffic movement, such as a minor left-turn movement?
f. Can part of the traffic be diverted to other thoroughfares where the crash potentialities are not as great?
g. Are night crashes out of proportion to daytime crashes, based on traffic volume, indicating need for special nighttime protection, such as street lighting, signal control, or reflectorized signs or marking?
h. Do conditions show that additional traffic laws or selective enforcement are required?
i. Is there a need for supplemental studies of traffic movement, such as driver observance of existing control devices, speed studies of vehicles approaching the crash location, and others?
j. Is parking in the area contributing to crashes? If so, perhaps reduction of the width of approach lanes or sight obstructions in advance of the intersection resulting from the parking are causing the crashes.
k. Are there adequate advance warning signs of route changes so that the proper lanes may be chosen by approaching motorists well in advance of the area, thus minimizing the need for lane changing near the crash location?

Table 2-4. On-Site Observation Report. [7]

Location____ Control_______________________

Date____ Time_________________________

Operational Checklist:	**No**	**Yes**
a. Do obstructions block the drivers' view of opposing vehicles?	_______	_______
b. Do drivers respond incorrectly to signals, signs, or other traffic control devices?	_______	_______
c. Do drivers have trouble finding the correct path through the locations?	_______	_______
d. Are vehicle speeds too high? Too low?	_______	_______
e. Are there violations of parking or other traffic regulations?	_______	_______
f. Are drivers confused about routes, street names, or other guidance information?	_______	_______
g. Can vehicle delay be reduced?	_______	_______
h. Are there traffic flow deficiencies or traffic conflict patterns associated with turning movements?	_______	_______
i. Would one-way operation make the location safer?	_______	_______
j. Is this volume of traffic causing problems?	_______	_______
k. Do pedestrian movements through the location cause conflicts?	_______	_______
l. Are there other traffic flow deficiencies or traffic conflict patterns?	_______	_______
Physical Checklist:		
a. Can sight obstructions be removed or lessened?	_______	_______
b. Are the street alignment or widths inadequate?	_______	_______
c. Are curb radii too small?	_______	_______
d. Should pedestrian crosswalks be relocated? Repainted?	_______	_______
e. Are signs inadequate as to usefulness, message, size, conformity, and placement? (See *MUTCD*)	_______	_______
f. Are signals inadequate as to placement, conformity, number of signal heads, or timing? (See *MUTCD*)	_______	_______
g. Are pavement markings inadequate as to their clearness or location?	_______	_______
h. Is channelization (island or paint markings) inadequate for reducing conflict areas, separating traffic flows, and defining movements?	_______	_______
i. Does the legal parking layout affect sight distance, through or turning vehicle paths, or traffic flow?	_______	_______
j. Do speed limits appear to be unsafe or unreasonable?	_______	_______
k. Is the number of lanes insufficient?	_______	_______
l. Is street lighting inadequate?	_______	_______
m. Are driveways inadequately designed or located?	_______	_______
n. Does the pavement condition (potholes, washboard, or slick surface) contribute to crashes?	_______	_______

Comments: ____

____

____

Collect Additional Field Data

The previous efforts identified potential trends; however, additional information was needed to better define the condition at the site. Table 2-5 lists supplemental traffic studies that can be considered to further define the nature of operational or safety problems, isolate the cause of the problem, and help identify appropriate solutions. The junior engineer decided to perform the following additional studies:

- ***Intersection Sight Distance.*** The available sight distance for each approach was measured. Because the junior engineer observed several large trucks on the east/west approaches, a combination truck was used in the analysis. Using the procedure for Intersection Sight Distance, Case D, the engineer used an 11.5-sec time gap (combination truck) with no adjustments (the intersection is level and does not have multiple lanes). The design speed was assumed to be 50 mph [80 km/h]. Therefore, the intersection sight distance for combination trucks is 845 ft [258 m]. For each corner, sight distances much greater than 845 ft [258 m] are present. The approaches are straight, on level grades, and with minimum vegetation growth or development near the intersection.
- ***Review of Signal Timing Plan.*** The review of the signal timing plan revealed that the signal was on a fixed-time cycle.

Table 2-5. Supplementary Engineering Studies.[7]

Supplementary Study	Purpose of Study	Symptom of Operational Study Problem that Indicates Study Needed
Capacity Studies	To determine operating condition and pinpoint bottlenecks.	♦ Congestion and delays
Travel Time and Delay Studies	To determine location and extent of delay and average travel speeds.	♦ Intersection congestion ♦ Other congestion along roadway ♦ Rear-end crashes during peak periods
Speed Studies	To determine actual vehicle speeds, actual speed profiles, and adequacy of legal and advisory speed limits.	♦ Extremely high or low speeds observed during on-site visits ♦ Run-off-road crashes ♦ Rear-end crashes near intersection
Traffic Conflict and Erratic Maneuver Studies	To supplement traffic crash data and identify potential crash problems.	♦ Hazardous driver actions observed during on-site visits ♦ Public complaints of safety problems not evident in crash data
Traffic Signal Studies	To determine need for and design of traffic signals; to identify improper phasing, timing, or interconnect strategy; and to identify unwarranted signals.	♦ Right-angle crashes at unsignalized intersections ♦ Excessive delay at Stop sign controlled intersections ♦ Excessive delay at existing signalized intersections
Sight Distance Studies	To determine adequacy of the length of highway visible to the driver.	♦ Rear-end crashes at horizontal curves, crest vertical curves, or decision points ♦ Right-angle crashes at uncontrolled intersections ♦ Turning crashes at intersection
Turning Radius Studies	To determine adequacy of existing curb radii.	♦ Sideswipe crashes involving vehicles traveling in opposite directions ♦ Rear-end crashes in right-turn lanes ♦ Evidence of large vehicles' encroachment on curb or shoulder
Skid Resistance Studies	To determine the coefficient of tire-pavement friction.	♦ Run-off-road or skidding crashes under wet-pavement conditions

Assess Situation and Select Treatments

The next series of steps assessed the condition at the site and selected appropriate safety treatment(s). The following steps were completed.

- ***Identify Crash Patterns and Conditions Present at the Site.*** The following crash patterns were identified:
  - Of the crashes, 61 percent occurred on wet pavement, and several narratives included comments regarding wet pavement.
  - Approximately one-third of the crashes involved left-turning vehicles and about one-half involved rear-end crashes.
  - Most crashes occurred during the day (i.e., nighttime crashes not an issue).
  - Less than 10 percent of the crashes involved DWI.
- ***Identify Potential Mitigation Measures.*** Suggested measures are contained in *Treatments for Crashes on Rural Two-Lane Highways in Texas*[2] along with other documents. The junior engineer identified potential treatments that would later be reviewed by a safety review team. The safety review team for the district has individuals with many different backgrounds, including both engineering and enforcement.
- ***Select Safety Treatment(s) for Site.*** The safety treatments selected for this site included the following:
  - Add left-turn bays on all approaches.
  - Retime signals to consider left-turn bays.
  - Resurface pavement (to improve skid resistance).
  - Repair pavement edge drop-offs.

Implement and Evaluate

The final elements in a safety study are to implement the selected improvements and, subsequently, to evaluate their effectiveness. The objective of an effectiveness evaluation is to compare the actual effects of the project with its predicted effects. Feedback from the evaluation of completed projects will enable the anticipated effects of planned projects to be more accurately quantified in the future. The junior engineer plans to compare the crash behavior after the treatments are installed with the data currently available.

Chapter 3
Design Elements

Contents:

Application 1
ISD, Case A

Overview

The sight triangles for an intersection with no control should allow the driver of a vehicle to see an approaching vehicle and have enough time to stop before reaching the intersection. Discussion on intersection sight distance is included in the *Urban Intersection Design Guide*, Chapter 3, Section 1 <link>.

Example at an Uncontrolled Location

Problem. Determine the sight triangles for all four legs of the intersection of Blythe and Franklin illustrated in Figure 3-1. There is no control at the intersection, therefore ISD, Case A is appropriate. Approach sight triangles are determined, but departure sight triangles are not determined for intersections with no control.

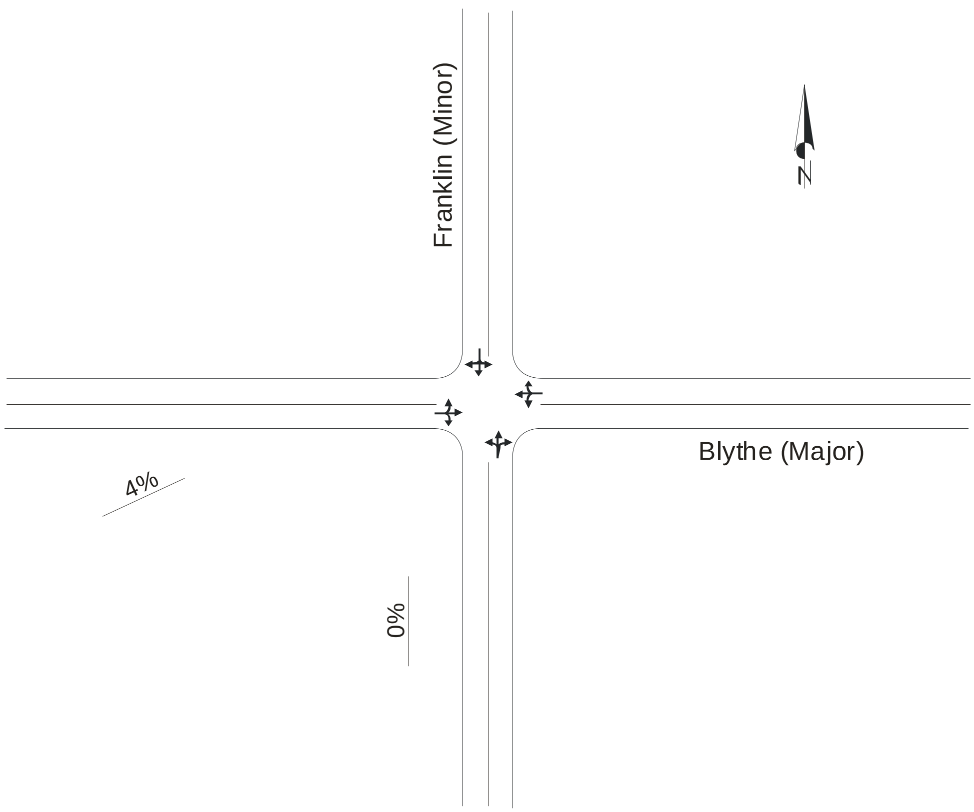


Figure 3-1. Blythe and Franklin Intersection.

Known Information. The information known for this site includes:

- Design speed on Franklin is 35 mph [56 km/h].
- Design speed on Blythe is 40 mph [64 km/h].

- Grade for Franklin is 0 percent.
- Grade for Blythe is 4 percent.

Solution. Following is the solution for this example:

- *Step 1: Identify needed adjustments.*

The grade for both northbound and southbound approaches on Franklin is 0 percent, which allows the use of *Green Book* Exhibit 9-51 (reproduced as Table 3-1). However, for Blythe, the approach is +4 percent, which is greater than the cutoff for using Exhibit 9-51 (3 percent grade). So, Exhibit 9-53 (reproduced as Table 3-2) must be used to determine the adjustment factor for this approach.

- *Step 2: Determine the sight triangle length for both approaches for Franklin.*

Since the design speed on Franklin is 35 mph [56 km/h], the length of the sight triangle leg “a” for both the northbound and southbound approaches is 165 ft [50 m], as shown in Table 3-1.

Table 3-1. Length of Sight Triangle Leg–Case A–No Traffic Control (Reproduction of *Green Book* Exhibit 9-51).

US Customary		Metric	
Design Speed (mph)	**Length of Leg (ft)**	**Design Speed (km/h)**	**Length of Leg (m)**
15	70	20	20
20	90	30	25
25	115	40	35
30	140	50	45
35	***165***	***60***	***55***
40	***195***	***70***	***65***
45	220	80	75
50	245	90	90
55	285	100	105
60	325	110	120
65	365	120	135
70	405	130	150
75	445		
80	485		

- *Step 3: Determine the sight triangle length for the eastbound approach for Blythe.*

For the eastbound approach, you need to find the adjustment factor for the sight distance from Table 3-2 and multiply that by the base sight distance length from Table 3-1. The adjustment factor for a +4 percent grade on a facility with a design speed of 40 mph [64 km/h] is 0.9, as highlighted on Table 3-2. The base length of the sight triangle leg “b” for this approach is 195 ft [59 m] as found in Table 3-1. Thus, the adjusted length of the sight triangle leg for the eastbound approach is as follows:

Adjusted sight triangle leg “b” length = base length × adjustment factor

Adjusted sight triangle leg “b” length = 195 ft [59 m] × 0.9 [0.9]

Adjusted sight triangle leg "b" length = 176 ft [54 m]

Table 3-2. Adjustment Factors for Sight Distance Based on Approach Grade (Reproduction of *Green Book* Exhibit 9-53).

US Customary														
Approach Grade (%)	**Design Speed (mph)**													
	15	20	25	30	35	***40***	45	50	55	60	65	70	75	80
-6	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2
-5	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2
-4	1.0	1.0	1.0	1.1	1.1	***1.1***	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
-3 to +3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
+4	1.0	1.0	1.0	1.0	1.0	***0.9***	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
+5	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
+6	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Metric														
Approach Grade (%)	**Design Speed (km/h)**													
	20	30	40	50	60	***70***	80	90	100	110	120	130		
-6	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.2		
-5	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2		
-4	1.0	1.0	1.0	1.1	1.1	***1.1***	1.1	1.1	1.1	1.1	1.1	1.1		
-3 to +3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0		
+4	1.0	1.0	1.0	1.0	0.9	***0.9***	0.9	0.9	0.9	0.9	0.9	0.9		
+5	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9		
+6	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9		

- ♦ *Step 4: Determine the sight triangle length for the westbound approach for Blythe.*

For the westbound approach, you also need to find the adjustment factor for the sight distance from Table 3-2 and multiply that by the base sight distance length from Table 3-1. The adjustment factor in this case is for a –4 percent grade. With a design speed of 40 mph [64 km/h] the adjustment factor is 1.1, as indicated by the highlighted text in Table 3-2. The base length of the sight triangle leg "b" for this approach is 195 ft [59 m] as found in Table 3-1. Thus, the adjusted length of the sight triangle leg for the eastbound approach is as follows:

Adjusted sight triangle leg "b" length = base length × adjustment factor

Adjusted sight triangle leg "b" length = 195 ft [59 m] × 1.1 [1.1]

Adjusted sight triangle leg "b" length = 215 ft [66 m]

- ♦ *Step 5: Illustrate findings.*

Figure 3-2 and Figure 3-3 illustrate the approach sight triangle legs as calculated above. Note that each triangle provides clear viewing of traffic approaching for adjoining legs of the intersection. Also note that the triangles are shifted depending on whether the driver is viewing traffic approaching from the left or the right. As noted previously, departure sight triangles are not determined for intersections with no control.

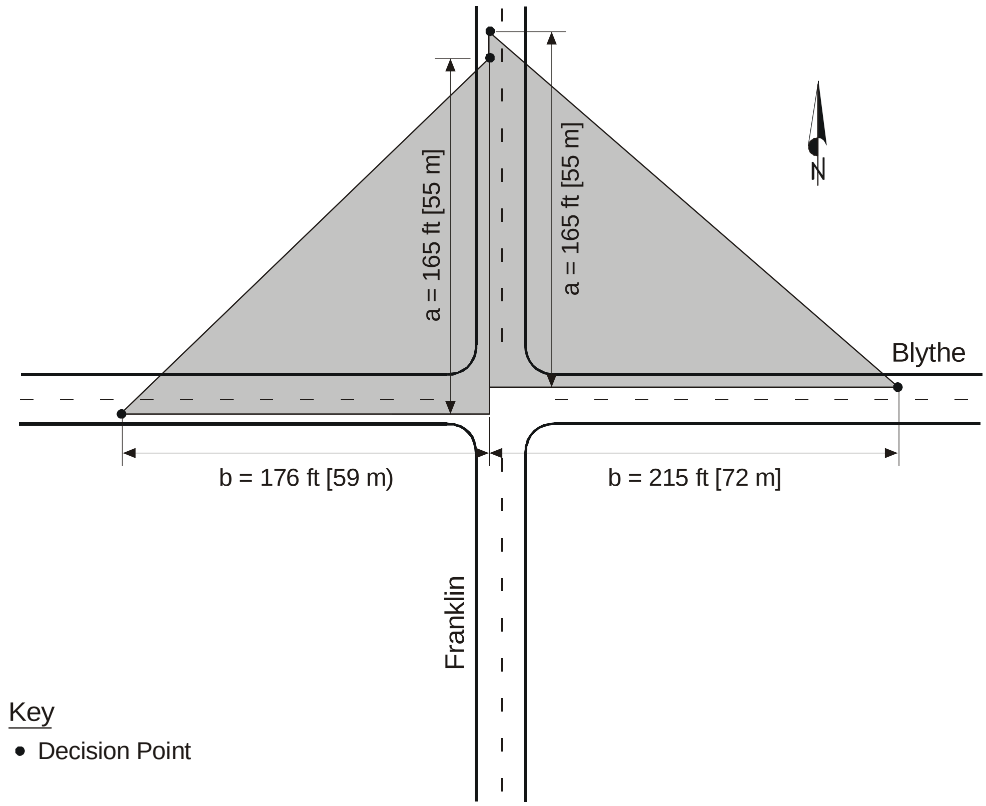


Figure 3-2. Case A – Sight Triangles for Southbound Approach.

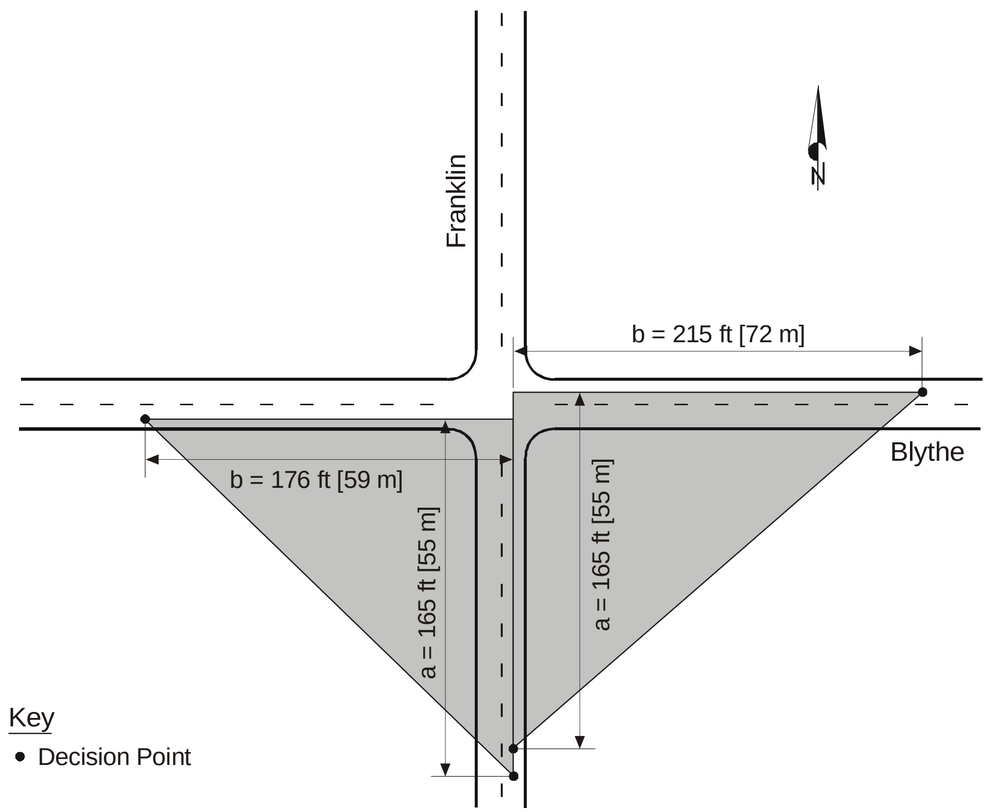


Figure 3-3. Case A – Sight Triangles for Northbound Approach.

Application 2
ISD, Case B1

Overview

The departure sight triangles for intersections with stop control on the minor road and left turns from a minor road to a major road should allow the driver of a vehicle to see approaching vehicles and choose gaps in the traffic that allow them to accelerate and complete a left turn without unduly interfering with major-road traffic operations. Discussion on intersection sight distance is included in the *Urban Intersection Design Guide*, Chapter 3, Section 1 <link>.

Single-Unit Truck Turning Left

Problem. Determine the required sight distance and departure sight triangles for a vehicle turning left from Forbes Boulevard onto Skinner Drive from either the northbound or southbound directions as illustrated in Figure 3-4. Traffic on Forbes is stop-controlled.

Because a large proportion of the vehicles in the light industrial area are single-unit trucks, that vehicle is used as the design vehicle.

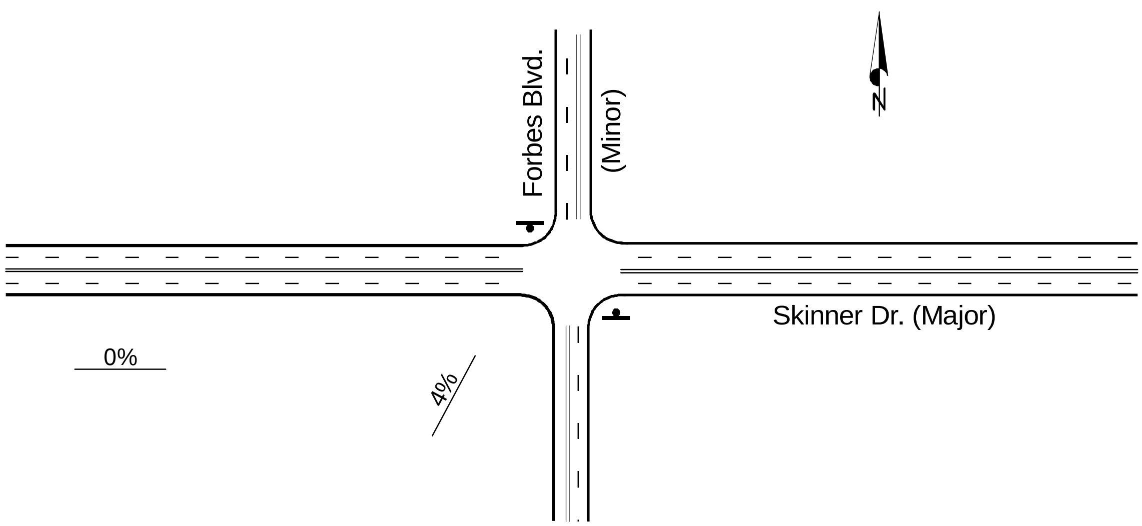


Figure 3-4. Forbes and Skinner Intersection.

Known Information. The information known for this site includes:

- Design speed on Skinner Drive is 40 mph [64 km/h].
- Grade for Forbes Blvd. is 4 percent.
- Grade for Skinner Drive is 0 percent.
- No medians are present on the approaches.
- Lane widths are 12 ft [3.7 m].

Solution. Following is the solution for this example:

- *Step 1: Identify needed adjustments.*

For Forbes, the southbound approach has a grade of +4 percent, which exceeds 3 percent, thereby requiring adjustments in the time gap. The northbound approach of –4 percent does not require adjustments in the time gap.

As shown in Figure 3-4, Skinner has two lanes in each direction, thereby requiring additional adjustments to the time gap listed in Table 3-3.

Table 3-3. Time Gap for Case B1–Left Turn from Stop (Reproduction of *Green Book* Exhibit 9-54).

Design Vehicle	Time gap (sec) at design speed of major road (t_g)
Passenger car	7.5
Single-unit truck	***9.5***
Combination truck	11.5
Note: Time gaps are for a stopped vehicle to turn right or left onto a two-lane highway with no median and grades 3 percent or less. The table values require adjustment as follows: ♦ For multilane highways: For left turns onto two-way highways with more than two lanes, add 0.5 second for passenger cars or ***0.7 second*** for trucks for each additional lane, from the left, in excess of one, to be crossed by the turning vehicle. ♦ For minor road approach grades: If the approach grade is an upgrade that exceeds 3 percent, add ***0.2 second*** for each percent grade for left turns.	

- *Step 2: Determine the sight triangle length "a" for a left turn from the southbound approach of Forbes Blvd.*

Based on the *Green Book* procedure, the "a" length for the sight triangle for vehicles turning left is the following:

"a" leg length = distance between major-road travel way and front of vehicle
+ distance between front of vehicle and driver's eye
+ distance to middle of lane of interest

a_R = "a" leg length to vehicles approaching from the right

a_R = distance from major-road travel way and front of vehicle
+ distance between front of vehicle to driver's eye
+ 2.5 lane widths (crossing two lanes before merging with major road through traffic)

a_R = 6.5 ft [2.0 m] + 8 ft [2.4 m] + 2.5 × 12 ft [3.7 m]

a_R = 45 ft [14 m]

When practical, it is desirable to increase the distance from the edge of the major road to the front of the vehicle. The *Green Book* recommends using a 10-ft [3 m] dimension rather than 6.5 ft [2.0 m] for the distance between major road travelway and front of vehicle when available. In this example, that would bring the a_R dimension to 48 ft [14.6 m].

a_L = "a" leg length to vehicles approaching from the left

a_L = 6.5 ft [2.0 m] + 8 ft [2.4 m] + 0.5 × 12 ft [3.7 m]

a_L = 21 ft [6 m]

- *Step 3: Determine the sight triangle length "b" for a left turn from the southbound approach of Forbes Boulevard.*

The equation for the "b" leg length is as follows:

US Customary	Metric
$ISD = 1.47\ V_{major}t_g$	$ISD = 0.278\ V_{major}t_g$

The initial time gap to be used in this equation is 9.5 sec for single-unit trucks, as highlighted in Table 3-3. However, because the grade on the southbound approach is +4 percent, the t_g should be increased by 0.8 sec since +4 percent is greater than +3 percent (0.2 sec × 4 percent = 0.8 sec). Furthermore, because Skinner has two lanes in each direction, rather than one, the t_g should be increased by 0.7 sec for each additional lane the truck must cross. In this case, the adjustment factor is 0.7 sec since the truck must cross one additional lane.

Thus, the t_g value is as follows:

t_g = base t_g + grade adjustment + major road width adjustment

t_g = 9.5 sec = (4 percent × 0.2 sec) + (1 lane × 0.7 sec)

t_g = 9.5 sec + 0.8 sec + 0.7 sec

t_g = 11.0 sec

Therefore, the "b" leg length is as follows:

US Customary	Metric
$ISD = 1.47\ V_{major}t_g$	$ISD = 0.278\ V_{major}t_g$
ISD = 1.47 (40 mph) (11.0 sec)	ISD = 0.278 (70 km/h) (11.0 sec)
ISD = 647 ft	ISD = 241 m

- *Step 4: Determine the sight triangle length "a" for a left turn from the northbound approach of Forbes Blvd.*

As noted above, the a_R length for the sight triangle is 45 ft [14 m]. The time gap to be used in this equation is 9.5 sec for single-unit trucks (see Table 3-3). No adjustment for grade needs to be made for the northbound approach (it has a downgrade of 4 percent). The adjustment for the number of lanes remains the same, thereby making the adjusted time gap the following:

t_g = base t_g + major road width adjustment

t_g = 9.5 sec + 0.7 sec

$t_g = 10.2$ sec

The "b" leg length is calculated as follows:

US Customary	Metric
$ISD = 1.47\ V_{major}t_g$	$ISD = 0.278\ V_{major}t_g$
$ISD = 1.47$ (40 mph) (10.2 sec)	$ISD = 0.278$ (70 km/h) (10.2 sec)
$ISD = 600$ ft	$ISD = 199$ m

- *Step 5: Illustrate findings.*

Figure 3-5 and Figure 3-6 illustrate the resulting sight triangles for a left turn from the minor road (Forbes Blvd.) in the southbound and northbound directions, respectively.

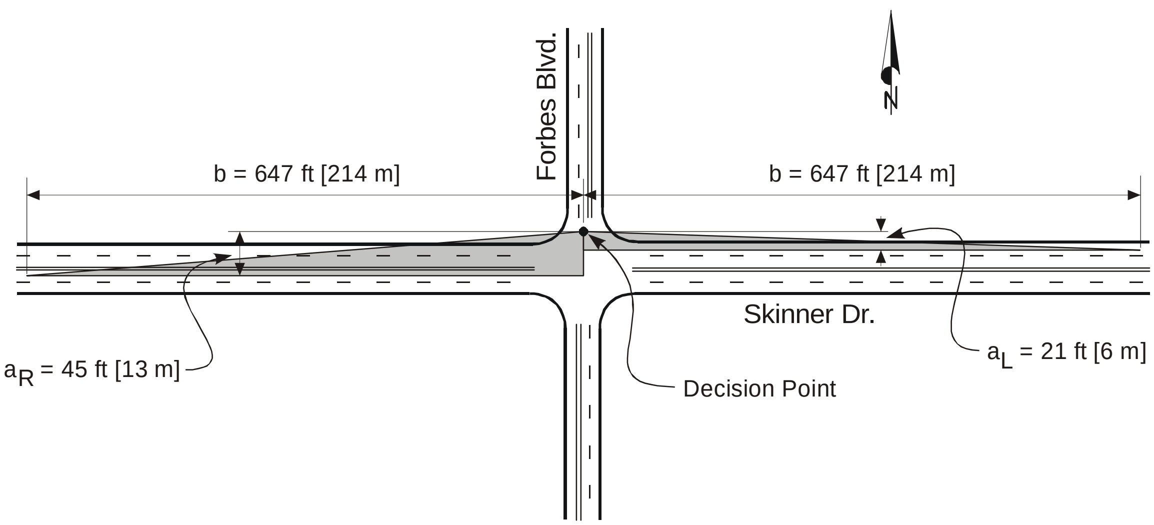


Figure 3-5. Case B1 – Sight Triangles for Left-Turn Movement from Southbound Minor Road for a Single-Unit Truck.

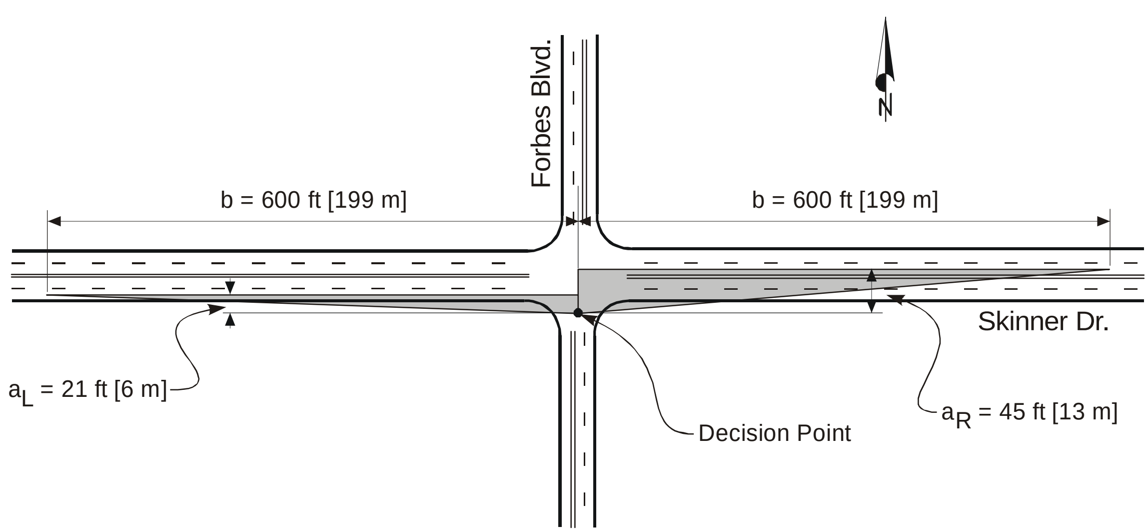


Figure 3-6. Case B1 – Sight Triangles for Left-Turn Movement from Northbound Minor Road for a Single-Unit Truck.

Application 3
ISD, Case B2

Overview

The departure sight triangles for intersections with stop control on the minor road and a right turn from the minor road are similar to the left-turn triangles except that the time gaps required can be reduced by 1 sec. Discussion on intersection sight distance is included in the *Urban Intersection Design Guide,* Chapter 3, Section 1 <link>.

Example 1: Passenger Car Turning Right

Problem. Determine the required sight distance and departure sight triangles for a passenger car turning right from Forbes Blvd. onto Skinner Drive from either the northbound or southbound directions (see Figure 3-7). Traffic on Forbes is stop-controlled.

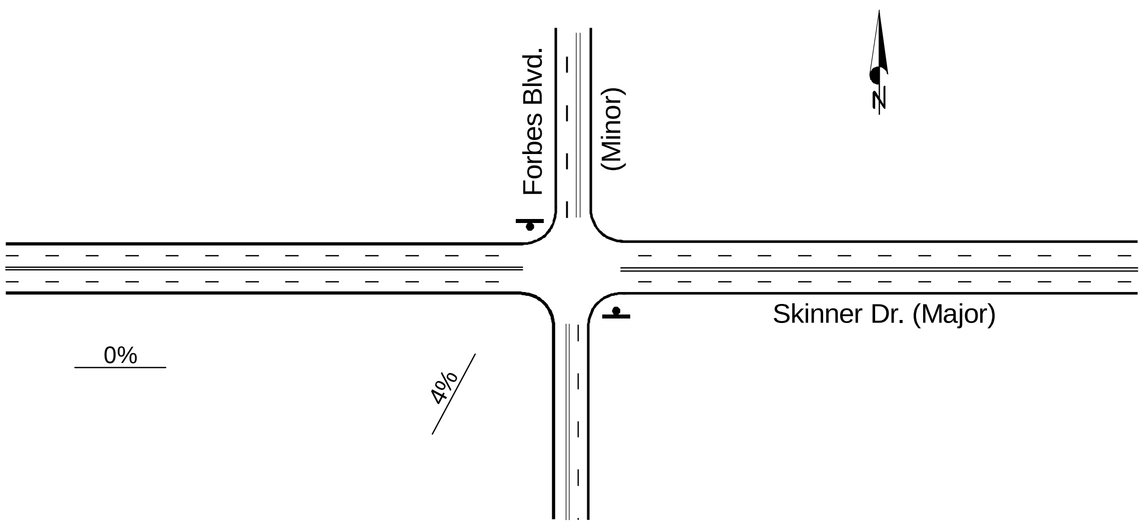


Figure 3-7. Forbes and Skinner Intersection.

Known Information. The information known for this site includes:

- Design speed on Skinner Drive is 40 mph [64 km/h].
- Grade for Forbes Blvd. is 4 percent.
- Grade for Skinner Drive is 0 percent.
- No medians are present on the approaches.
- Lane widths are 12 ft [3.7 m].

Solution. Following is the solution for this example:

- *Step 1: Identify needed adjustments.*

The potential adjustments are listed in Table 3-4. For Forbes, the grade of 4 percent exceeds 3 percent, thereby requiring adjustments in the time gap. The adjustment for multilane highways is only used when crossing the major road, not when turning right onto the major road. Therefore, no multilane adjustment is needed in this example.

Table 3-4. Time Gap for Case B2-Right Turn from Stop (Reproduction of *Green Book* Exhibit 9-57).

Design Vehicle	Time gap (sec) at design speed of major road (t_g)
Passenger car	***6.5***
Single-unit truck	8.5
Combination truck	***10.5***

Note: Time gaps are for a stopped vehicle to turn right onto or cross a two-lane highway with no median and grades 3 percent or less. The table values require adjustment as follows:

- For multilane highways: For crossing a major road with more than two lanes, add 0.5 second for passenger cars or 0.7 second for trucks for each additional lane to be crossed and for narrow medians that cannot store the design vehicle.
- For minor road approach grades: If the approach grade is an upgrade that exceeds 3 percent, add ***0.1 second*** for each percent grade.

- *Step 2: Determine the sight triangle length for a right turn from Forbes Blvd.*

Based on the AASHTO procedure, the "a" length for the sight triangle for vehicles turning right is the following:

"a" leg length = distance from major-road traveled way and front of vehicle
+ distance between front of vehicle and driver's eye + 0.5 lane width

a = 6.5 ft [2.0 m] + 8 ft [2.4 m] + 0.5 × 12 ft [3.7 m]

a = 21 ft [6 m]

The equation for the "b" leg length is as follows:

US Customary	Metric
$ISD = 1.47\ V_{major} t_g$	$ISD = 0.278\ V_{major} t_g$

Southbound. The initial time gap to be used in this equation is 6.5 for passenger cars, as highlighted in Table 3-4. Because the grade on Forbes is +4 percent, the t_g should be increased by 0.4 sec (0.1 sec × 4 percent = 0.4 sec) since +4 percent is greater than +3 percent.

Thus, the t_g value is as follows:

t_g = base t_g + grade adjustment

t_g = 6.5 sec + 0.4 sec

t_g = 6.9 sec

Therefore, the "b" leg length is as follows:

US Customary	Metric
ISD = 1.47 $V_{major}t_g$	ISD = 0.278 $V_{major}t_g$
ISD = 1.47 (40 mph) (6.9 sec)	ISD = 0.278 (70 km/h) (6.9 sec)
ISD = 406 ft	ISD = 134 m

Northbound. Because northbound vehicles are on a –4 percent grade, no adjustment is required for the approach grade. Thus, the t_g value is 6.5 sec. Therefore, the "b" leg length is:

US Customary	Metric
ISD = 1.47 $V_{major}t_g$	ISD = 0.278 $V_{major}t_g$
ISD = 1.47 (40 mph) (6.5 sec)	ISD = 0.278 (70 km/h) (6.5 sec)
ISD = 382 ft	ISD = 126 m

- *Step 3: Illustrate findings.*

Figure 3-8 illustrates the resulting sight triangle for a right turn from the minor road (Forbes Blvd.) in the northbound or southbound directions.

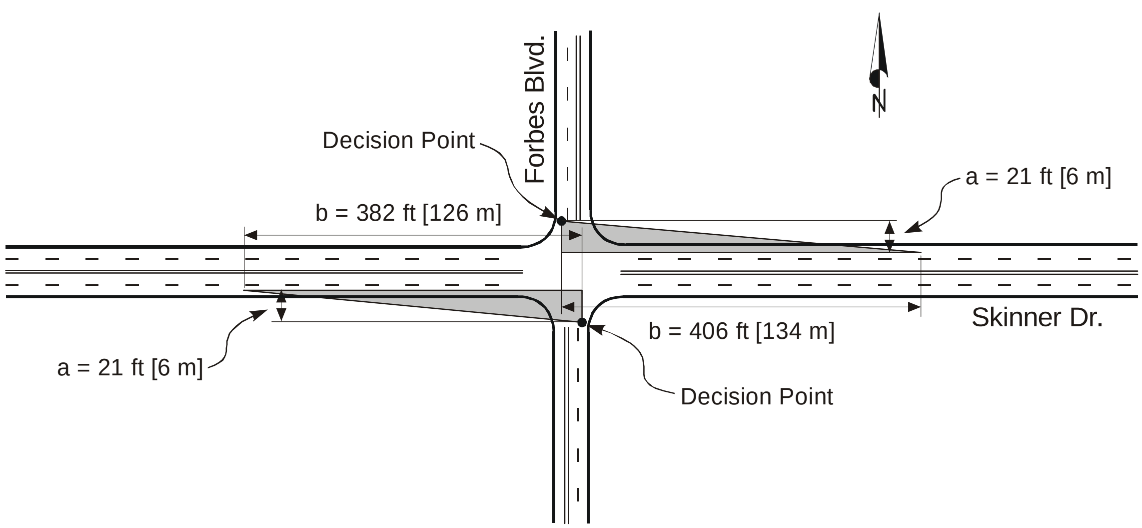


Figure 3-8. Case B2 – Sight Triangles for Right-Turning Passenger Cars.

Example 2: Combination Truck Turning Right on Northbound Approach

Problem. A processing plant is located south of the Forbes and Skinner intersection. The combination trucks that are leaving the intersection turn right toward a nearby interstate. Determine the required sight distance and departure sight triangles for a combination truck turning right from Forbes Blvd. onto Skinner Drive for the northbound direction.

Known Information. The information known for this site is listed above at the beginning of this application.

Solution. Following is the solution for this example:

- *Step 1: Identify needed adjustments.*

For northbound Forbes, the grade of –4 percent does not require an adjustment in the time gap. The adjustment for multilane highways is only used when crossing the major road, not when turning right onto the major road. Therefore, no multilane adjustment is needed in this example.

- *Step 2: Determine the sight triangle length for a right-turning combination truck from the northbound approach of Forbes Blvd.*

As noted above in Example 1, the "a" length for the sight triangle is 21 ft [6 m]. The time gap to be used in this equation is 10.5 sec for combination trucks, as highlighted in Table 3-4.

Because the grade on Forbes is –4 percent, the t_g used is the base t_g, 10.5 sec.

The "b" leg length is as follows:

US Customary	Metric
ISD = 1.47 $V_{major}t_g$	ISD = 0.278 $V_{major}t_g$
ISD = 1.47 (40 mph) (10.5 sec)	ISD = 0.278 (70 km/h) (10.5 sec)
ISD = 617 ft	ISD = 204 m

- *Step 3: Illustrate findings.*

Figure 3-9 illustrates the resulting sight triangles for a right turn for a combination truck from the minor road (Forbes Blvd.) in the northbound direction.

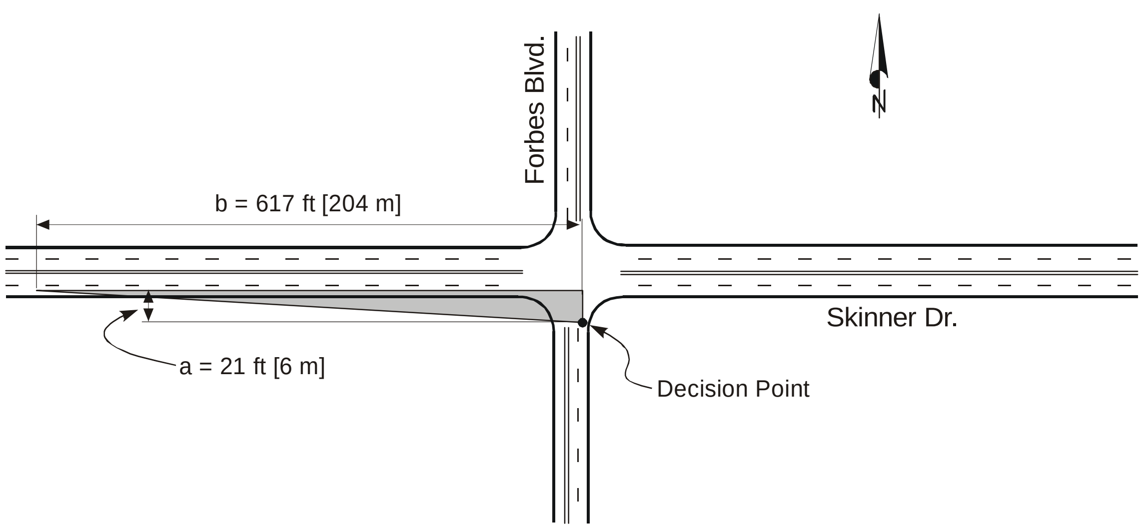


Figure 3-9. Case B2 – Sight Triangle for Right-Turning Combination Truck on Northbound Approach.

Application 4
ISD, Case B3

Overview

When vehicles are crossing the major road from a stop-controlled approach, the sight triangles provided for right and left turns should be sufficient; however, the following situation should be addressed if necessary:

- where left and/or right turns are not permitted from a particular approach and the crossing maneuver is the only legal maneuver;
- where the crossing vehicle would cross the equivalent width of six or more lanes;
- where substantial volumes of heavy vehicles cross the roadway and steep grades that might slow the vehicle while its back portion is still in the intersection are present on the departure roadway on the far side of the intersection.

Discussion on intersection sight distance is included in the *Urban Intersection Design Guide*, Chapter 3, Section 1 <link>.

Crossing a Six-Lane Highway

Problem. Determine the required sight distance and departure sight triangles for a passenger car crossing Cook Avenue from either the northbound or southbound direction of Sender Drive (see Figure 3-10).

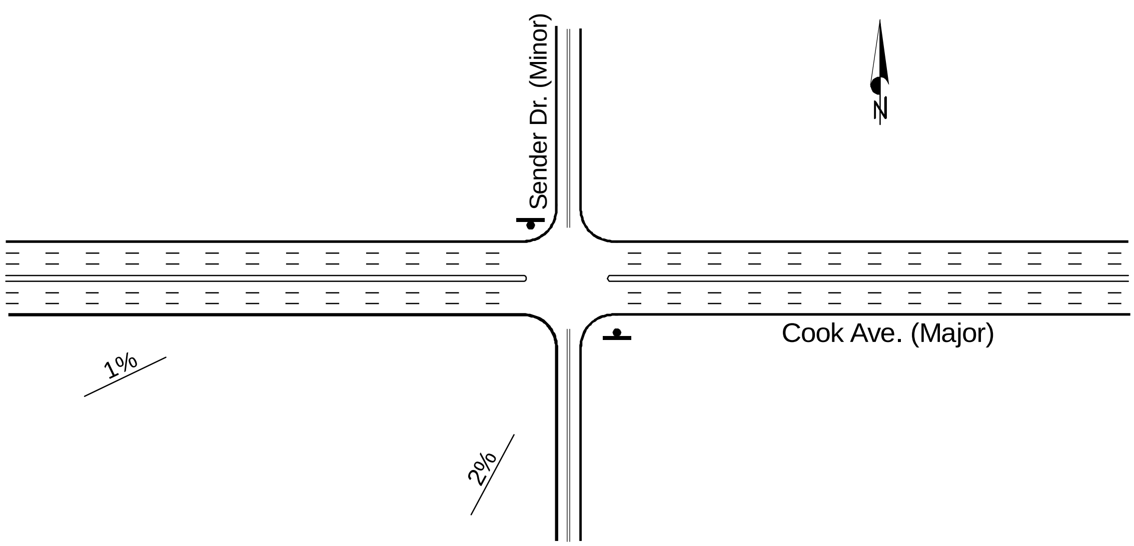


Figure 3-10. Cook Avenue and Sender Drive Intersection.

Known Information. The information known for this site includes:

- Design speed on Cook Avenue is 45 mph [72 km/h].
- Grade on Sender Drive is 2 percent.

- Grade on Cook Avenue is 1 percent.
- Median on Cook Avenue is 5 ft [1.5 m] wide.
- Lane widths are 12 ft [3.7 m].
- Median is not wide enough to store vehicles.

Solution. Following is the solution for this example:

- *Step 1: Identify needed adjustments.*

Both approaches on Sender are less than 3 percent; therefore, there is no need for adjustments in the time gap.

An adjustment will be needed due to the number of lanes to be crossed. The time gap values in Table 3-5 are for a two-lane highway. Because Cook has three lanes in each direction, the width of Cook will require an adjustment in the time gap value.

Table 3-5. Time Gap for Case B3 – Crossing Maneuver (Reproduction of *Green Book* Exhibit 9-57).

Design Vehicle	Time gap (sec) at design speed of major road (t_g)
Passenger car	***6.5***
Single-unit truck	8.5
Combination truck	10.5

Note: Time gaps are for a stopped vehicle to turn right onto or cross a two-lane highway with no median and grades 3 percent or less. The table values require adjustment as follows:

- For multilane highways: For crossing a major road with more than two lanes, add ***0.5 second*** for passenger cars or 0.7 second for trucks for ***each additional lane*** to be crossed and for ***narrow medians*** that cannot store the design vehicle.
- For minor road approach grades: If the approach grade is an upgrade that exceeds 3 percent, add 0.1 second for each percent grade.

- *Step 2: Determine the sight triangle length for a crossing maneuver from the southbound approach of Sender Drive.*

Based on the *Green Book* procedure, the "a" length for the sight triangle for vehicles crossing the road is the following:

"a" leg length = distance between major-road travel way and front of vehicle
+ distance between front of vehicle and driver's eye
+ distance to middle of lane of interest

The lane of interest for traffic approaching from the right would be to the far median lane for that direction and for traffic approaching from the left would be the near curb lane for that direction. Selecting these lanes rather than the lane farthest from the subject approach (i.e., the far curb lane) will result in more of the sight triangle covering the roadside rather than the roadway, which is the more critical concern. For this example, the minor road vehicle needs to cross 3.5 lanes to turn into the outside lane for the westbound approach.

a_R = "a" leg length to vehicles approaching from the right

a_R = distance from major-road travel way and front of vehicle
+ distance between front of vehicle and driver's eye

+ 3.5 (lane width) + median width

a_R = 6.5 ft [2.0 m] + 8 ft [2.4 m] + 3.5 (12 ft [3.7 m]) + 5 ft [1.5 m]

a_R = 62 ft [19 m]

a_L = "a" leg length to vehicles approaching from the left

a_L = distance from major-road travel way and front of vehicle

+ distance between front of vehicle and driver's eye

+ 0.5 (lane width)

a_L = 6.5 ft [2.0 m] + 8 ft [2.4 m] + 0.5 (12 ft [3.7 m])

a_L = 21 ft [6 m]

The equation for the "b" leg length is as follows:

US Customary	Metric
ISD = 1.47 $V_{major}t_g$	ISD = 0.278 $V_{major}t_g$

The initial time gap to be used in this equation is 6.5 sec for passenger cars, as highlighted in Table 3-5. However, because the vehicle must cross more than two lanes, the multilane highway adjustment is needed. The adjustment adds 0.5 sec for each additional lane to be crossed and for narrow medians that cannot store the design vehicle. In this example, the passenger car must cross four additional lanes and the median. Because the approaches are on a less than 3 percent grade, no grade adjustment is needed.

Thus, the t_g value is as follows:

t_g = base t_g + grade adjustment + multilane highway adjustment (4 additional lanes + median)

t_g = 6.5 sec + 0.0 sec + 0.5 sec (5)

t_g = 9.0 sec

Therefore, the "b" leg length is as follows:

US Customary	Metric
ISD = 1.47 $V_{major}t_g$	ISD = 0.278 $V_{major}t_g$
ISD = 1.47 (45 mph) (9.0 sec)	ISD = 0.278 (80 km/h) (9.0 sec)
ISD = 595 ft	ISD = 200 m

- *Step 3: Determine the sight triangle length for a crossing maneuver from the northbound approach of Sender Drive.*

Sight distances for northbound Sender Drive are similar to southbound Sender Drive.

- *Step 4: Illustrate findings.*

Figure 3-11 illustrates the sight distances for the northbound minor road approach.

- *Step 5: Identify landscaping limits in median.*

Landscaping is being considered for the 5-ft [1.5 m] median, so the distance from the intersection where only low-growing plants should be used was needed. Also debated was whether the sight distance should be to the median lane of the westbound direction or to the curb lane since this will have an impact on the length of low-growing plants. The *Green Book* does not provide guidance on which major road lane to use in the analysis. All of the examples included in the *Green Book* use two-lane highways; therefore, a designer would need to decide which lane would be most appropriate. If we assume that the minor road driver is turning into the median lane, then the sketch shown in Figure 3-11 would reflect the needed sight distance for the intersection. The distance of low-growing plants would be 547 ft [167 m] as illustrated in Figure 3-12A. The landscape limit was also checked for the scenario of assuming the intersection sight distance is to a vehicle in the curb lane of the major road (see Figure 3-12B). In that scenario only 394 ft [120 m] of the median would need to have low-growing plants, and taller growing plants could be planted beyond that point. Assuming that the intersection sight distance is to the curb lane rather than the median lane could result in the minor road driver not seeing a major road vehicle in the median lane at the 595 ft [181 m] distance. Therefore, the engineers designing this intersection selected low-growing plants for the initial 547 ft [167 m] of the median.

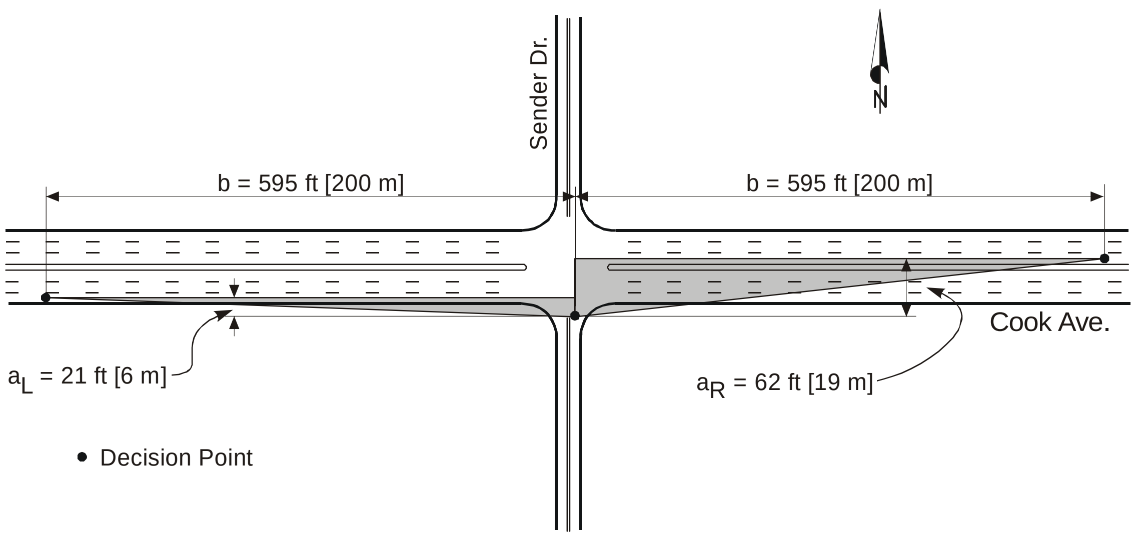
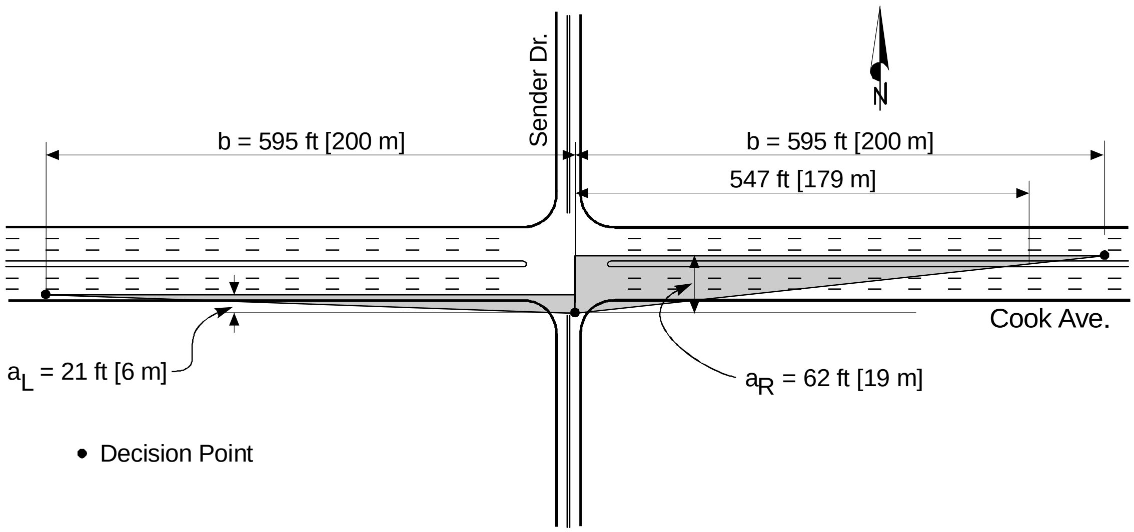
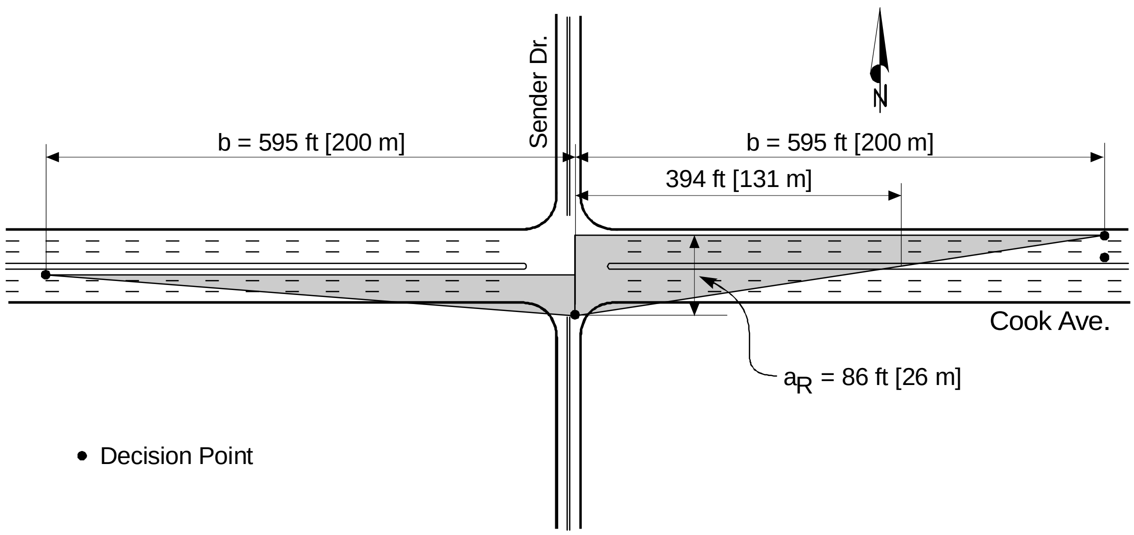


Figure 3-11. Case B3 – Sight Triangles for Crossing Maneuver from One of the Minor Road Approaches.



(A) Major-Road Vehicle in Far Median Lane



(B) Major-Road Vehicle in Far Curb Lane

Figure 3-12. Sight Distance Through Median.

Application 5
ISD, Case C1

Overview

The length of the leg of the sight triangle along the minor roadway for Case C (intersections with yield control on the minor road crossing maneuver from the minor road) is based on the same assumptions as those for Case A (see Chapter 3, Application 1 <link>) except that minor-road vehicles that do not stop are assumed to decelerate to 60 percent of the minor roadway design speed rather than 50 percent. Discussion on intersection sight distance is included in the *Urban Intersection Design Guide*, Chapter 3, Section 1 <link>.

Crossing at a Yield-Controlled Intersection

Problem. Determine the sight triangle for a crossing maneuver for a passenger car from the minor road at the intersection of Bluebonnet Lane and Cherry Grove (see Figure 3-13).

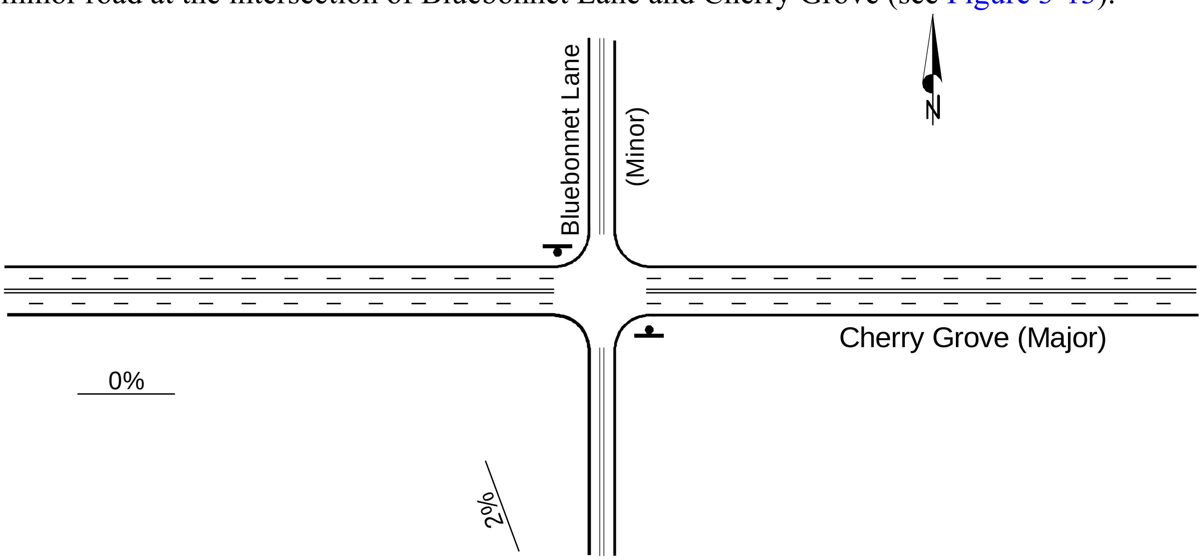


Figure 3-13. Cherry Grove and Bluebonnet Lane Intersection.

Known Information. The information known for this site includes:

- Design speed on Cherry Grove is 40 mph [64 km/h].
- Design speed on Bluebonnet Lane is 40 mph [64 km/h].
- Grade on Cherry Grove is 0 percent.
- Grade for Bluebonnet Lane is 2 percent.
- Cherry Grove is a four-lane undivided highway with a width of 48 ft [14.6 m].
- Bluebonnet Lane is a two-lane highway with no median.

Solution. The solution is provided below:

- *Step 1: Identify needed adjustments.*

The northbound grade for Bluebonnet Lane is 2 percent, which is less than the 3 percent threshold for adjusting the ISD values. Therefore, no adjustment for the approach grade is necessary.

- *Step 2: Determine the minor road leg length for a crossing maneuver for both approaches of Bluebonnet Lane.*

The minor road leg length is provided in Table 3-6 as a function of the design speed of the minor road. For a minor road with a design speed of 40 mph [64 km/h], the “a” length of the leg on the minor road is 235 ft [72 m].

- *Step 3: Determine the major road leg length for a crossing maneuver for both approaches of Bluebonnet Lane.*

The major road length is calculated using the following equation:

US Customary

$b = 1.47_{major}t_g$ Where $t_g = t_a + (w + L_a)/(0.88\ V_{minor})$

Metric

$b = 0.278\ V_{major}t_g$ Where $t_g = t_a + (w + L_a)/(0.167\ V_{minor})$

Where:

b = length of leg of sight triangle along the major road, ft or m

t_g = travel time to reach and clear the major road, sec

t_a = travel time to reach the major road from the decision point for a vehicle that does not stop, sec

w = width of the intersection to be crossed, ft or m

L_a = length of the design vehicle, ft or m

V_{minor} = design speed of minor road, mph or km/h

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

For this example, Cherry Grove is 48 ft [14.6 m] wide and the length of a passenger car is 19 ft [5.8 m]. The travel time is 4.9 sec for a 40 mph [64 km/h] design speed [or 5.1 sec for a 70 km/h design speed] as shown in Table 3-6.

Table 3-6. Case C1 – Crossing Maneuvers from Yield-Controlled Approaches – Length of Minor Road Leg and Travel Times (Reproduction of *Green Book* Exhibit 9-60).

US Customary				
	Minor-road approach		Travel time (t_g) (seconds)	
Design Speed (mph)	Length of Leg[a] (ft)	Travel Time t_a[a,b] (seconds)	Calculated Value	Design Value[c,d]
15	75	3.4	6.7	6.7
20	100	3.7	6.1	6.5
25	130	4.0	6.0	6.5
30	160	4.3	5.9	6.5
35	195	4.6	6.0	6.5
40	***235***	***4.9***	6.1	6.5
45	275	5.2	6.3	6.5
50	320	5.5	6.5	6.5
55	370	5.8	6.7	6.7
60	420	6.1	6.9	6.9
65	470	6.4	7.2	7.2
70	530	6.7	7.4	7.4
75	590	7.0	7.7	7.7
80	660	4.3	7.9	7.9

Metric				
	Minor-road approach		Travel time (t_g) (seconds)	
Design Speed (km/h)	Length of Leg[a] (m)	Travel Time t_a[a,b] (seconds)	Calculated Value	Design Value[c,d]
20	20	3.2	7.1	7.1
30	30	3.6	6.2	6.5
40	40	4.0	6.0	6.5
50	55	4.4	6.0	6.5
60	65	4.8	6.1	6.5
70	***80***	***5.1***	6.2	6.5
80	100	5.5	6.5	6.5
90	115	5.9	6.8	6.8
100	135	6.3	7.1	7.1
110	155	6.7	7.4	7.4
120	180	7.0	7.7	7.7
130	205	7.4	8.0	8.0

[a] For minor-road approach grades that exceed 3 percent, multiply the distance or the time in this table by the appropriate adjustment factor.

[b] Travel time applies to a vehicle that slows before crossing the intersection but does not stop.

[c] The value of t_g should equal or exceed the appropriate time gap for crossing the major road from a stop-controlled approach.

[d] Values shown are for a passenger car crossing a two-lane highway with no median and grades 3 percent or less.

Thus, the travel time to cross Cherry Grove is:

US Customary

$t_g = t_a + (w + L_a)/(0.88\ V_{Minor})$

$t_g = 4.9$ sec + (48 ft + 19 ft)/(0.88) (40 mph)

$t_g = 6.80$ sec

Metric

$t_g = t_a + (w + L_a)/(0.167\ V_{Minor})$

$t_g = 5.1$ sec + (14.4 m + 5.8 m)/(0.167) (70 km/h)

$t_g = 6.83$ sec

The value for t_g should be checked to ensure that its value meets or exceeds t_g for a stop-controlled approach (note c from Table 3-6). The values for t_g for a stop-controlled approach are in the *Green Book* Exhibit 9-57 and reproduced as Table 3-7. From Table 3-7, t_g for a passenger car is 6.5 sec. The adjustment for crossing a major road with more than two lanes is to add 0.5 seconds for each lane. Therefore:

$t_g = 6.5$ sec + 2 × 0.5 sec

$t_g = 7.5$ sec

Table 3-7. Time Gap for Case B2 – Right Turn from Stop (Reproduction of *Green Book* Exhibit 9-57).

Design Vehicle	Time gap (sec) at design speed of major road (t_g)
Passenger car	***6.5***
Single-unit truck	8.5
Combination truck	10.5

Note: Time gaps are for a stopped vehicle to turn right onto or cross a two-lane highway with no median and grades 3 percent or less. The table values require adjustment as follows:

- *For multilane highways:* For crossing a major road with more than two lanes, add ***0.5 second*** for passenger cars or 0.7 second for trucks for each additional lane to be crossed and for narrow medians that cannot store the design vehicle
- *For minor road approach grades:* If the approach grade is an upgrade that exceeds 3 percent, add 0.1 seconds for each percent grade.

Because t_g for a stop-controlled approach (7.5 sec) exceeds t_g for yield control (6.8 sec) at the 40 mph [64 km/h] design speed, the 7.5 sec should be used to determine the sight distance along the major road (Cherry Grove). As a result, the major road leg length is as follows:

US Customary	Metric
$b = 1.47\ V_{major} t_g$	$b = 0.278\ V_{major} t_g$
b = 1.47 (40 mph) (7.5 sec)	b = 0.278 (70 km/h) (7.5 sec)
b = 441 ft	b = 146 m

- *Step 4: Illustrate findings.*

Figure 3-14 illustrates the resulting sight triangles for a crossing maneuver from the minor road for the northbound direction from a yield control. The southbound direction would have similar sight distances.

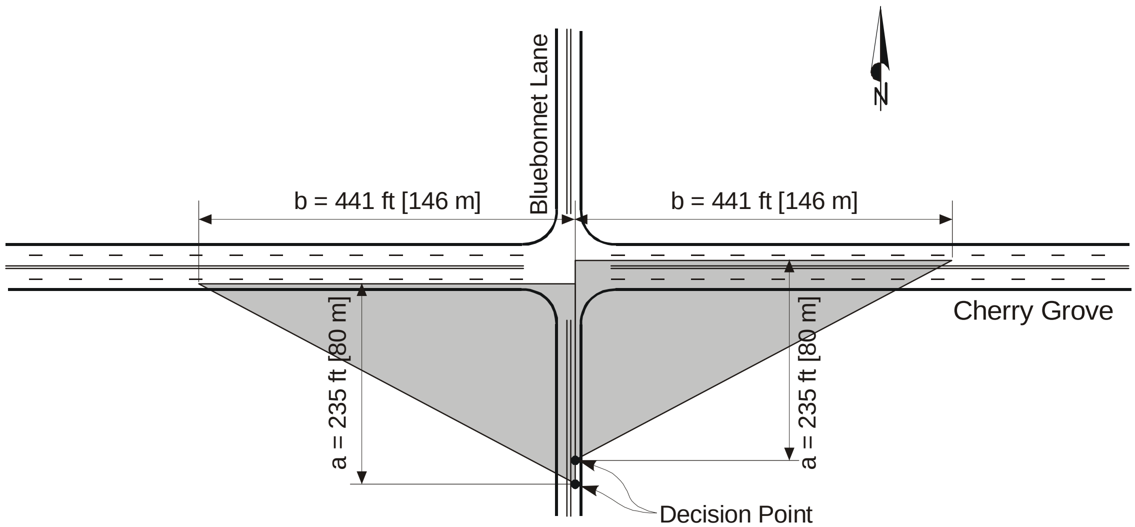


Figure 3-14. Case C1 – Sight Triangles for Crossing Maneuver from Minor Road with Yield Control for Northbound Approach (Southbound Would Be Similar).

Application 6
ISD, Case C2

Overview

Discussion on intersection sight distance is included in the *Urban Intersection Design Guide,* Chapter 3, Section 1 <link>. This application presents an example for Case C2, intersections with yield control on the minor road, left or right turn from the minor road.

Drivers approaching Yield signs are permitted to enter or cross the major road without stopping, if there are no potentially conflicting vehicles on the major road. Figure 3-1 (A) of the *Urban Intersection Design Guide* <link> shows an illustration of the approach sight triangles. Per the *Green Book,* the length of the leg of the approach sight triangle along the minor roadway to accommodate left and right turns without stopping is 82 ft [25 m]. This is based on the assumption that drivers will slow to a turning speed of 10 mph [16 km/h].

The length of the leg of the approach sight triangle along the major roadway is shown in Table 3-8 for passenger cars. The lengths are slightly longer than the values for the stop-controlled case. The longer sight distances represent additional travel time needed at a yield-controlled intersection (3.5 sec) minus the lower acceleration time needed (3.0 sec) since the turning vehicle is accelerating from 10 mph [16 km/h] rather than from a stop condition. The net is a 0.5 sec increase in travel time.

Departure sight triangles like those used in the stop-controlled cases should also be provided to accommodate vehicles that have stopped to traffic. However, since approach sight triangles for turning maneuvers at yield-controlled approaches are larger than the departure sight triangles used at stop-controlled intersections, no specific check of departure sight triangles at yield-controlled intersections should be needed.

Table 3-8. Intersection Sight Distance – Case C2 – Left or Right Turn at Yield-Controlled Intersection (Reproduction of *Green Book* Exhibit 9-64).

US Customary			
		Length of leg, Passenger cars	
Design Speed (mph)	**Stopping Sight Distance (ft)**	**Calculated (ft)**	**Design (ft)**
15	80	176.4	180
20	115	235.2	240
25	155	294.0	295
30	200	352.8	355
35	250	411.6	415
40	305	470.4	***475***
45	360	529.2	530
50	425	588.0	590
55	495	646.8	650
60	570	705.6	710
65	645	764.4	765
70	730	823.2	825
75	820	882.0	885
80	910	940.8	945
Metric			
		Length of leg, Passenger cars	
Design Speed (km/h)	**Stopping Sight Distance (m)**	**Calculated (m)**	**Design (m)**
20	20	44.5	45
30	35	66.7	70
40	50	89.0	90
50	65	111.2	115
60	85	133.4	135
70	105	155.7	***160***
80	130	177.9	180
90	160	200.2	205
100	485	222.4	225
110	220	244.6	245
120	250	266.9	270
130	285	289.1	290

Note: Intersection sight distance shown is for a passenger car making a right or left turn without stopping onto a two-lane road.

Single-Unit Truck Turning at a Yield-Controlled Intersection

Problem. Determine the sight triangle for a southbound left-turn vehicle for a single-unit truck at the intersection of Bluebonnet Lane and Cherry Grove (see Figure 3-15).

Known Information. The information known for this site includes:

- Design speed on Cherry Grove is 40 mph [64 km/h].
- Design speed on Bluebonnet Lane is 40 mph [64 km/h].
- Grade on Cherry Grove is 0 percent.

- Grade for Bluebonnet Lane is 2 percent.
- Cherry Grove is a four-lane undivided highway with a width of 48 ft [14.6 m].
- Design vehicle for left turns on the southbound approach is a single-unit truck.

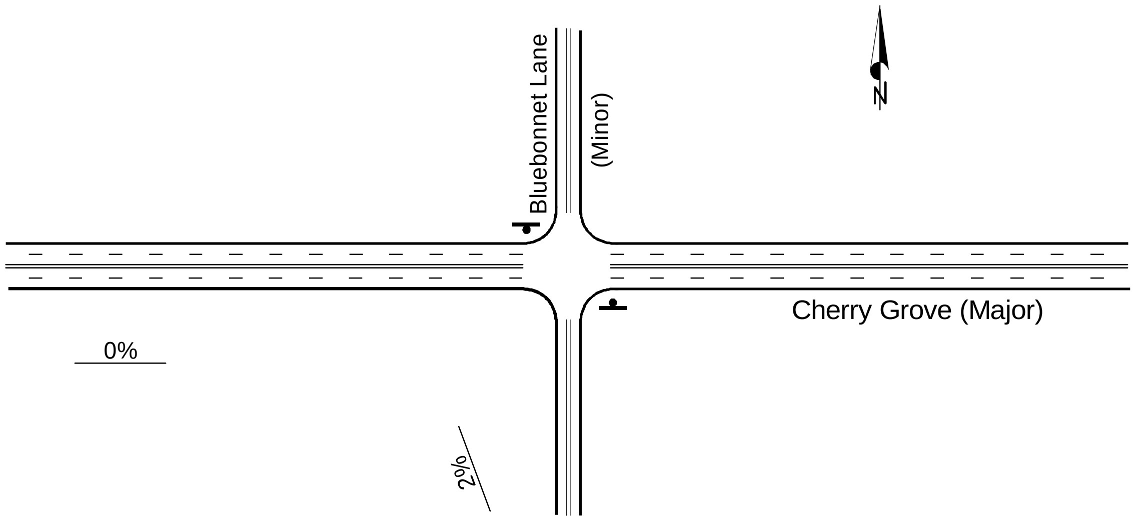


Figure 3-15. Cherry Grove and Bluebonnet Lane Intersection.

Solution. The solution is provided below:

- *Step 1: Identify needed adjustments.*

The approach grades are less than 3 percent so no adjustments are needed for grade. The vehicle is crossing more than one lane during the left turn so an adjustment for number of lanes will be needed.

- *Step 2: Determine the minor road leg length.*

The minor road leg length is 82 ft [25 m] as stated in the *Green Book*.

- *Step 3: Determine the major road leg length for a left-turning truck onto Cherry Grove from Bluebonnet Lane.*

When the major road is a two-lane highway and the vehicle is a passenger car, then the values in Table 3-8 can be used. (If the major road in this example had two lanes, then the sight distance would have been 475 ft [145 m] as shown in Table 3-8.) Because the major road is a multilane highway, an adjustment is needed to the travel time. The major road length is calculated using the same equations as used for determining the distance for a left turn from a minor road at a stop-controlled intersection:

US Customary	Metric
$b = 1.47\ V_{major}t_g$	$b = 0.278_{major}t_g$

The base value for t_g for a single-unit truck is 10.0 sec as shown in Table 3-9.

Table 3-9. Time Gap for Case C2 – Left or Right Turn (Reproduction of *Green Book* Exhibit 9-63).

Design Vehicle	Time gap (sec) at design speed of major road (t_g)
Passenger car	8.0
Single-unit truck	***10.0***
Combination truck	12.0

Note: Time gaps for a vehicle to turn right or left onto a two-lane highway with no median. The table values require adjustments for multilane highways as follows:

- For left turns onto two-way highways with more than two lanes, add 0.5 second for passenger cars and ***0.7 second*** for trucks for each additional lane, from the left, in excess of one, to be crossed by the turning vehicle.
- For right turns, no adjustment is necessary.

Recall that we need to make a multilane roadway adjustment to this travel time. In the case of Cherry Grove, in order to turn left the single-unit truck will have to cross one additional lane when compared to a two-lane highway. Thus, the adjustment for the t_g is as follows:

$t_g = t_g$ (base) + multilane adjustment

$t_g = 10.0$ sec + 0.7 sec

$t_g = 10.7$ sec

As a result, the major road leg length is as follows:

US Customary	Metric
$b = 1.47\ V_{major}\ t_g$	$b = 0.278\ V_{major}\ t_g$
b = 1.47 (40 mph) (10.7 sec)	b= 0.278 (70 km/h) (10.7 sec)
b = 629 ft	b = 208 m

- *Step 4: Illustrate findings.*

Figure 3-16 illustrates the resulting sight triangles for a left-turn, single-unit truck from the minor road for the southbound direction at a yield-controlled intersection.

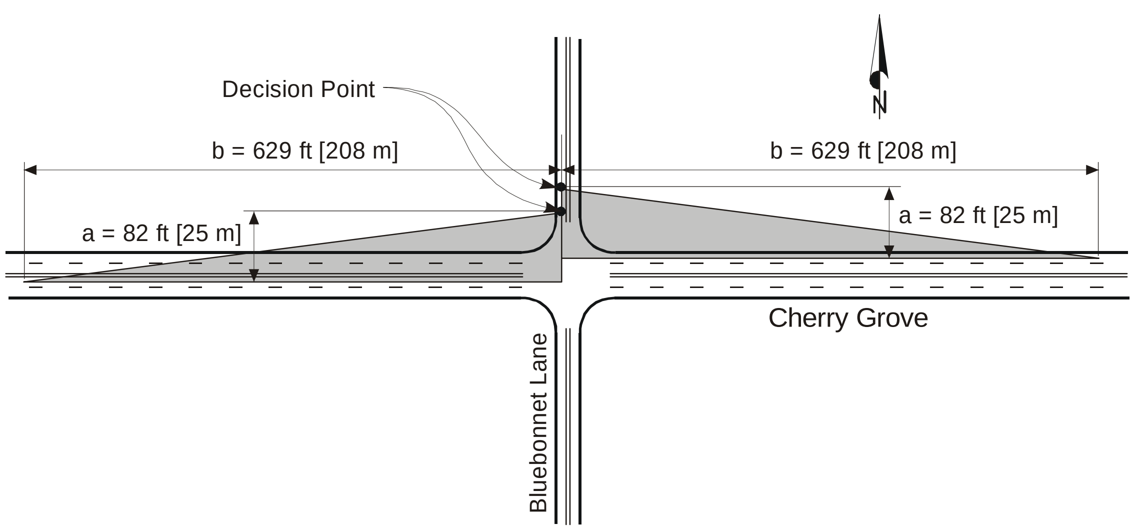


Figure 3-16. Case C2 – Sight Triangles for Left-Turn, Single-Unit Truck from Minor Road with Yield Control.

Application 7

ISD, Case D

Overview

Generally, there are no required sight triangles for signalized intersections, although the first vehicle at one approach should be visible to the first vehicles on all the other approaches, and left-turning vehicles should have sufficient sight distance to select gaps in oncoming traffic and complete their left turns.

If the signal will be placed on flashing mode (yellow for the major roadway and red for the minor roadway) then the appropriate sight triangles for stop control should be provided on the minor road approaches. If right turns on red are allowed, sight triangles to the left should be provided from each approach.

Discussion on intersection sight distance is included in the *Urban Intersection Design Guide*, Chapter 3, Section 1 <link>.

Example 1: Sight Distance for Flashing Operations

Problem. The intersection of Jersey and Brighton will be signalized and will be placed in flashing mode at night, with Jersey having a flashing yellow and Brighton have a flashing red. Determine the sight triangles for a left turn for a passenger car from Brighton onto Jersey from both the northbound and southbound directions. Figure 3-17 is a schematic of the intersection.

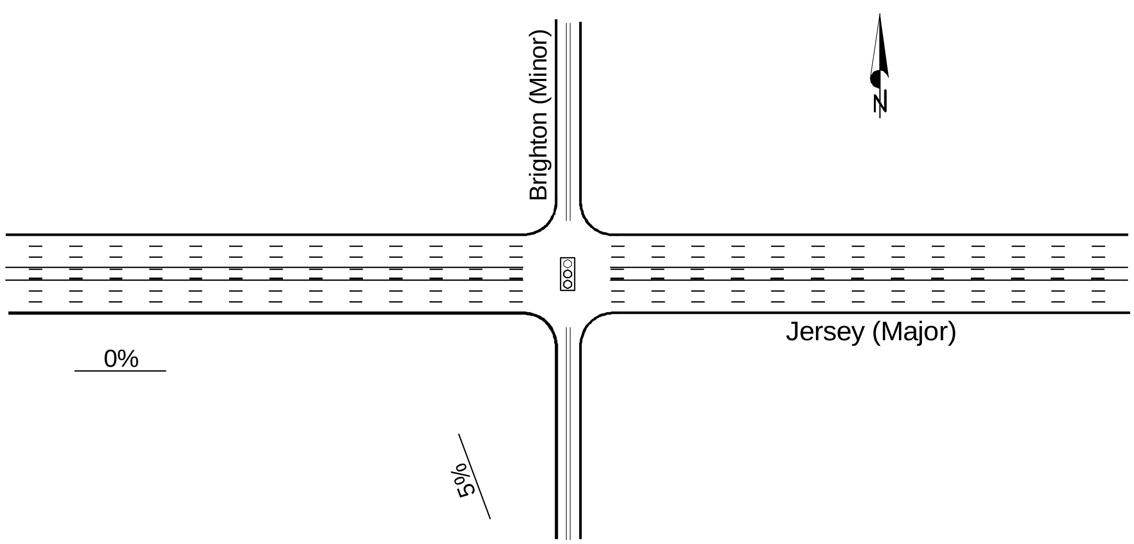


Figure 3-17. Jersey and Brighton Intersection.

Known Information. The following information is known about the site:

- Design speed on Jersey is 45 mph [72 km/h].
- Design speed on Brighton is 30 mph [48 km/h].

- Grade for Jersey is 0 percent.
- Grade for Brighton is 5 percent.
- Jersey has six lanes and a two-way left-turn lane (TWLTL) that is 14 ft [4.3 m] wide.
- Brighton has two lanes and no median.
- Lane widths are 12 ft [3.7 m] on both streets.

Solution. The solution is provided below:

- *Step 1: Identify needed adjustments.*

For northbound Brighton, the grade is +5 percent, which exceeds 3 percent, thereby requiring adjustments in the time gap.

- *Step 2: Determine the minor road sight triangle length for a left turn from northbound Brighton.*

Based on the *Green Book* procedure, the "a" length for the sight triangle is the following:

"a" leg length = distance between major-road travel way and front of vehicle
+ distance between front of vehicle and driver's eye
+ distance to middle of lane of interest

a_L = "a" leg length to vehicles approaching from the left

a_L = distance from major-road traveled way
+ distance from front of the vehicle to the driver's eye
+ 0.5 lane width

$a_L = 6.5$ ft [2.0 m] + 8 ft [2.4 m] + 0.5 × 12 ft [3.7 m]
$a_L = 21$ ft [6 m]

a_R = "a" leg length to vehicles approaching from the right

a_R = distance from major-road traveled way
+ distance from front of the vehicle to the driver's eye
+ 3.5 lane width + median

$a_R = 6.5$ ft [2.0 m] + 8 ft [2.4 m] + 3.5 × 12 ft [3.7 m] + 14 ft [4.3 m]
$a_R = 71$ ft [22 m]

- *Step 3: Determine the major road sight triangle length for a left turn from northbound Brighton.*

The equation for the "b" leg length is as follows:

US Customary	Metric
$ISD = 1.47\ V_{major}t_g$	$ISD = 0.278\ V_{major}t_g$

The initial time gap to be used in this equation is 7.5 for passenger cars, as highlighted in Table 3-10. The necessary adjustment for the grade is 0.2 sec for each percent grade (5 percent). Thus, the adjustment is 1.0 sec. Because Jersey has three lanes in each direction and a left-turn lane, the t_g should be increased by 0.5 sec for each additional lane the car must cross. In this case, the adjustment factor is 1.5 sec since the vehicle must cross three additional lanes.

Table 3-10. Time Gap for Case B1 – Left Turn from Stop (Reproduction of *Green Book* Exhibit 9-54).

Design Vehicle	Time gap (sec) at design speed of major road (t_g)
Passenger car	***7.5***
Single-unit truck	9.5
Combination truck	11.5

Note: Time gaps are for a stopped vehicle to turn right or left onto a two-lane highway with no median and grades 3 percent or less. The table values require adjustment as follows:

- For multilane highways: For left turns onto two-way highways with more than two lanes, add ***0.5 second*** for passenger cars or 0.7 second for trucks for each additional lane, from the left, in excess of one, to be crossed by the turning vehicle.
- For minor road approach grades: If the approach grade is an upgrade that exceeds 3 percent, add ***0.2 second*** for each percent grade for left turns.

Thus, the t_g value is as follows:

$$t_g = \text{base } t_g + \text{grade adjustment} + \text{major road width adjustment}$$

$$t_g = 7.5 \text{ sec} + 1.0 \text{ sec (grade adjustment)} + 1.5 \text{ sec (width adjustment)}$$

$$t_g = 10.0 \text{ sec}$$

Therefore, the "b" leg length is as follows:

US Customary	Metric
$ISD = 1.47\ V_{major}t_g$	$ISD = 0.278\ V_{major}t_g$
ISD = 1.47 (45 mph) (10.0 sec)	ISD = 0.278 (70 km/h) (10.0 sec)
ISD = 662 ft	ISD = 195 m

- *Step 4: Illustrate findings.*

Figure 3-18 illustrates the sight triangles for a left turn from the minor road (Brighton) in the northbound direction.

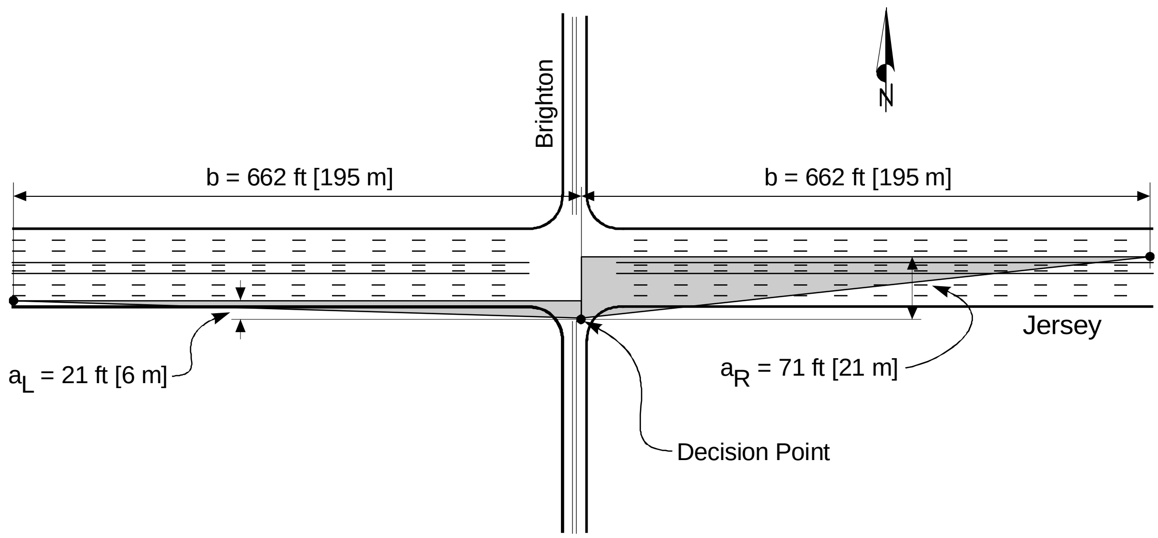


Figure 3-18. Case D – Sight Triangles for Left Turn from Minor Road with Traffic Signal Control in Flashing Mode, Northbound Approach.

- *Step 5: Determine the major road sight triangle for a left turn from southbound Brighton.*

A similar method to that used for northbound Brighton is used. Because the approach grade is –5 percent, however, the grade adjustment for t_g must be re-examined. No grade adjustment is necessary because it is a downgrade.

Thus, the t_g value is as follows:

t_g = base t_g + major road width adjustment

t_g = 7.5 sec + 1.5 sec (width adjustment)

t_g = 9.0 sec

Therefore, the "b" leg length is as follows:

US Customary	Metric
ISD = 1.47 $V_{major}t_g$	ISD = 0.278 $V_{major}t_g$
ISD = 1.47 (45 mph) (9.0 sec)	ISD = 0.278 (70 km/h) (9.0 sec)
ISD = 595 ft	ISD = 175 m

- *Step 6: Illustrate findings.*

Figure 3-19 illustrates the sight triangles for a left turn from the minor road (Brighton) in the southbound direction.

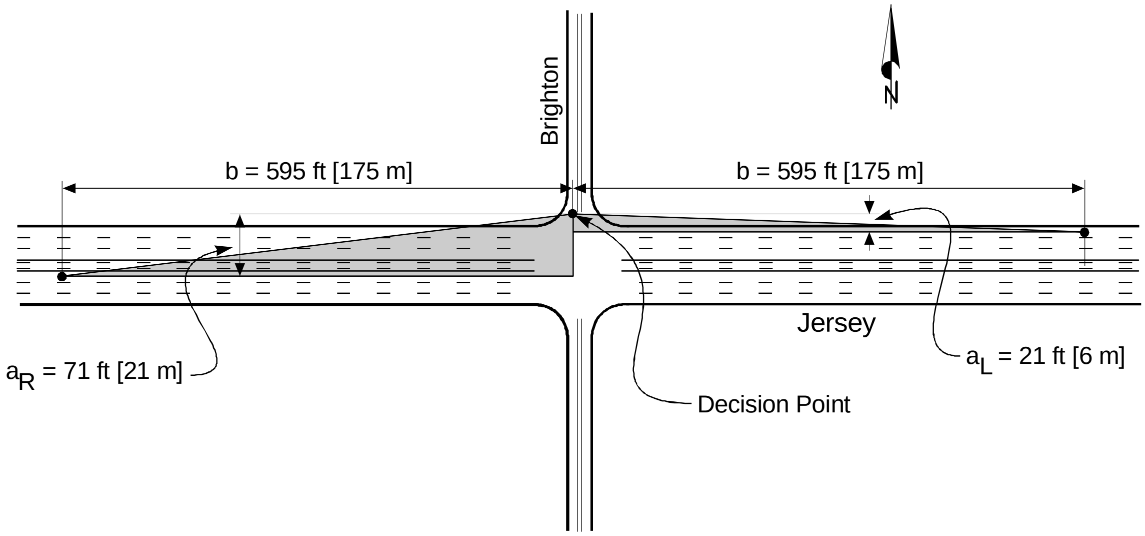


Figure 3-19. Case D – Sight Triangle for Left Turn from Minor Road with Traffic Signal Control in Flashing Mode, Southbound Approach.

Example 2: Sight Distance for Right Turn on Red

Problem. Right turns on red are allowed at the intersection of Vista and Fourth Street. Determine the sight triangles for a right turn for a passenger car from Vista onto Fourth Street for both the northbound and southbound directions. Figure 3-20 shows a schematic of the intersection.

Known Information. The following information is known about the site:

- Design speed on Fourth Street is 50 mph [80 km/h].
- Design speed on Vista is 30 mph [48 km/h].
- Grade for Fourth Street is 1 percent.
- Grade for Vista is 2 percent.
- Fourth Street has four lanes and a two-way left-turn lane.
- Vista has two lanes and no median.
- The width of the two-way left-turn lane is 14 ft [4.3 m].
- Lane widths are 12 ft [3.7 m].

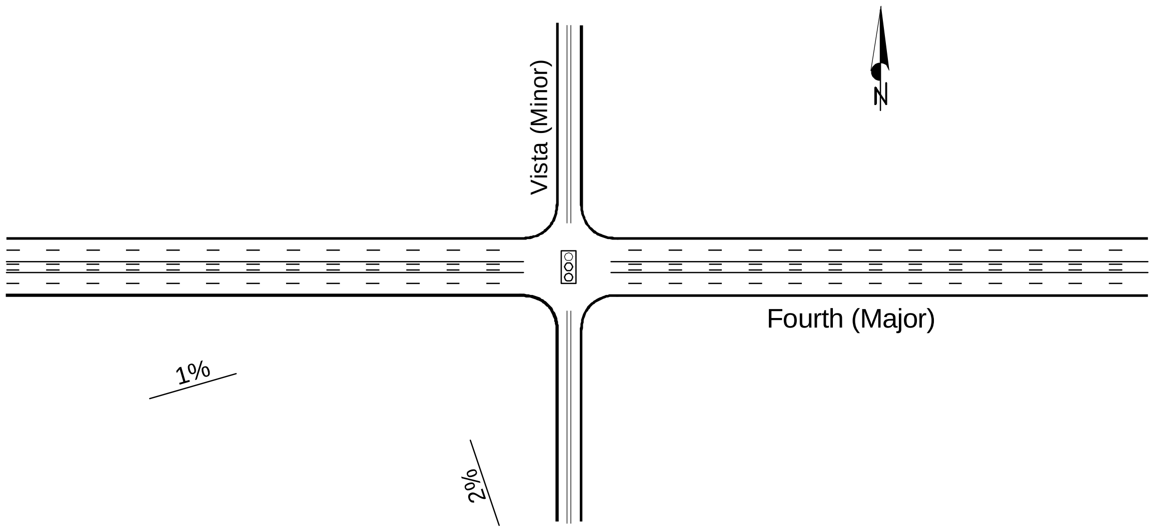


Figure 3-20. Fourth and Vista Intersection.

Solution for Northbound Vista. The solution is provided below:

- *Step 1: Identify needed adjustments.*

For Fourth Street, the approach grades are 1 percent, which is below the 3 percent limit. Therefore, no adjustments in the time gap are needed.

- *Step 2: Determine the minor road sight triangle length for a right turn from Vista.*

Based on the *Green Book* procedure, the "a" length for the sight triangle is the following:

"a" leg length = distance between major-road travel way and front of vehicle
+ distance between front of vehicle and driver's eye
+ distance to middle of lane of interest

a_L = "a" leg length to vehicles approaching from the left

a_L = distance from major-road traveled way
+ distance from front of the vehicle to the driver's eye
+ 0.5 lane width

$a_L = 6.5$ ft [2.0 m] + 8 ft [2.4 m] + 0.5 × 12 ft [3.7 m]
$a_L = 21$ ft [6 m]

- *Step 3: Determine the major road sight triangle length for a right turn from Vista.*

The equation for the "b" leg length is as follows:

US Customary	Metric
$ISD = 1.47\ V_{major}t_g$	$ISD = 0.278\ V_{major}t_g$

The initial time gap to be used in this equation is 6.5 sec for passenger cars, as highlighted in Table 3-11. Because the grade on the southbound approach is within the 3 percent limit, no adjustment for the grade is necessary. There are also no adjustments for number of lanes for a right turn.

Thus, the t_g value is as follows:

t_g = base t_g + adjustments

t_g = 6.5 sec + 0 sec

t_g = 6.5 sec

Therefore, the "b" leg length is as follows:

US Customary	Metric
$ISD = 1.47\ V_{major}t_g$	$ISD = 0.278\ V_{major}t_g$
ISD = 1.47 (45 mph) (6.5 sec)	ISD = 0.278 (80 km/h) (6.5 sec)
ISD = 478 ft	ISD = 145 m

- *Step 4: Illustrate findings.*

Figure 3-21 illustrates the sight triangle for a right turn from the northbound minor road (Vista); because the conditions are similar for southbound Vista, the ISD sight triangles would have similar dimensions as those for the northbound approach.

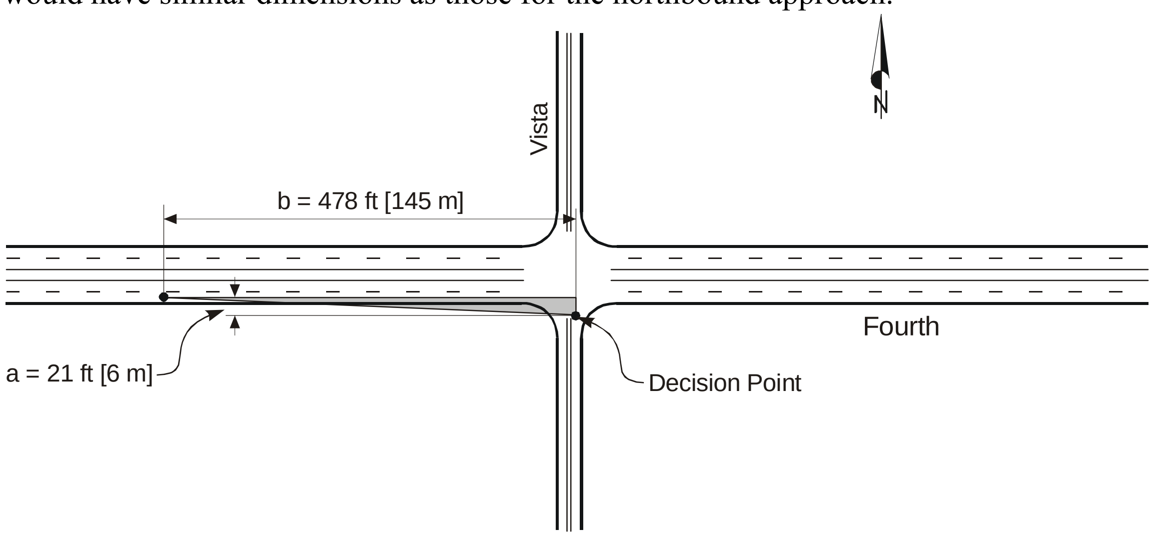


Figure 3-21. Case D – Sight Triangles for a Right Turn from Minor Road with Traffic Signal Control for Right Turn on Red.

Table 3-11. Time Gap for Case B2 – Right Turn from Stop (Reproduction of *Green Book* Exhibit 9-57).

Design Vehicle	Time gap (sec) at design speed of major road (t_g)
Passenger car	***6.5***
Single-unit truck	8.5
Combination truck	10.5

Note: Time gaps are for a stopped vehicle to turn right onto or cross a two-lane highway with no median and grades 3 percent or less. The table values require adjustment as follows:

- For multilane highways: For crossing a major road with more than two lanes, add 0.5 second for passenger cars or 0.7 second for trucks for each additional lane to be crossed and for narrow medians that cannot store the design vehicle.
- For minor road approach grades: If the approach grade is an upgrade that exceeds 3 percent, add 0.1 second for each percent grade.

Application 8
ISD, Case F

Overview

Drivers turning left across oncoming traffic of a major roadway require sufficient sight distance to determine when it is safe to turn left across the lanes used by opposing traffic. Sight distance is based on a left turn by a stopped vehicle, since a vehicle that turns left without stopping would need less sight distance. Discussion on intersection sight distance is included in the *Urban Intersection Design Guide*, Chapter 3, Section 1 <link>.

Example 1: Left Turn from Two-Lane Highway

Problem. Determine the sight distance necessary for a passenger car to turn left from Elmo to Bird. Figure 3-22 is a schematic of the intersection.

Figure 3-22. Bird and Elmo Intersection.

Known Information. The information known for this intersection includes:

- Bird is the major roadway with no traffic control.
- Elmo has stop control.
- Both Bird and Elmo are two-lane highways.
- Design speed on Bird is 40 mph [64 km/h].

- Design speed on Elmo is 35 mph [56 km/h].
- Grade for Bird is 4 percent.
- Grade for Elmo is 0 percent.
- No medians are present on the approaches.
- Lane width is 12 ft [3.7 m].

Solution. The solution is provided below:

- *Step 1: Identify needed adjustments.*

Potential adjustment includes number of lanes to cross and vehicle type. Since both Bird and Elmo are two-lane highways, there is no adjustment for number of additional lanes to cross. The design vehicle is a passenger car; therefore, no adjustment for vehicle type is needed.

- *Step 2: Determine the sight distance for a left turn from the major highway.*

The values in Table 3-12 can be used to determine the needed sight distance since no adjustments for number of lanes or vehicle type are needed. For Bird, with a design speed of 40 mph [64 km/h], the sight distance is 325 ft [99 m].

- *Step 3: Illustrate findings.*

Figure 3-23 illustrates the resulting sight distance for a left turn from Bird to Elmo.

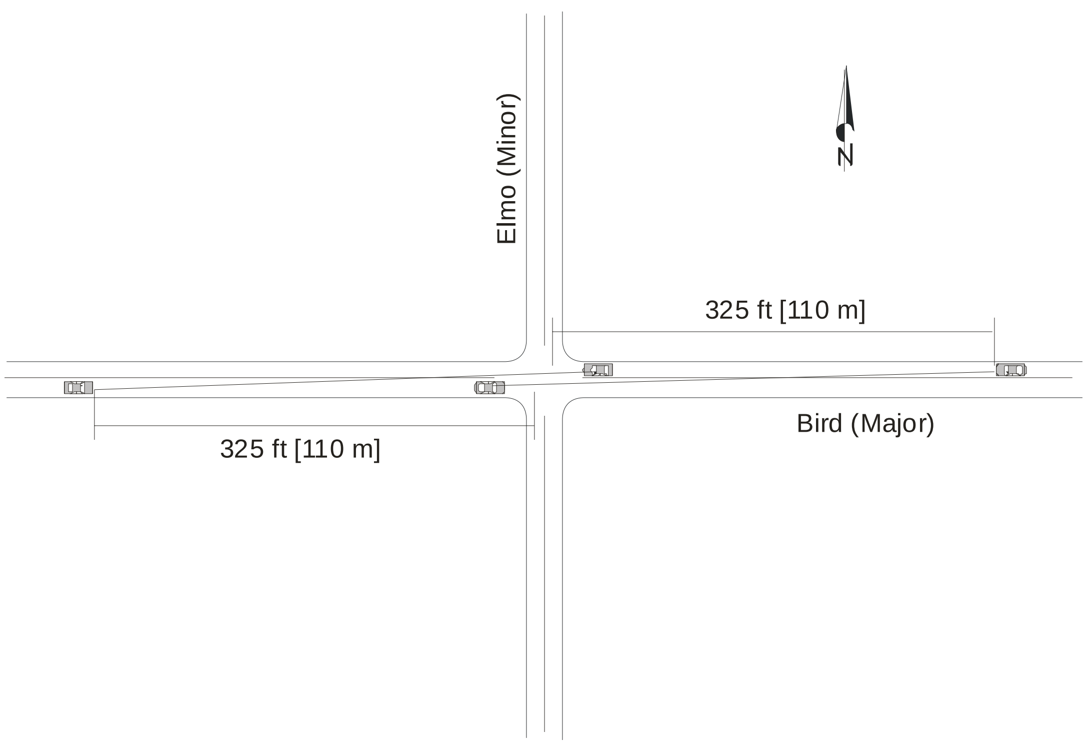


Figure 3-23. Case F – Sight Distance for Left Turns from Two-Lane Major Road.

Table 3-12. Intersection Sight Distance – Case F – Left Turn from Major Road (Reproduction of *Green Book* Exhibit 9-67).

US Customary			
		Intersection Sight Distance	
		Passenger Cars	
Design Speed (mph)	**Stopping Sight Distance (ft)**	**Calculated (ft)**	**Design (ft)**
15	80	121.3	125
20	115	161.7	165
25	155	202.1	205
30	200	242.6	245
35	250	283.4	***285***
40	305	323.4	***325***
45	360	363.8	365
50	425	404.3	405
55	495	444.7	445
60	570	485.1	490
65	645	525.5	530
70	730	566.0	570
75	820	606.4	610
80	910	646.8	650
Metric			
		Intersection Sight Distance	
		Passenger Cars	
Design Speed (km/h)	**Stopping Sight Distance (m)**	**Calculated (m)**	**Design (m)**
20	20	30.6	35
30	35	45.9	50
40	50	61.2	65
50	65	76.5	80
60	85	91.7	***95***
70	105	107.0	***110***
80	130	122.3	125
90	16	137.6	140
100	185	152.9	155
110	220	168.2	170
120	250	183.5	185
130	285	198.8	200
Note: Intersection sight distance shown is for a passenger car making a left turn from an undivided highway. For other conditions and design vehicles, the time gap should be adjusted and the sight distance recalculated.			

Example 2: Left Turn from Six-Lane Highway

Problem. Determine the sight distance necessary for a combination truck to turn left from Elm onto Hazel (see Figure 3-24).

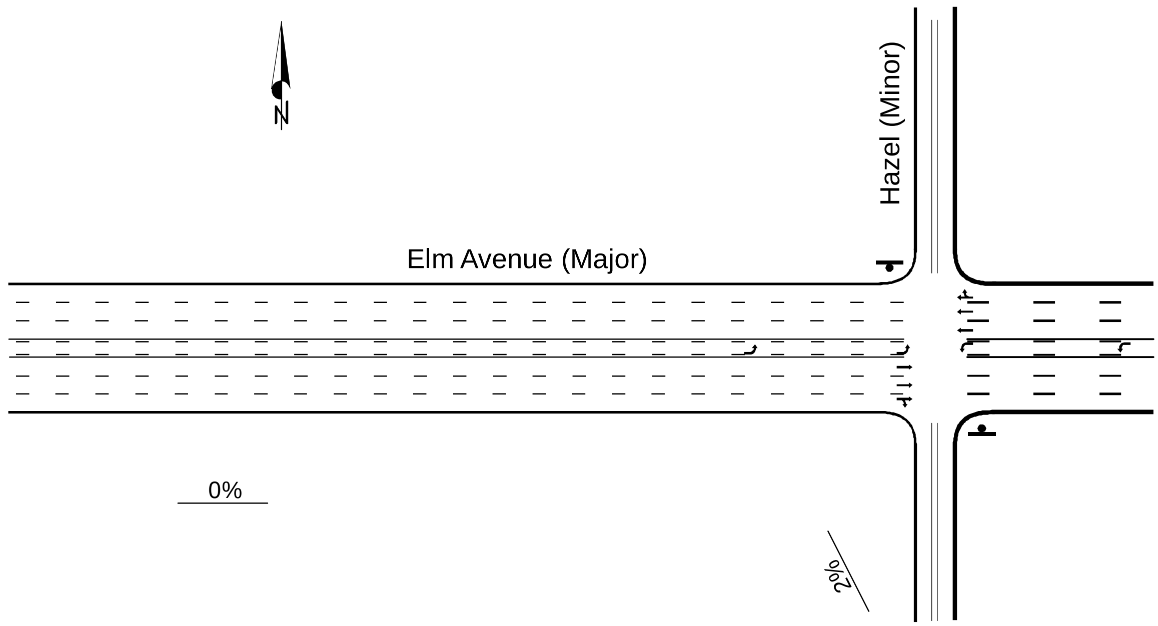


Figure 3-24. Elm and Hazel Intersection.

Known Information. The following information is known about the site:

- Design speed on Elm Avenue is 45 mph [72 km/h].
- Design speed on Hazel is 30 mph [48 km/h].
- Grade for Elm Avenue is 0 percent.
- Grade on Hazel is 2 percent.
- Elm Avenue has six lanes and a two-way left-turn lane.
- Hazel has two lanes and no median.
- The width of the TWLTL on Elm is 14 ft [4.3 m].
- Lane widths are 12 ft [3.7 m].

Solution. The solution is provided below:

- *Step 1: Identify needed adjustments.*

Because Elm Avenue has three lanes in each direction as well as a left-turn lane, adjustments to the time gap are needed.

- *Step 2: Determine the sight distance of a left turn from the eastbound approach of Elm.*

The sight distance required for the turning vehicle is based on the following equation:

US Customary	Metric
$ISD = 1.47_{major}t_g$	$ISD = 0.278\ V_{major}t_g$

In this case, the base t_g is 7.5 sec as highlighted in Table 3-13. Since the vehicle has to cross three opposing lanes, the adjustment factor is 1.4 sec (two additional lanes at 0.7 sec per lane) to account for crossing the additional lanes. The total t_g is as follows:

t_g = 7.5 sec + 1.4 sec (width adjustment)

t_g = 8.9 sec

Table 3-13. Time Gap for Case F – Left Turn from Major Road (Reproduction of *Green Book* Exhibit 9-66).

Design Vehicle	Time gap (sec) at design speed of major road (t_g)
Passenger car	5.5
Single-unit truck	6.5
Combination truck	***7.5***
Adjustment for multilane highways: ♦ For left-turning vehicles that cross more than one opposing lane, add 0.5 second for passenger cars or ***0.7 second*** for trucks for ***each additional lane*** to be crossed.	

Therefore, the sight distance required for the turning vehicle is as follows:

US Customary

ISD = 1.47 V_{major} t_g

ISD = 1.47 (45 mph) (8.9 sec)

ISD = 589 ft

Metric

ISD= 0.278 V_{major} t_g

ISD = 0.278 (70 km/h) (8.9 sec)

ISD = 173 m

- *Step 3: Illustrate findings.*

Figure 3-25 illustrates the resulting sight distance for a left turn from the major road for a combination truck.

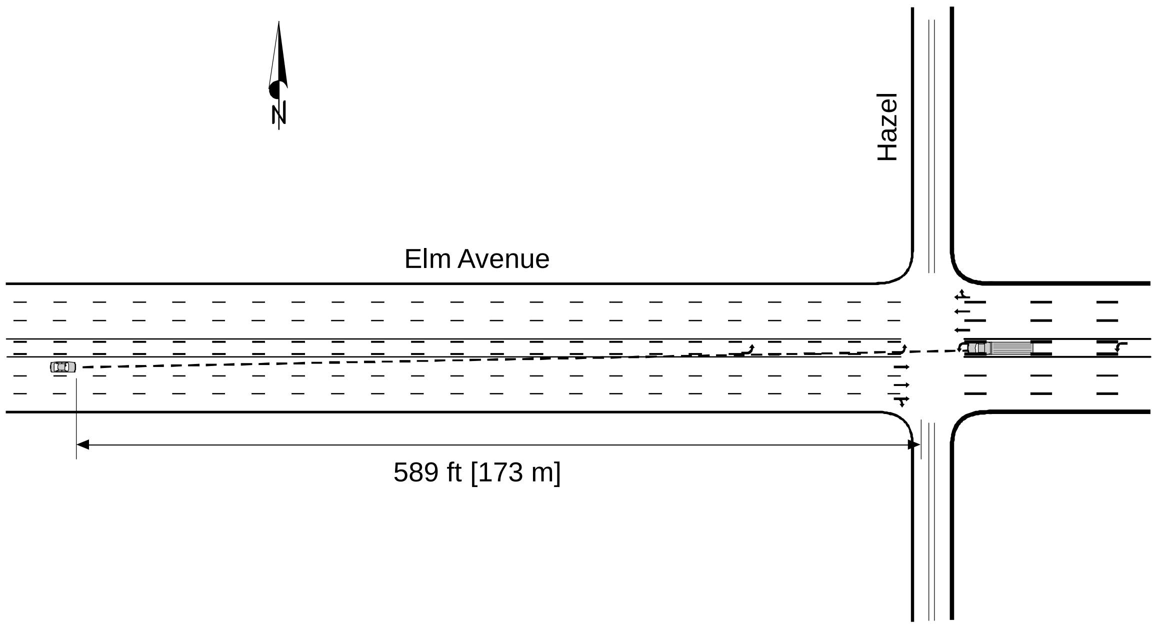


Figure 3-25. Case F – Sight Distance for Combination Truck Turning Left from a Six-Lane Highway.

Application 9

Example of a Superelevation Design at an Intersection

Overview

The use of superelevation on an urban roadway may present a problem with connections to crossing roadways because of the necessity to match grades and provide a smooth ride through the intersection. If the intersection is signalized or is expected to be signalized in the future a smooth ride should be ensured both on the major and minor roadways. The *Urban Intersection Design Guide*, Chapter 3, Section 2 <link> provides information on superelevation.

Background

Problem. The superelevation on the major roadway due to the downstream horizontal curve must be integrated with the vertical profile on the minor roadway at the intersection between the two roadways. Figure 3-26 shows the intersection layout.

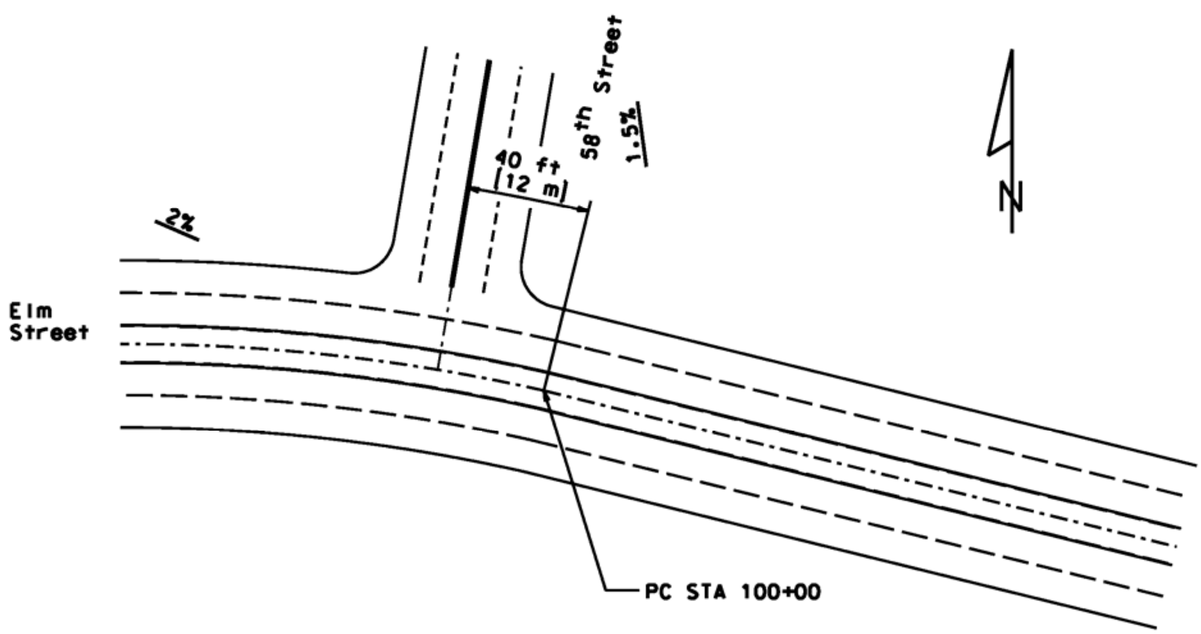


Figure 3-26. Intersection Layout.

Known Information. The information known for this intersection includes:

- Elm is the major roadway with no traffic control.
- 58th Street has stop control.
- Elm Street is a five-lane roadway with two lanes per direction and a TWLTL.
- 58th Street is a four-lane roadway with two lanes per direction.
- Horizontal curve on Elm has a radius of 700 ft [213 m].

- 58th Street has a 1.5 percent downgrade toward Elm Street.
- Elm Street has a 2 percent downgrade toward 58th Street.
- Maximum superelevation to be used is 4 percent (based on urban location).
- Design speeds are 45 mph [72 km/h] for both roadways.
- 58th Street is expected to be extended across Elm Street in the future as the city expands, with a resulting four-legged intersection.
- Normal cross slope of 2 percent exists on both roadways.
- Lane widths are:
  - 58th Street: four lanes at 12 ft [3.7 m] each, and
  - Elm Street: four lanes at 12 ft [3.7 m] each, TWLTL at 14 ft [4.3 m].

Proposed Design

The solution is provided below:

- *Step 1: Identify need for superelevation.*

From the *Roadway Design Manual,*[1] a design speed of 45 mph [72 km/h] is considered to be low speed (see Chapter 2 – Basic Design Criteria Section, Section 2 – Traffic Characteristics, Traffic Speed <link>). Checking Table 2-5 in the *Roadway Design Manual* (and reproduced in this document as Table 3-14), the provision of superelevation is required because the radius of 700 ft [213 m] is less than the value of 940 ft [287 m] shown in bold. The value (in bold) indicates the minimum radius that may be provided with adverse superelevation equal to the 2 percent cross slope on the roadway.

[1] Texas Department of Transportation. *Texas Roadway Design Manual*. February 2004. http://manuals.dot.state.tx.us:80/docs/coldesig/forms/rdw.pdf. Accessed August 30, 2002.

Table 3-14. Minimum Radii and Superelevation Transition Lengths for Limiting Values of e and f for Low-Speed Urban Streets (Reproduction of *Roadway Design Manual* Table 2-5 <link>).

US Customary					
Design Speed (mph)	**Max. e**	**Max. f**	**C**	**Min. R (ft)**	**Superelevation Transition Length,[1] L (ft)**
15	0.04	0.330	4.25	40	55
20	0.04	0.300	4.00	80	75
25	0.04	0.252	3.75	145	80
30	0.04	0.221	3.50	230	90
35	0.04	0.197	3.25	345	100
40	0.04	0.178	3.00	490	115
45	***0.04***	***0.163***	***2.75***	***665***	***125***
15	-0.02[2]	0.350	1.25	10	Not Required
20	-0.02[2]	0.312	1.20	25	Not Required
25	-0.02[2]	0.252	1.15	55	Not Required
30	-0.02[2]	0.214	1.10	105	Not Required
35	-0.02[2]	0.186	1.05	175	Not Required
40	-0.02[2]	0.163	1.00	270	Not Required
45	***-0.02[2]***	***0.163***	***2.75***	***940***	***Not Required***
Metric					
Design Speed (km/h)	**Max. e**	**Max. f**	**C**	**Min. R (m)**	**Superelevation Transition Length,[1] L (m)**
20	0.04	0.350	1.25	10	15
30	0.04	0.312	1.20	20	20
40	0.04	0.252	1.15	45	25
50	0.04	0.214	1.10	80	25
60	0.04	0.186	1.05	125	30
70	***0.04***	***0.163***	***1.00***	***190***	***30***
20	-0.02[2]	0.350	1.25	10	Not Required
30	-0.02[2]	0.312	1.20	25	Not Required
40	-0.02[2]	0.252	1.15	55	Not Required
50	-0.02[2]	0.214	1.10	105	Not Required
60	-0.02[2]	0.186	1.05	175	Not Required
70	***-0.02[2]***	***0.163***	***1.00***	***270***	***Not Required***

[1] L based on two-lane roadway rotated about centerline. For rotation about a pavement edge, or for multilane streets, the design L is determined by multiplying the above tabulated L value times the number of lanes between the rotation axis and edge of pavement. Thus for four-and six-lane streets, with the axis of rotation about the centerline, the design L is double and triple, respectively, the tabulated L.

[2] Normal crown maintained.

- *Step 2: Determine superelevation rate.*

As shown in Figure 3-27 (Figure 2-2 of the *Roadway Design Manual* <link>), a radius of 700 ft [213 m] and a 45-mph [70 km/h] design speed results in a superelevation rate of 3 percent.

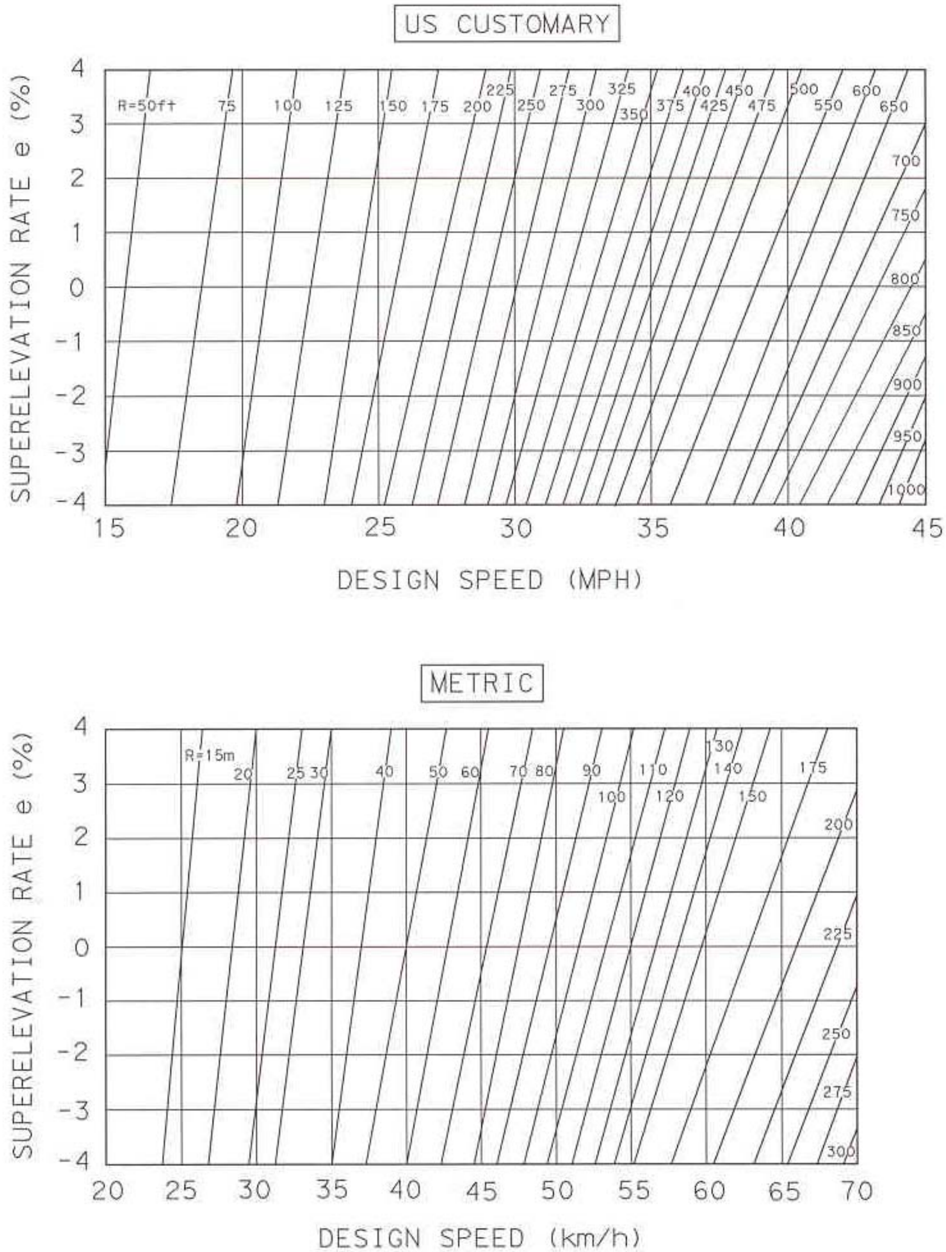


Figure 3-27. Relationship of Radius, Superelevation Rate, and Design Speed for Low-Speed Urban Street Design (Reproduction of Roadway Design Manual Figure 2-2 <link>).

♦ *Step 3: Determine superelevation transition lengths.*

From the *Roadway Design Manual*, the length of superelevation transition for these design parameters is 125 ft [38 m] (see Table 3-14), although note 1 of that table states that the length should be increased by a factor based on the number of lanes. The transition length as adjusted for the number of lanes (2.5) is 312 ft [95 m]. The adjustment factor was based on rotating the five-lane section about the centerline. On many urban streets the section is rotated about the gutter elevation on the inside of the curve, which would have resulted in a factor of 5.

In general, two-thirds of the transition takes place on the tangent, with the remaining one-third of the transition occurring within the horizontal curve, as illustrated in Figure 2-1 of the *Roadway Design Manual* <link>. Figure 3-28 shows the placement of the superelevation transition on Elm Street.

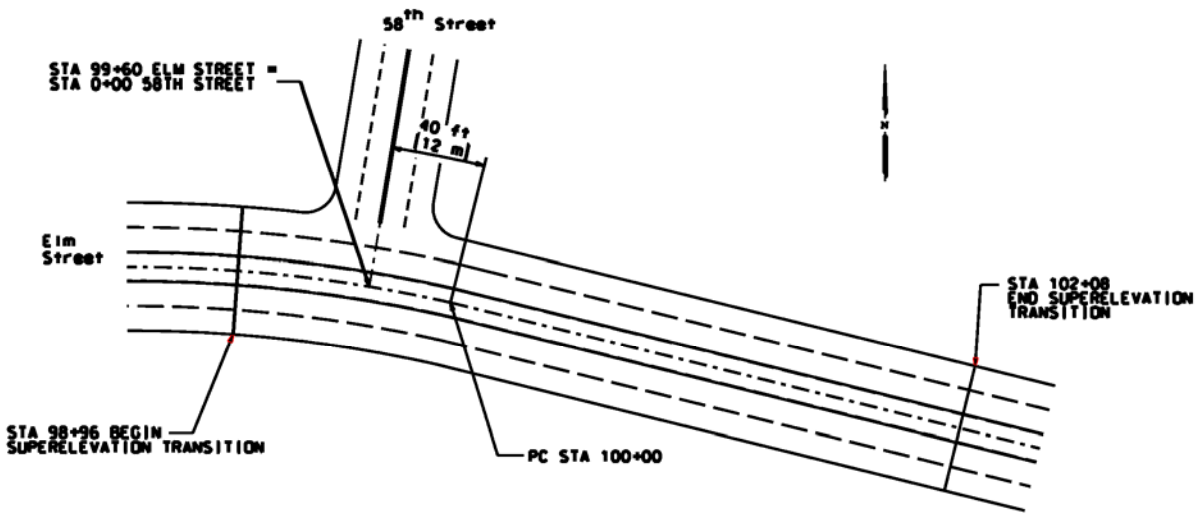


Figure 3-28. Layout Showing Superelevation Transition Placement.

- *Step 4: Tie superelevation on Elm with grade on 58th Street.*

The beginning and end of the superelevation transition should be adjusted so that the intersection falls within an area where the superelevation cross slopes can be made to match the grade of the intersecting roadway. If this is not possible, the *Roadway Design Manual*[1] allows for grade changes without vertical curves as long as the algebraic difference in grade does not exceed 1 percent. With this in mind, the superelevation transition can be placed such that the algebraic difference between the grades of the centerline of the minor road at the intersection with the major road and the cross slope of the major road is less than 1 percent.

As designed, the profile of 58th Street is shown in Figure 3-29. The change in grade of the 58th Street profile is 1 percent as it crosses the centerline of Elm Street. A small change in the beginning point for the superelevation transition could reduce this grade change, resulting in a smoother profile for 58th Street. By beginning the Elm Street superelevation transition earlier, the grade change at the centerline of Elm Street can be reduced. The revised superelevation layout is shown in Figure 3-30. The improved profile of 58th Street is shown in Figure 3-31, with a smaller grade change of 0.7 percent.

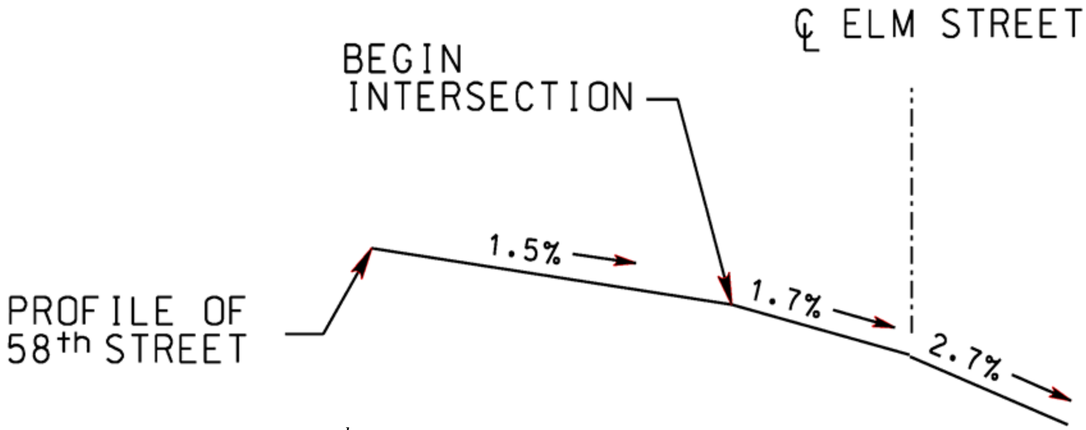


Figure 3-29. Profile of 58th Street as It Meets Elm Street's Cross Slope.

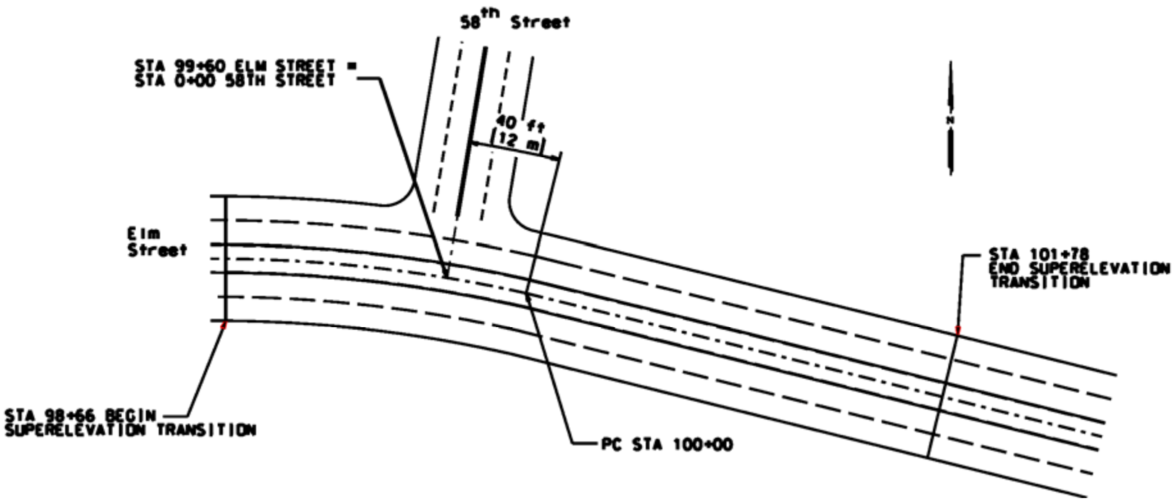


Figure 3-30. Revised Layout of Superelevation Transition.

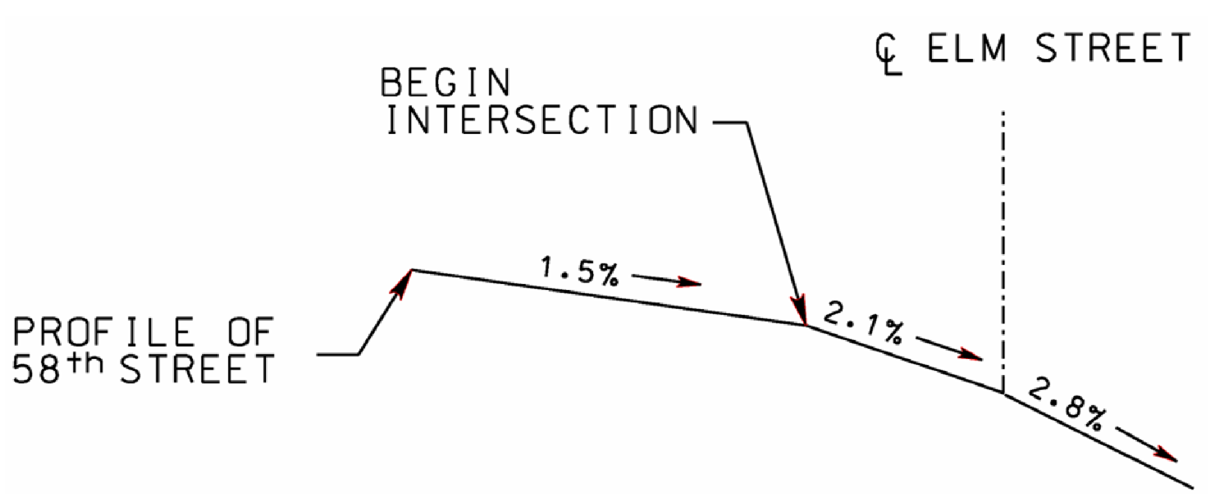


Figure 3-31. Revised Profile of 58th Street as It Meets Elm Street's Cross Slope.

- *Step 5: Design intersection cross section of 58th Street.*

Since the drainage design chosen was to warp the 58th Street cross section to meet the grades on Elm Street, the cross section of 58th Street will be controlled by this design. Elevations must be cal

culated at the north edge of pavement of Elm Street to establish the controlling elevations for 58th Street (see Figure 3-32).

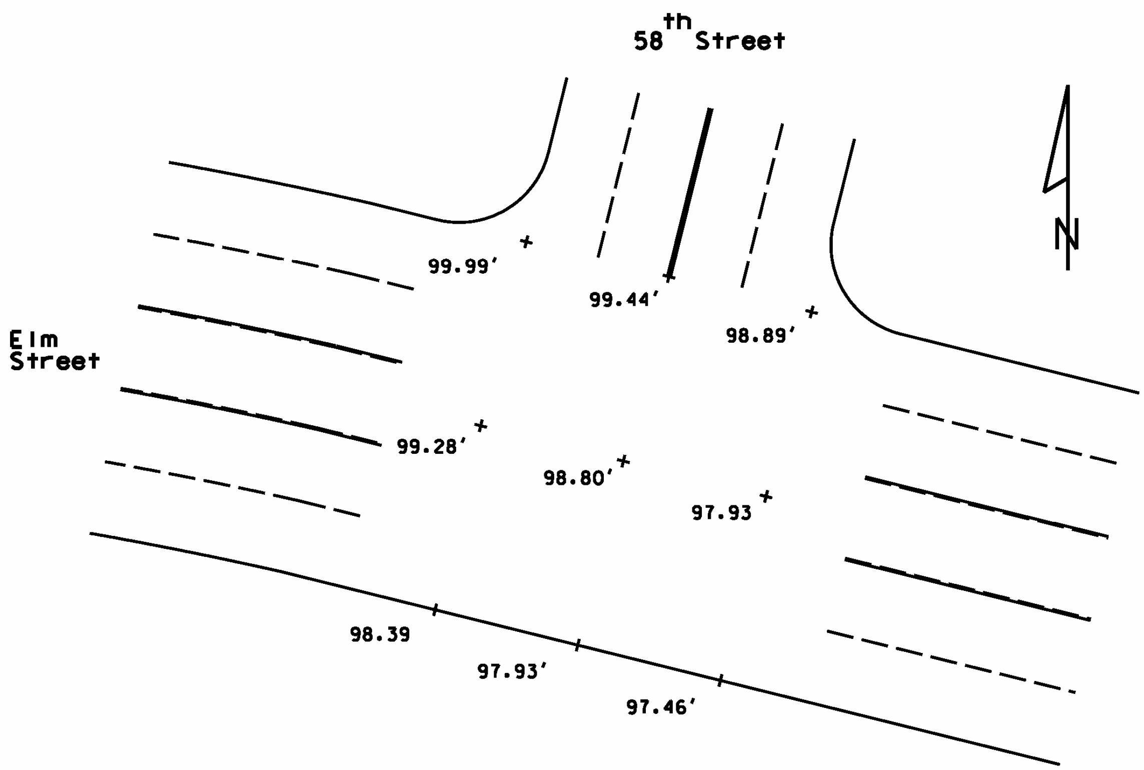


Figure 3-32. Elevations in Intersection.

These elevations can then be used to establish a cross section of 58th Street directly as it intersects with Elm Street (shown in Figure 3-33). Fifty-eighth Street's typical cross section next must be transitioned to meet the proposed cross section at Elm Street.

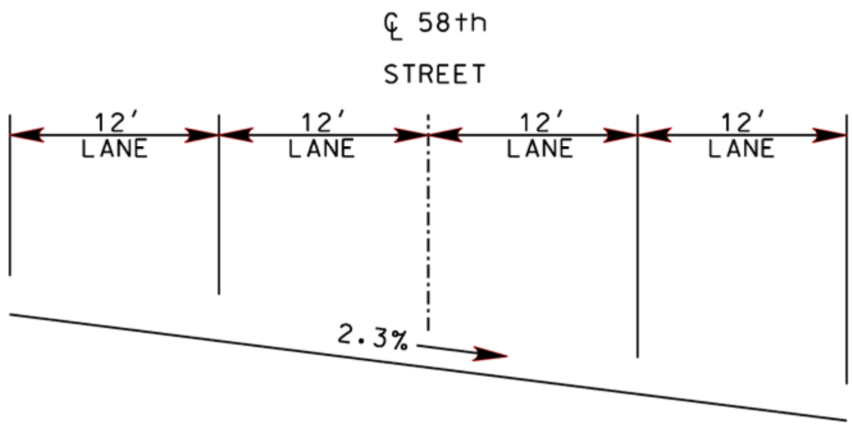


Figure 3-33. Cross Section of 58th Street Entering Intersection (STA 0+31).

Table 3-15 shows how the cross sections on 58th Street were modified to meet the grades on Elm Street. Note how the cross slopes are modified from a typical slope at STA 3+00 to the controlling slopes at STA 0+31.0.

Table 3-15. Cross Sections of 58th Street.

STA	West EOP (ft)	Cross Slope	CL Elevation (ft)	Cross Slope	East EOP (ft)	Remarks
3+00	104.32	-2.0%	104.80	-2.0%	104.32	
2+00	102.66	-0.6%	102.81	-2.1%	102.30	
1+00	101.08	1.1%	100.81	-2.2%	100.28	
0+31	**99.99**	**2.3%**	**99.44**	**-2.3%**	**98.89**	**Gutter**
0+00	*99.28*	*2.0%*	*98.80*	*-2.0%*	*98.32*	Centerline Intersection
0-31	98.39	1.9%	97.93	-2.0%	97.46	Gutter

- *Step 6: Contour area and review for drainage issues.*

Once the profiles, cross sections, and transition areas have been designed, the intersection and curve can be drawn with contour lines to aid in the review process. An illustration of the contoured area (as shown in Figure 3-34) can greatly aid in the identification of errors or problematic drainage areas. It is also generally a good idea to provide this contour layout in the Plans, Specifications, and Estimates (PS&E) to be sure the grading plan is clearly communicated to the contractor.

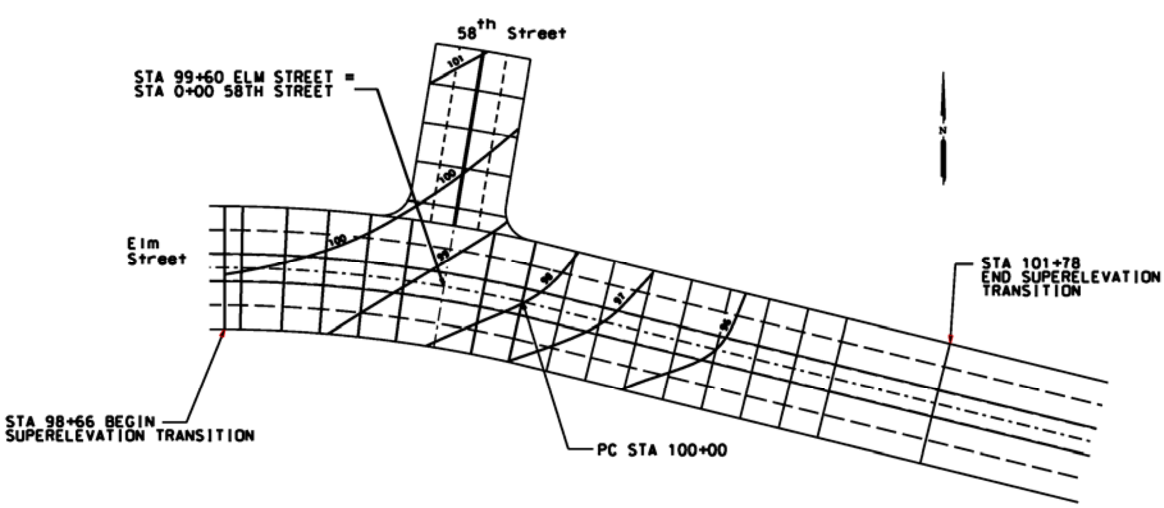


Figure 3-34. Contour of Intersection.

Application 10
Right-Turn Radius Selection Influences

Overview

The design of the right-turn radii is affected by a number of issues, including:

- design vehicle,
- available right of way,
- intersection skew,
- use of free-flow right-turn lanes or deceleration/acceleration lanes,
- desired presence of islands,
- pedestrian facilities, and
- desired turning vehicle speed.

The *Urban Intersection Design Guide*, Chapter 3, Section 3 <link> provides information on turning radius.

Background

An exploration of the impacts of the above factors will be undertaken to show their influence on the design of a major intersection. The primary variables used in the evaluation are shown in Table 3-16.

Table 3-16. Design Variables Used in Example.

Variable	Range of Values
Design Vehicle	WB-50 [WB-15]
Intersection Angle	90 deg (no skew) 75 deg (15-deg skew)
Corner Radii	100 ft [30 m] 60 ft [18 m] Simple curve radius with taper 50 ft [15 m] 30 ft [9 m]

This application uses turning templates to approximate the wheel paths of the vehicle. Simulation software such as AutoTURN or IGIDS can be used to better customize the turning path to the geometry present at an intersection.

The variables in Table 3-16 will be used to show their influence on the design of the intersection, including influences on turning vehicle speed, pedestrian facilities, and the desirability of including corner islands.

The selection of the design vehicle for an intersection should be made after consideration of the vehicle mix that is projected to use the facility. For more information regarding design vehicle selection, see *Roadway Design Manual* Chapter 7, Section 7 <link>. When determining the appropriate design vehicle at a specific location, it is advisable to check the Statewide Traffic and Recording System (STARS) to determine the types of vehicles (i.e., vehicle classification) actually present at a given location. The data are available from the Transportation Planning and Programming Division (TPP).

The WB-50 [WB-15] truck is used in this application, although other design vehicles are appropriate in other circumstances. Passenger cars would be capable of traversing the designs created for a WB-50 [WB-15] truck; therefore their turning paths are not included on the figures for clarity. It is noted that the choice of a WB-50 [WB-15] truck as a design vehicle is not appropriate for many locations, and its use as a design vehicle may undesirably affect intersection designs with regard to pedestrian facilities (i.e., crossing distance and vehicle turning speed) and the layout of the resulting intersection design (i.e., island use may not be an option and a large poorly defined paved area may result).

The designs shown share the following dimensions:

- Outside, or curb, lanes: 12 ft [3.7 m]
- Curb offset: 2 ft [0.6 m]
- Inside lanes (if present): 12 ft [3.7 m]

Proposed Designs

100-ft [30 m] Radius, WB-50 Design Vehicle. Figure 3-35 shows a design using a 100-ft [30 m] radius with the turning template of a WB-50 [WB-15] truck. The truck is able to turn right without infringing on other lanes of the original or receiving roadway. It is apparent that the use of a large simple radius, while effective at allowing the truck to turn without infringing on other lanes, results in a very large, poorly defined intersection area. The turning path shown in Figure 3-35 shows that the radius could be reduced while still allowing the design vehicle to complete the right turn.

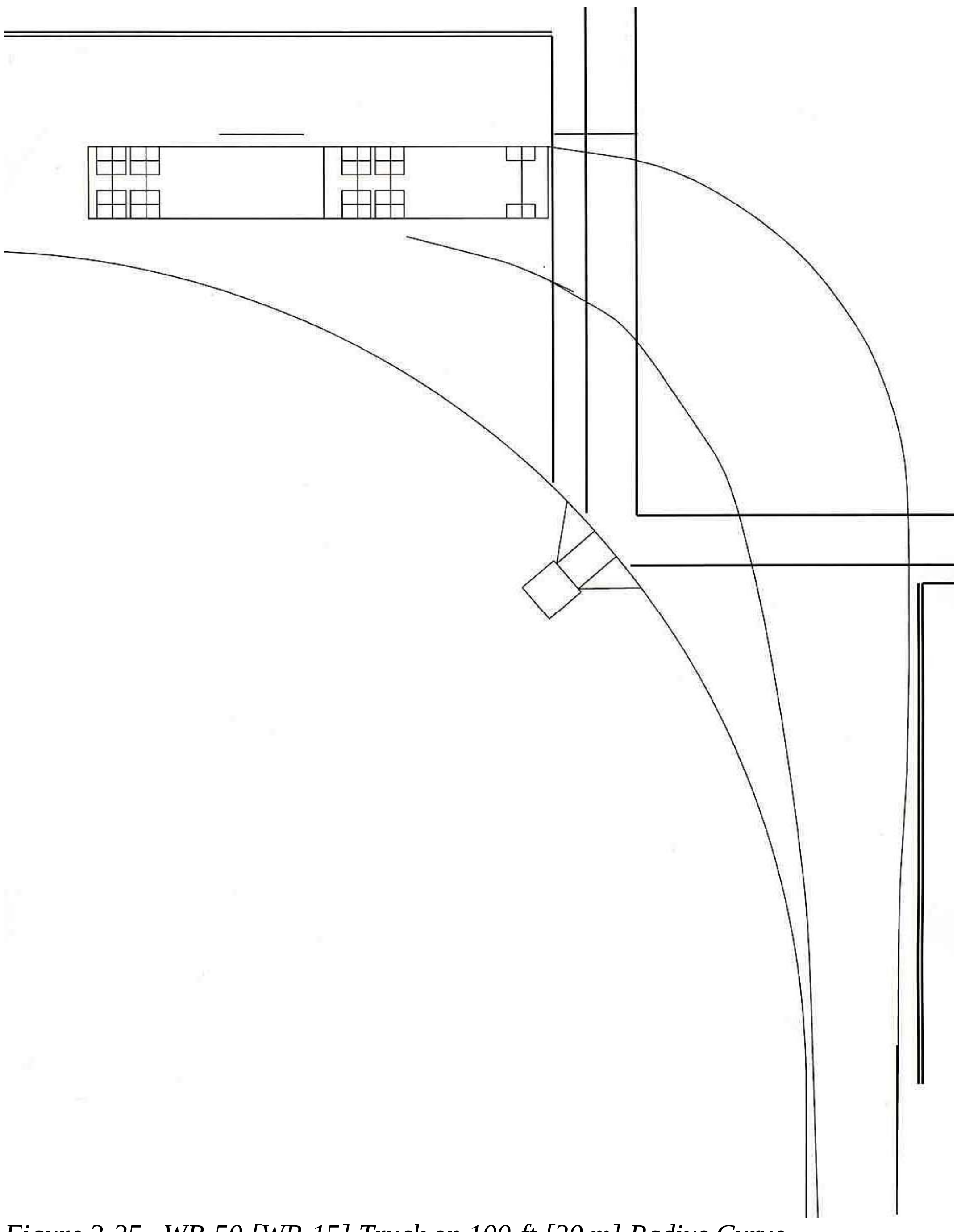


Figure 3-35. WB-50 [WB-15] Truck on 100-ft [30 m] Radius Curve.

Figure 3-36 shows the design as modified by the inclusion of an island. The use of the island provides better definition for the intersection, by channelizing the traffic. The islands also provide refuge for pedestrians and locations for traffic control devices. The island is shown with a cut-through pedestrian path rather than curb ramps because the island is too small to allow the necessary 5 ft by 5 ft [1.5 m by 1.5 m] landing area at the top of the ramps.

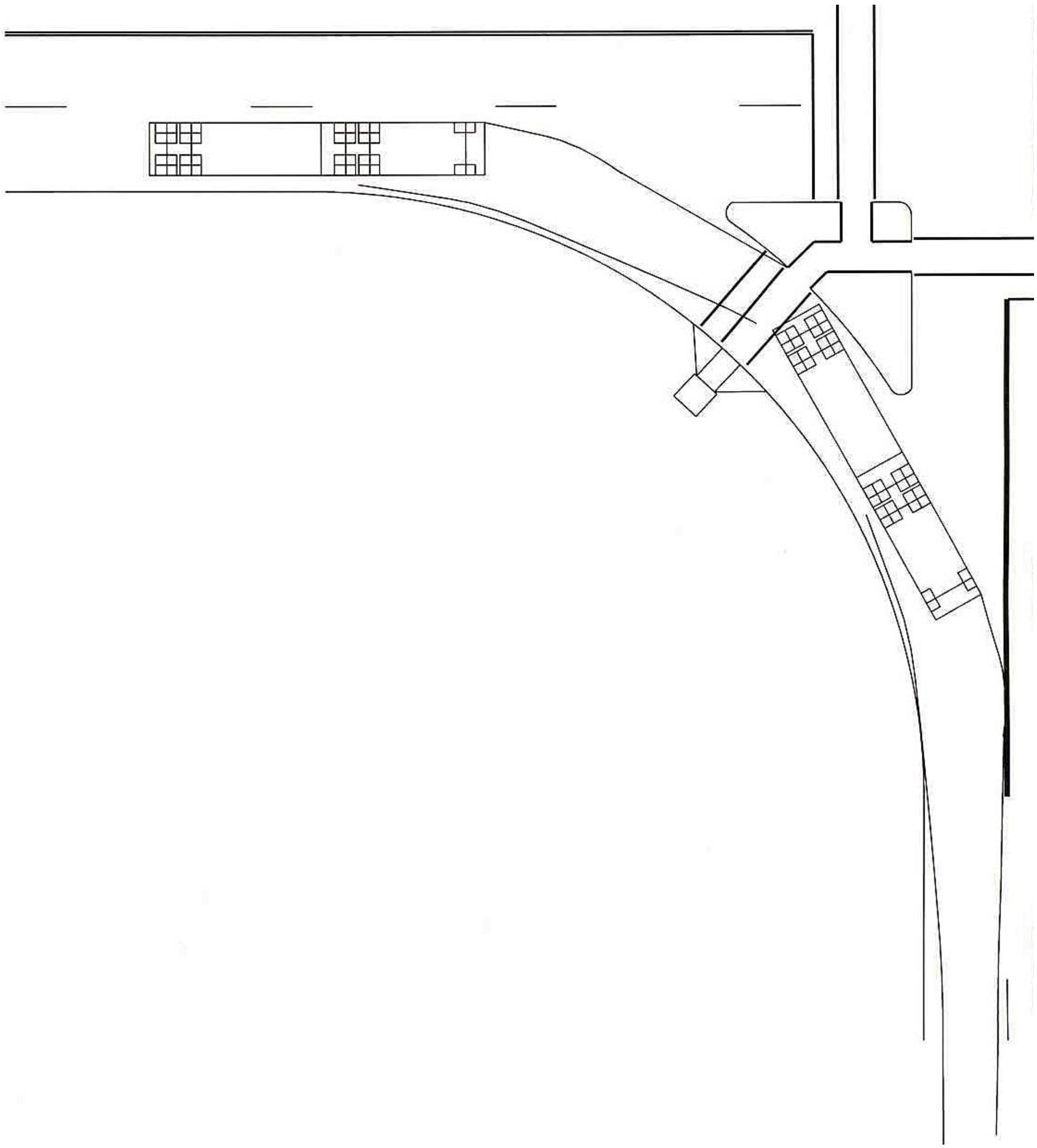


Figure 3-36. WB-50 [WB-15] Truck on 100-ft [30 m] Radius Curve with Island.

Passenger car turning speeds on the roadways shown in Figure 3-35 and Figure 3-36 can be predicted using equations developed as part of TxDOT Project 4365-4[2] and are included in the *Urban Intersection Design Guide*, Chapter 3, Section 3 <link>. These equations include consideration of channelization present, and corner radius, length of right-turn lane, and width of right-turn lane. In this example, the corner radius is 100 ft [30 m], the width of the right-turn lane is 12 ft [3.7 m], and an island is assumed to be built. The length of the right-turn lane has yet to be determined for this example, and so the average length used to generate the original equations (193 ft [59 m]) was used to predict the speed of the passenger car at the beginning and near the middle of the right turn.

Speed at the beginning of the turn:

$$V85BT = 17.50 - 1.00\ Chan + 0.10\ CR - 0.006\ Len + 0.13\ Wid$$

$$V85BT = 17.50 - 1.00\ (0) + 0.10\ (100) - 0.006\ (193) + 0.13\ (12)$$

$$V85BT = 27\ \text{mph}\ [43\ \text{km/h}]$$

Where:

V85BT = 85th percentile free-flow speed near the beginning of the right turn (mph)
Chan = channelization present at site, Chan = 0 for islands and 1 for lines
CR = corner radius (ft)
Len = length of right-turn lane (ft)
Wid = width of right-turn lane at start of right turn (ft)

[2] Fitzpatrick, K., and W.H. Schneider IV. *Turn Speeds in Right-Turn Lanes*. FHWA/TX-05/4365-4. September 2004.

Speed near the middle of the turn:

$$V85MT = 13.03 + 0.23\ Chan + 0.06\ CR – 0.01\ Len + 0.40\ Wid$$
$$V85MT = 13.03 + 0.23\ (0) + 0.06\ (100) – 0.01\ (193) + 0.40\ (12)$$
$$V85MT = 22\ mph\ [35\ km/h]$$

Where:

V85MT = 85th percentile free-flow speed near the middle of the right turn (mph)
Chan = channelization present at site, Chan = 0 for islands and 1 for lines
CR = corner radius (ft)
Len = length of right turn lane (ft)
Wid = width of right-turn lane at start of right turn (ft)

For this example, the 85th percentile speed of turning vehicles at the start of the turn would be 27 mph [43 km/h] slowing to 22 mph [35 km/h] near the middle of the turn.

Although recommended limits for vehicle turning speeds in various environments have not been established, it has been found that survival rates of pedestrians struck by motor vehicles are much higher if vehicle speeds are reduced.[3] Eighty percent of pedestrians are killed when struck by motor vehicles traveling 35 to 45 mph [56 to 72 km/h]; only 5 percent are killed at speeds of 18 mph [29 km/h]. Stopping sight distance for 20 mph [32 km/h] is 115 ft [35 m].[1] Because of the potential for vehicle-pedestrian conflicts at an intersection, this stopping distance is relatively high. If the turning speed were reduced by one-fourth to 15 mph [24 km/h], the stopping sight distance would be 80 ft [24 m], a 30 percent reduction.

The use of corner islands would be desirable with respect to reducing crossing distances and providing refuge areas, although drivers of WB-50 [WB-15] trucks would have to exercise care to avoid over-running the curb. The turning speeds of passenger cars would remain an issue.

[3] *Killing Speed: Saving Lives*. Department of Transport, London, United Kingdom, 1992.

60-ft [18 m] Simple Curve Radius with Taper. Figure 3-37 shows a design using a 60-ft [18 m] simple radius with a 4-ft [1.2 m] taper and a 1:15 taper (see Figure 7-7 in the *Roadway Design Manual* <link> for an example of the pavement edge geometry for this type of design). As shown in the figure, this design more closely approximates the turning path of the WB-50 [WB-15] truck, reducing the amount of paved area in the intersection and the crossing distance for pedestrians. The turning speed would be reduced by the smaller corner radius (60 ft [18 m]), with a predicted midturn speed of 19 mph [31 km/h] and a beginning turn speed of 24 mph [39 km/h].

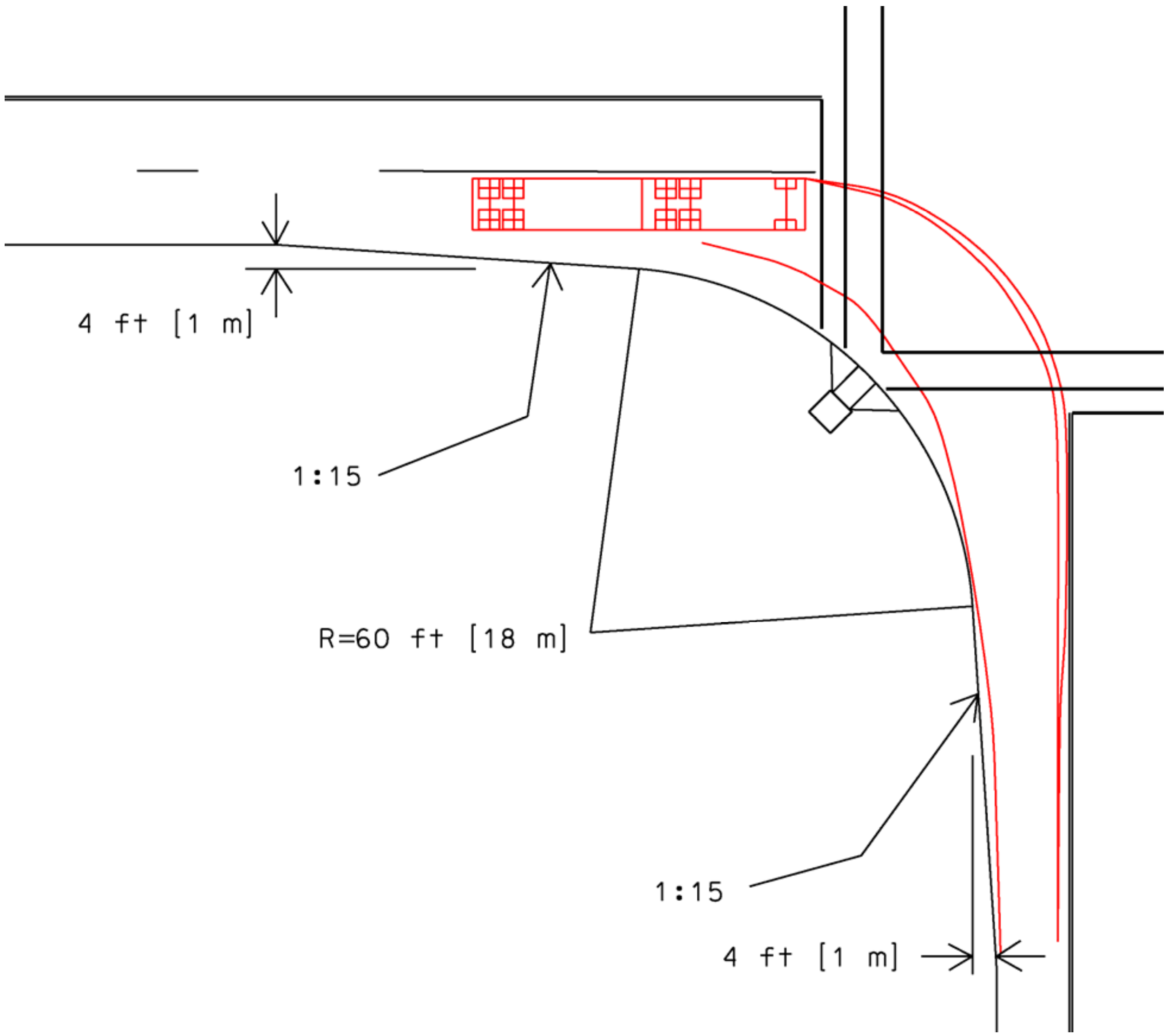


Figure 3-37. WB-50 [WB-15] on 60-ft [18 m] Radius with Taper.

50-ft [15 m] Radius, WB-50 [WB-15] Design Vehicle. Figure 3-38 shows a design using a 50-ft [15 m] radius with the turning template of a WB-50 [WB-15] truck. The truck is able to turn right only by infringing on the opposing lane of the receiving roadway by approximately 4 ft [1.2 m], yielding an unacceptable design.

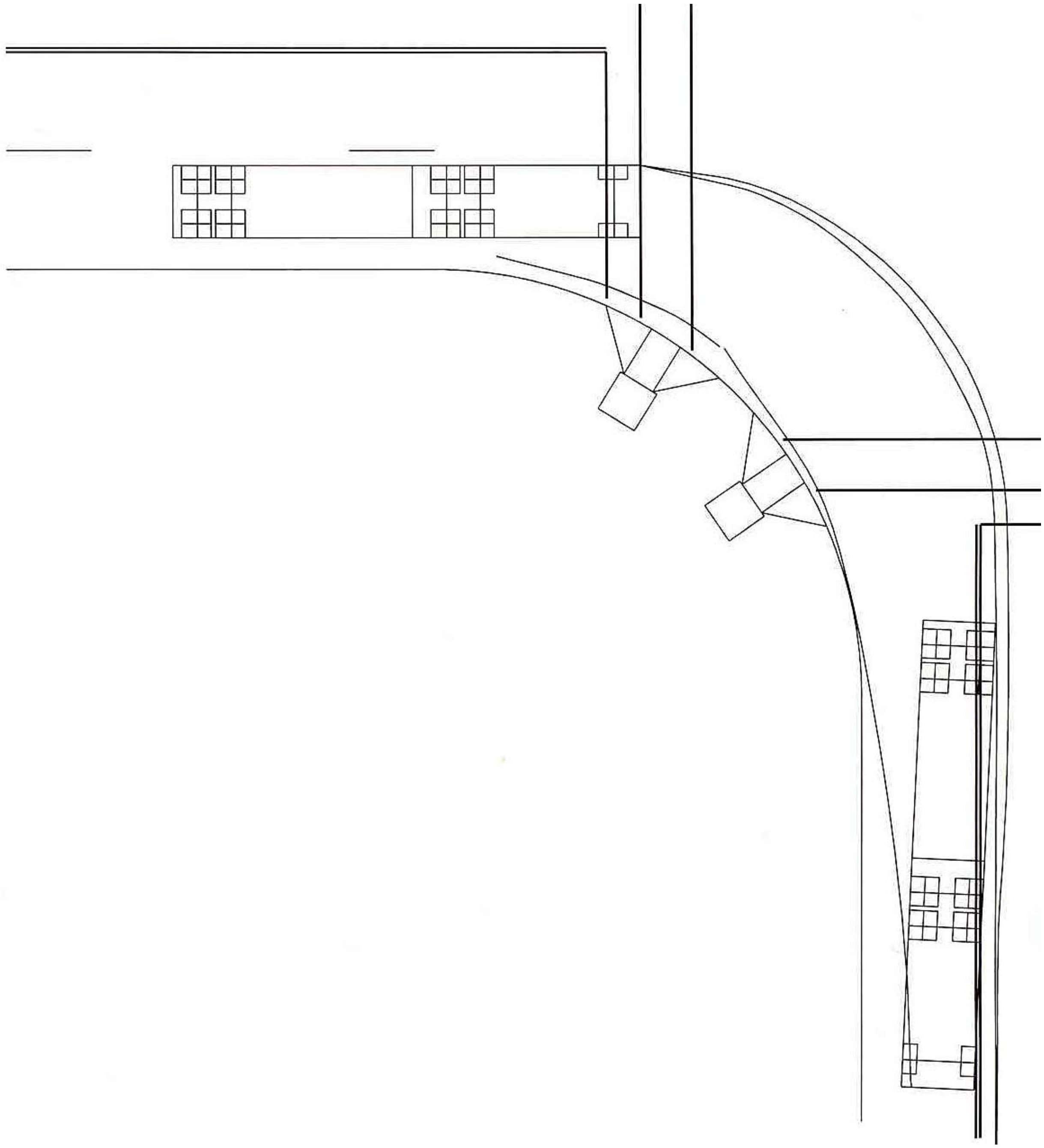


Figure 3-38. WB-50 [WB-15] on 50-ft [15 m] Radius.

If the receiving roadway has more than one lane per direction, trucks may normally encroach onto an adjacent lane traveling in the same direction with little impact on operations. Texas law states that vehicles turning right must stay as close as practicable to the right-hand curb or edge of the roadway. Figure 3-39 shows the truck turning into the inside lane of a four-lane cross street, an acceptable design.

The predicted turning speed of passenger vehicles near the middle on this right-turn radius is 18 mph [29 km/h]. The intersection area is still fairly large, and pedestrians would again have a long crossing distance.

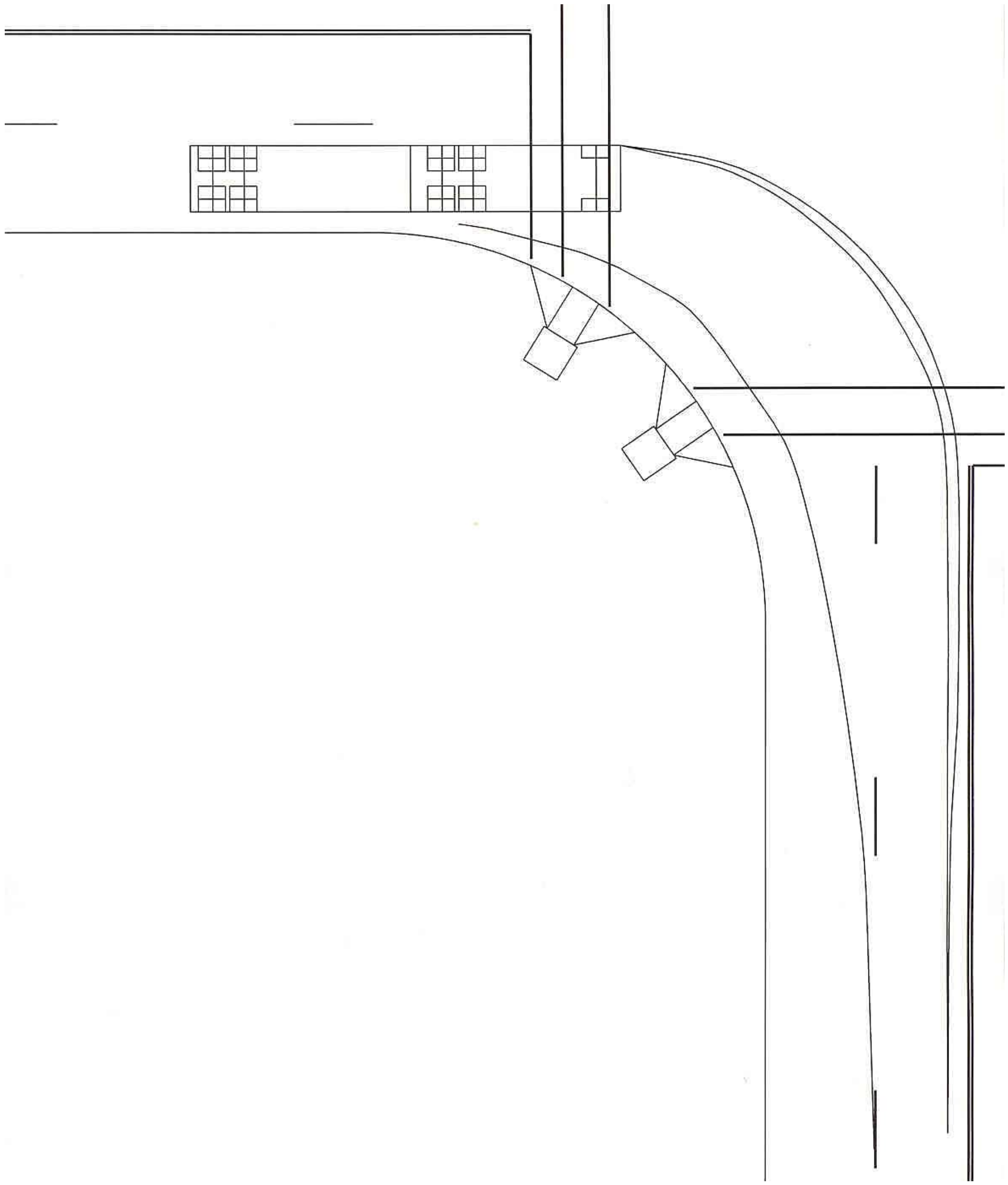


Figure 3-39. WB-50 [WB-15] on 50-ft [15 m] Radius Curve with Four-Lane Crossroad.

30-ft [9 m] Radius, WB-50 Design Vehicle. Figure 3-40 shows a design using a 30-ft [9 m] radius curve and a WB-50 [WB-15] truck. The truck is not able to negotiate the curve without entering the oncoming lane of the receiving roadway, therefore, the design is unacceptable.

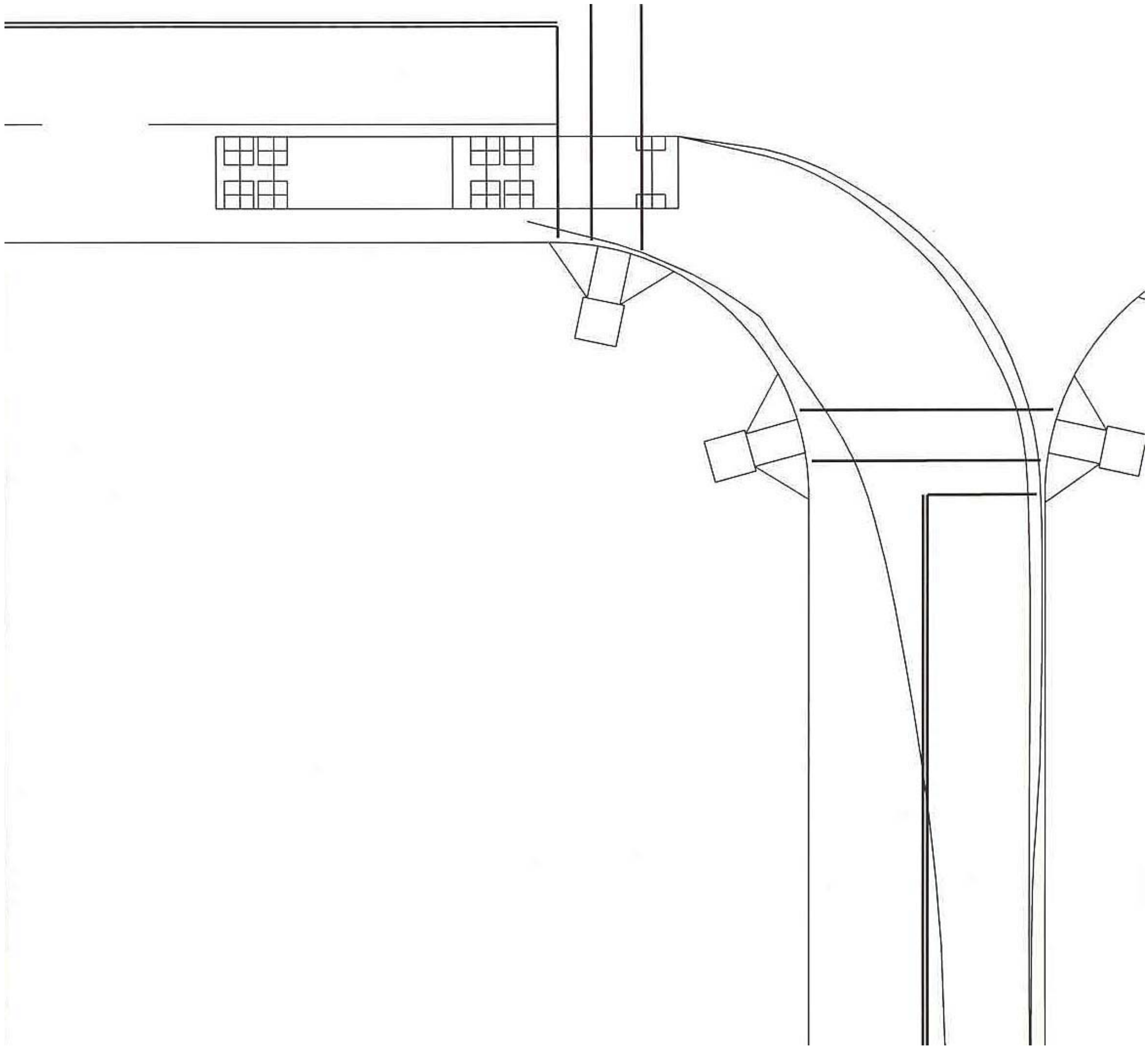


Figure 3-40. WB-50 [WB-15] on 30-ft [9 m] Radius Curve with Two-Lane Crossroad.

Figure 3-41 shows a design that also uses a 30-ft [9 m] radius curve and a WB-50 [WB-15] truck. Instead of a two-lane crossroad, a four-lane crossroad is shown. The truck is able to turn into the inner lane without encroaching into oncoming lanes although the turn would require optimal positioning by the driver.

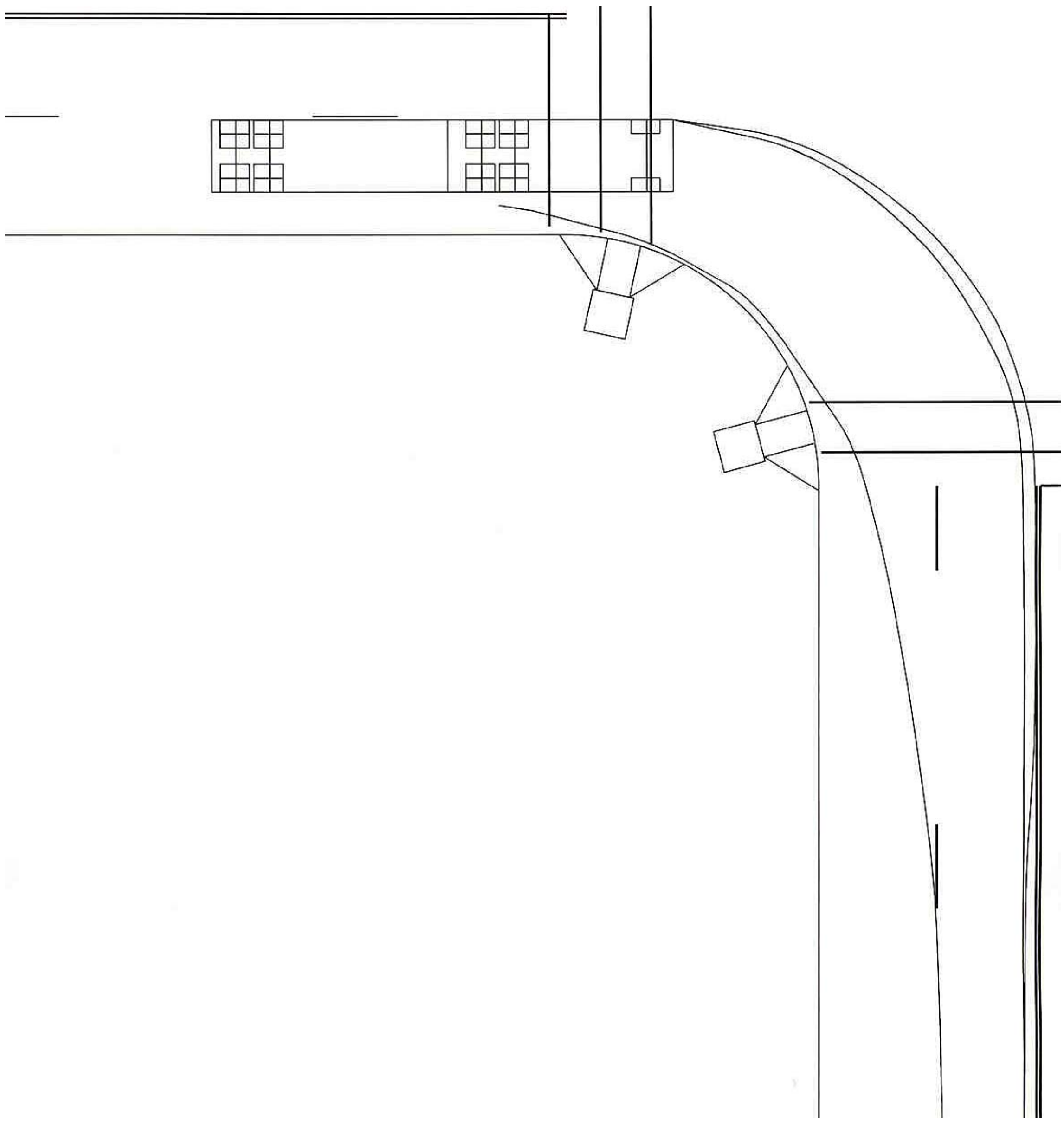


Figure 3-41. WB-50 [WB-15] on 30-ft [9 m] Radius Curve with Four-Lane Crossroad.

100-ft [30 m] Radius, WB-50 [WB-15] Design Vehicle, 15-deg Skew. Figure 3-42 shows a WB-50 [WB-15] truck turning template on a 100-ft [30 m] radius curve in an intersection with a 15-deg skew. Because of the skew, truck-turning capability must be reviewed at both corners A and B. Both corners are negotiable by the design vehicle; however, the intersection design is not optimal because of the large size of the intersection. Passenger car turning speeds would be predicted to be 22 mph [35 km/h], which is higher than desired for pedestrians. It is noted that the equations used to predict speed in this example are not sensitive to turning angle; it appears likely that the speeds on corner B could be even greater because the vehicles do not turn through 90 deg.

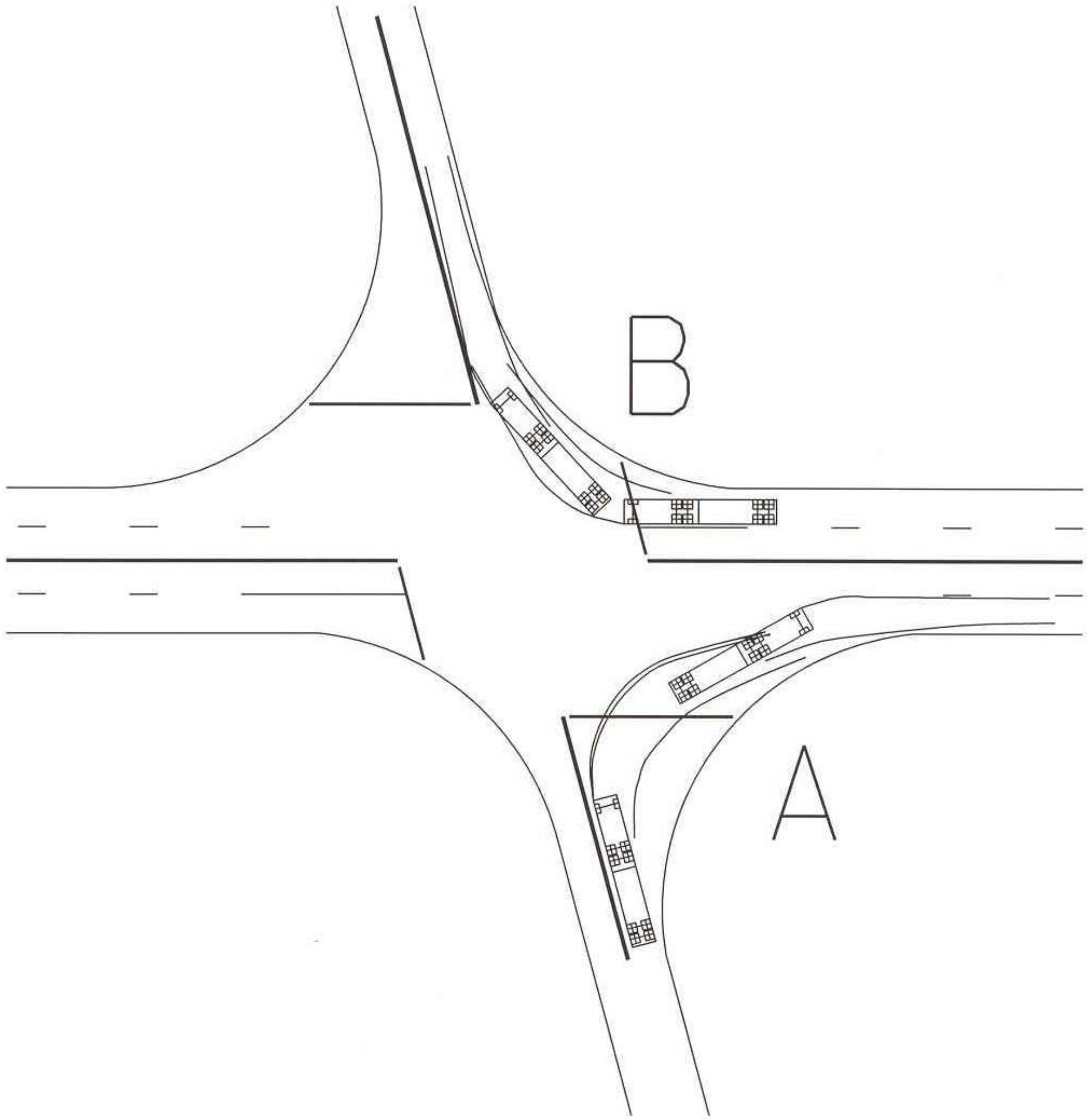


Figure 3-42. WB-50 [WB-15] on 100-ft [30 m] Radius Curve with 15-deg Skew (Pedestrian Elements Not Shown).

When crosswalk markings are added to the intersection in Figure 3-43, the design becomes more difficult to complete. According to the *TMUTCD*, stop lines must be placed no more than 30 ft [9 m] from the nearest edge of the intersecting roadway, and must be parallel to and 4 ft [1.2 m] in advance of any crosswalk markings present. Figure 3-43 shows the stop lines and crosswalk markings at the *TMUTCD* limits. As shown in corner A of the figure, it would not be possible to satisfactorily mark the crosswalk without infringing on those requirements.

Other possibilities for the intersection that could be investigated include the use of smaller curve radii on corner A, and the use of alternative corner designs such as a simple curve radius with taper or compound curves. The use of these alternative designs might alleviate the problems shown in Figure 3-43.

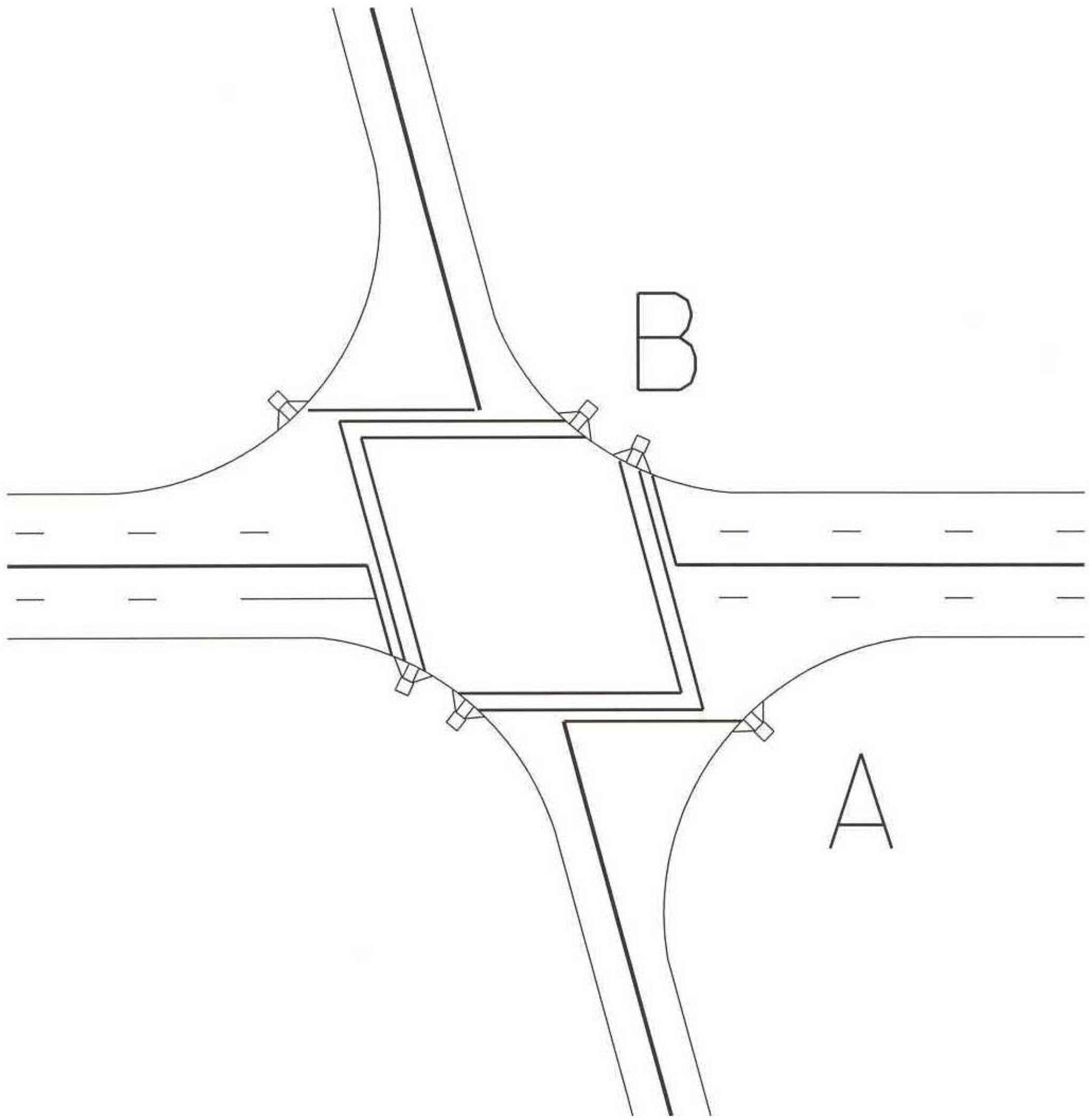


Figure 3-43. WB-50 [WB-15] on 100-ft [30 m] Radius Curve with 15-deg Skew for Pedestrian Elements and Stop Lines Shown.

Figure 3-44 shows a WB-50 [WB-15] truck turning template on the same skewed intersection, but islands have been added to provide channelization. The presence of the islands greatly reduces the area of the intersection and allows the appropriate placement of crosswalks and stop lines.

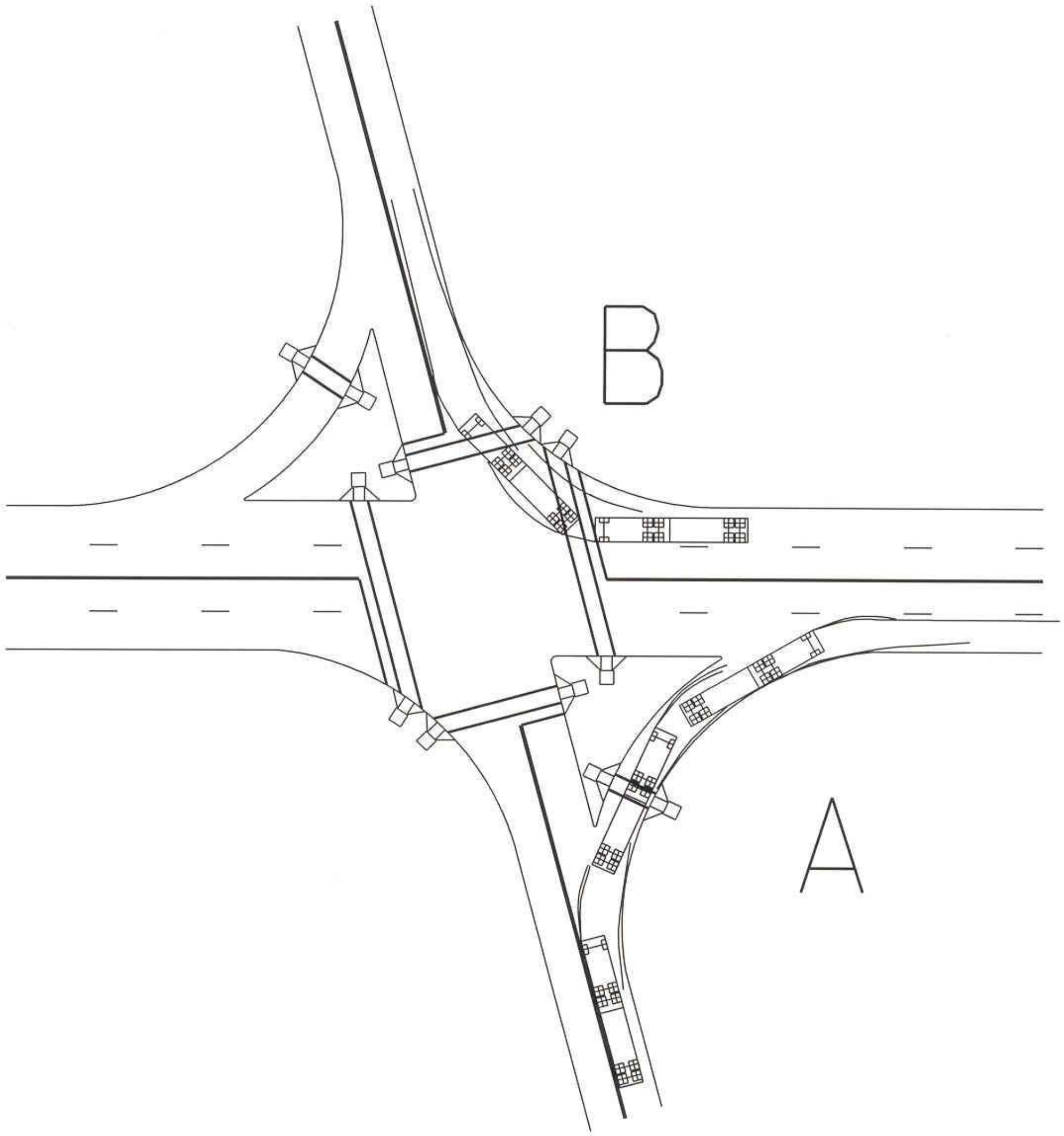


Figure 3-44. Use of Islands on 100-ft [30 m] Radius Curve with 15-deg Skew.

Chapter 4
Cross Section

Contents:

Application 1

Lane Drop After Intersection

Overview

Discussion on dropping a lane after an intersection is presented in the *Urban Intersection Design Guide,* Chapter 4, Section 1 <link>. Lanes may be dropped after intersections because of reduced volumes on succeeding roadway segments or because of the limits of a particular project. If an overall corridor is being provided with an increased number of through lanes but the construction is in segments, it may be more efficient to construct the end intersections using the "final" section and drop the additional lanes after the intersection. This can allow future construction projects to avoid performing work in the intersection.

Background

Problem. Birch Street is being expanded to three through lanes, with the project ending just east of its intersection with 13th Street. The project will end past 13th Street to avoid reconstructing the intersection in a future construction project planned for 5 years hence. The design of the lane drop should consider the required separation distance from the intersection and the appropriate taper.

Known Information. Figure 4-1 illustrates the current intersection layout. The following is known:

- The existing median openings are designed using a 40-ft [12.2 m] radius.
- The existing right-turn radii are 20 ft [6.1 m].
- The intersection is signalized with a cycle length of 90 sec.
- Truck percentage on Birch St. is 14 percent.
- The area is a newly designated industrial development.
- Pedestrians are relatively few in number.
- Projected traffic volumes in vph, design speeds, and roadway classifications are shown in Figure 4-1.

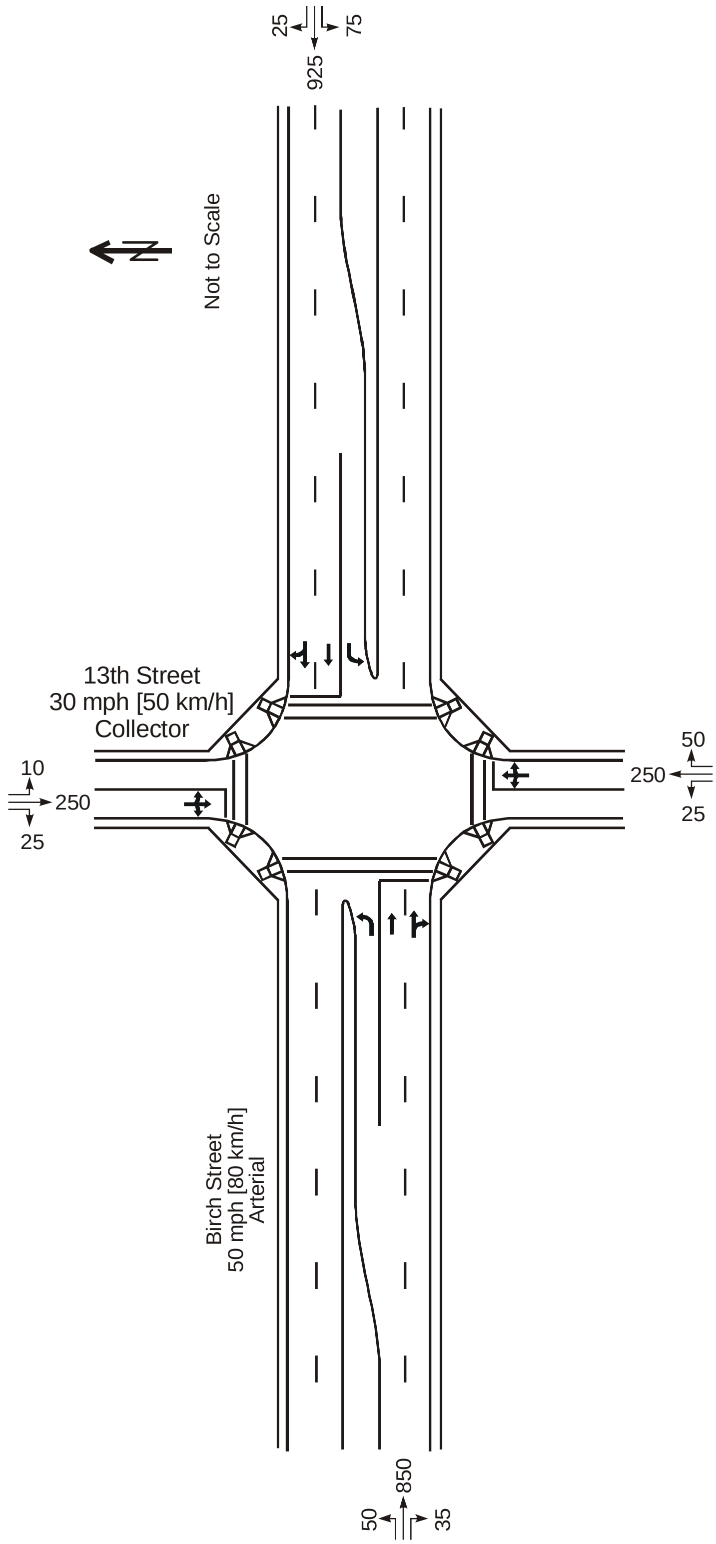
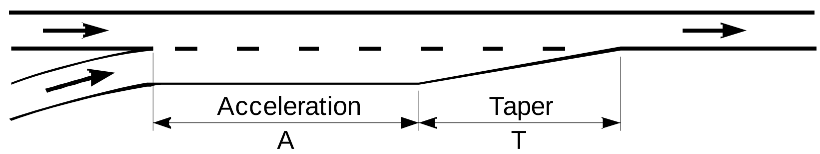


Figure 4-1. Existing Conditions.

Proposed Design. Following are the steps used to generate the proposed design for adding through lanes.

- *Step 1: Calculate taper length.*

The taper length on Birch Street is determined from Figure 3-10 of the *Roadway Design Manual* <link> (reproduced as Figure 4-2 in this document) and is determined by the design speed. From Figure 4-2, a taper length of 230 ft [70 m] is used with a design speed of 50 mph [80 km/h].



Highway Design Speed (mph)	Minimum Length of Taper T (ft)	Acceleration Length, A (ft) for Entrance Curve Design Speed (mph).								
		Stop Condition	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
		AND INITIAL SPEED (mph)								
		0	**14**	**18**	**22**	**26**	**30**	**36**	**40**	**44**
30	150	180	140	–	–	–	–	–	–	–
35	165	280	220	160	–	–	–	–	–	–
40	180	360	300	270	210	120	–	–	–	–
45	200	560	490	440	380	280	160	–	–	–
50	**230**	**720**	**660**	**610**	**550**	**450**	**350**	**130**	**–**	**–**
55	250	960	900	810	780	670	550	320	150	–
60	265	1200	1140	1100	1020	910	800	550	420	180
65	285	1410	1350	1310	1220	1120	1000	770	600	370
70	300	1620	1560	1520	1420	1350	1230	1000	820	580
75	330	1790	1730	1630	1580	1510	1420	1160	1040	780

Note:
Uniform 50:1 to 70:1 tapers are recommended where lengths of acceleration lanes exceed 1300 ft.
Lengths of Right-Turn Acceleration Lanes (US Customary).

Figure 4-2. Length of Right-Turn Acceleration Lanes[1] *(Reproduced from Roadway Design Manual Figure 3-10 <link>).*

- *Step 2: Calculate acceleration length.*

The acceleration distance from a stop condition with a design speed of 50 mph [80 km/h] is provided also in Figure 3-10 of the *Roadway Design Manual* <link> (see Figure 4-2 in this document). From Figure 4-2, acceleration length is 720 ft [219 m].

- *Step 3: Calculate storage length for left-turn lanes.*

The required storage may be obtained using an acceptable traffic model such as the latest version of the HCM software (HCS), SYNCHRO, VISSIM, or other acceptable simulation models as suggested in the *Roadway Design Manual*. Alternatively, the required storage

[1] Texas Department of Transportation. *Roadway Design Manual*. Revised April 2002. http://manuals.dot.state.tx.us/dynaweb/coldesig/rdw.pdf. Accessed September 2003.

length can be estimated according to the *Roadway Design Manual's* Table 3-3 (see Table 4-1 of this document) or with the following *storage length* equation:

L = (V/N)(2)(S)

Where:

L = storage length, ft

V = left-turn volume per hour, vph

N = number of cycles/hour for the traffic signal,

2 = factor that provides for all left-turning vehicles on most cycles; a value of 1.8 may be acceptable on collector streets;

S = queue storage length per vehicle, ft.

Table 4-1. Lengths of Single Left-Turn Lanes on Urban Streets[1]
(From *Roadway Design Manual* Table 3-3).

(US Customary)						
Speed (mph)	**Deceleration Length[A,B] (ft)**	**Taper Length (ft)**	**Storage Length[A]**			
			Signalized		**Non-Signalized**	
			Calculated	**Minimum[D]**	**Calculated[E]**	**Minimum[D]**
30	160	50	See footnote C	100	See footnote E	100
35	215	50	See footnote C	100	See footnote E	100
40	275	50	See footnote C	100	See footnote E	100
45	345	100	See footnote C	100	See footnote E	100
50	***425***	***100***	***See footnote C***	***100***	***See footnote E***	***100***
55	510	100	See footnote C	100	See footnote E	100
Metric						
Speed (km/h)	**Deceleration Length[A,B] (m)**	**Taper Length (m)**	**Storage Length**			
			Signalized		**Non-Signalized**	
			Calculated	**Minimum[D]**	**Calculated[E]**	**Minimum[D]**
50	50	15	See footnote C	30	See footnote E	30
60	65	15	See footnote C	30	See footnote E	30
70	85	30	See footnote C	30	See footnote E	30
80	***105***	***30***	***See footnote C***	***30***	***See footnote E***	***30***
90	130	30	See footnote C	30	See footnote E	30

[A]The minimum length of a left-turn lane is the sum of the deceleration length plus queue storage. In order to determine the design length, the deceleration plus storage length must be calculated for peak and off-peak periods; the longest total length will be the minimum design length.

[B]See Deceleration Length discussion immediately following Table 3-3.

[C] ***See Storage Length Calculations discussion immediately following Table 3-3A.***

[D] ***The minimum storage length shall apply when: 1) the required queue storage length calculated is less than the minimum length, or 2) there is no rational method for estimating the left-turn volume.***

[E]The calculated queue storage at unsignalized location using a traffic model or simulation model or by the following:

L=(V/30)(2)(S)

Where: (V/30) is the left-turn volume in a two-minute interval and other terms are as defined in the Storage Length Calculations discussion immediately following Table 3-3A.

The storage length of vehicle, S, is determined by the percentage of trucks. The *Roadway Design Manual* provides the following:

% of Trucks	*S, ft [m]*
<5	25 [7.6]
5 to 9	30 [9.1]
10 to 14	**35 [10.7]**
15 to 19	40 [12.2]

Because the percent trucks on Birch Street is 14 percent, S is determined to be 35 ft [10.7 m]. The number of cycles per hour is determined by the cycle length used at the intersection. There are 40, 90-sec cycles in one hour (3600 sec/90 sec = 40 cycles).

Eastbound Birch Street Through Lanes. Because the through (and right-turn) traffic will now be distributed over three lanes, for the eastbound direction the traffic, volume per lane is given by:

$V = (V_{Thru} + V_{Rt})/NL$

Where:

V = traffic volume per hour per lane, vphpl

V_{Thru} = through traffic volume, vphpl

V_{Rt} = right-turn traffic volume, vphpl

NL = number of lanes

Substituting in the equation:

$V = (850 + 35)/3$

$V = 295$ vphpl

Substituting in the storage equation to obtain the expected queue length for the through lanes (and the through/right-turn lane):

L = (295 vph/40)(2)(35)

L = 516 ft [157 m]

Westbound Birch Street Through Lanes. Traffic volume per lane for westbound Birch Street is given by:

$V = (925 + 25)/3$

$V = 320$ vphpl

Substituting in the *storage length* equation to obtain the expected queue length for the through lanes (and the through/right-turn lane):

L = (320 vph/40)(2)(35)

L = 560 ft [171 m]

- *Step 4: Calculate storage length for left-turn lane.*

The storage length of the left-turn lane is also determined by the *storage length* equation:

L = (V/N)(2)(S)

Eastbound Birch Street Left-Turn Lane. From the traffic volumes in Figure 4-1, the left-turn volume is 50 vph. Substituting in the equation:

L = (50/40)(2)(35)

L = 88 ft [27 m]

This length is less than the minimum queue length of 100 ft [30 m] shown in Table 4-1 (which is a reproduction of Table 3-3 of the *Roadway Design Manual* *<link>)*, and less than the storage length determined for the through lanes (516 ft [157 m]). Therefore, the left-turn storage length should be increased. By increasing the storage length to match that of the through lanes, the through-lane queue should not block the entrance to the left-turn lane.

Westbound Birch Street Left-Turn Lane. From the traffic volumes in Figure 4-1, the left-turn volume is 75 vph. Substituting in the equation:

L = (75/40)(2)(35)

L = 131 ft [40 m]

This length is greater than the minimum queue length of 100 ft [30 m], but less than the storage length for the through lanes (560 ft [171 m]). Therefore, the left-turn storage length should be increased to match that of the through lanes.

- *Step 5: Determine taper and deceleration length for left-turn lane.*

The taper length for the left-turn lanes on Birch Street is shown in Table 4-1 as 100 ft [30 m] using the design speed of 50 mph [80 km/h]. The deceleration length is also provided in Table 4-1; the length given is 425 ft [130 m].

- *Step 6: Provide dimensions for lane lengths.*

The proposed design for the addition of the through lane on each of the Birch Street approaches along with the left-turn lane is shown in Figure 4-3.

- *Step 7: Select right-turn radius and median-turn radius.*

The radii used in the intersection design shown in Figure 4-3 were selected with regard to the location and traffic mix found at the site. Because the site is in an industrial area with high truck volumes and low pedestrian volumes, relatively large radii were used. A WB-50 [WB-15] design vehicle was used to select the radii for both the right-turn and median turns.

Right-Turn Radius. The 40-ft [12.2 m] right-turn radii were used to accommodate the larger vehicles found at the site, based on recommendations in the *Roadway Design Manual*, Chapter 7, Section 7 <insert link to page 7-26 of RDM> for urban intersections with frequent turns by combination trucks. Islands were not used because of their potential for impeding these vehicles. The use of radii of this size may result in higher turning speeds for vehicles. This is undesirable for areas with larger numbers of pedestrians but acceptable for an industrial area with few pedestrians. The turning path of a WB-50 [WB-15] truck with a right-turn radius of 40 ft [12.2 m] is shown in Figure 4-4.

Median-Turn Radius. A 60-ft [18 m] median-turn radius was selected to accommodate the WB-50 [WB-15] truck without increasing the size of the intersection more than necessary. A turn template is overlaid on the intersection design in Figure 4-4 to show the minimum path of the design vehicle used.

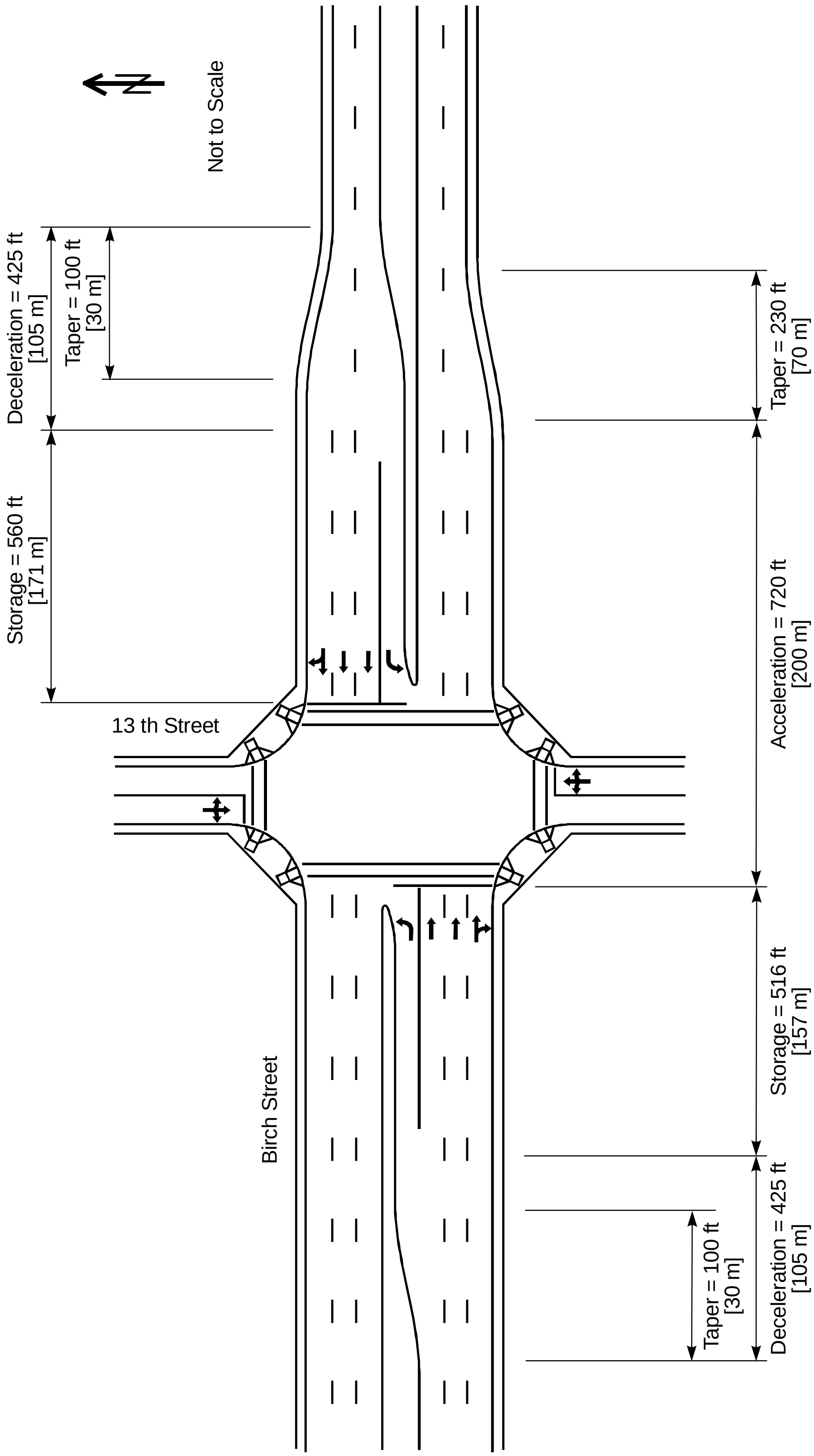


Figure 4-3. Proposed Design.

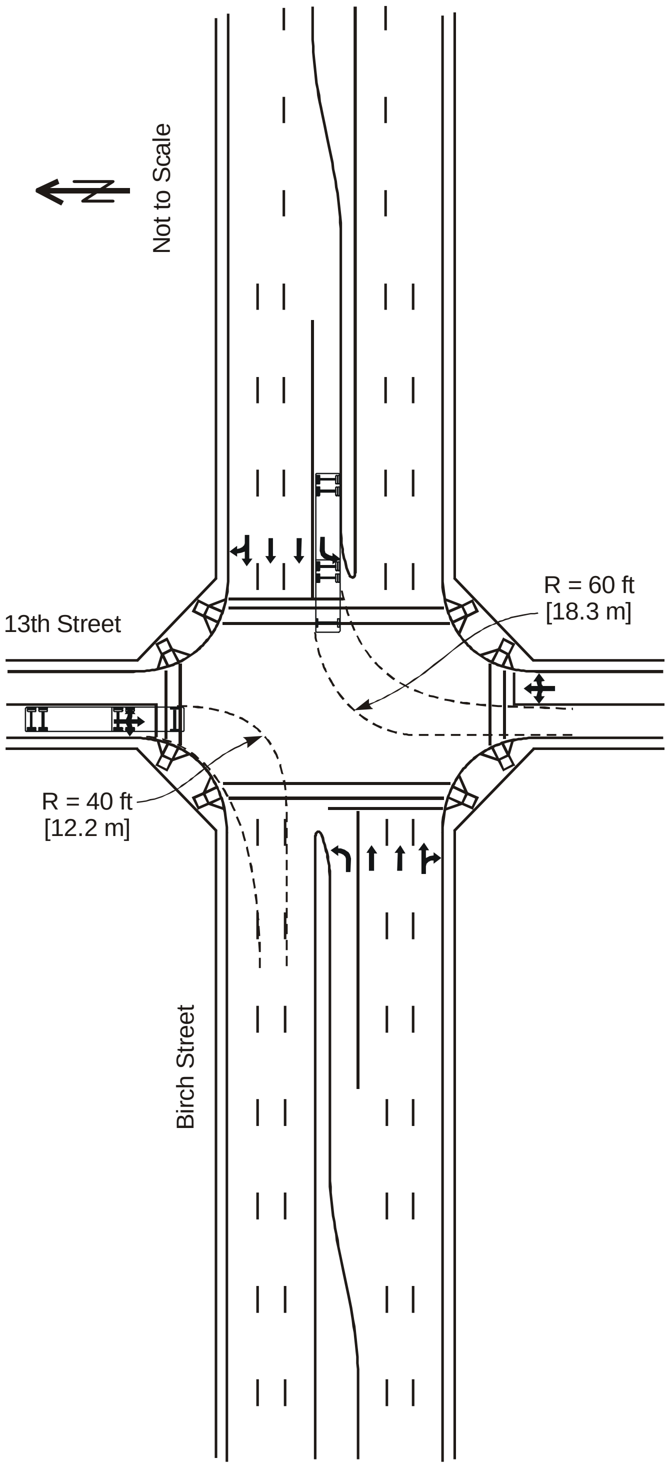


Figure 4-4. Design Overlaid with WB-50 [WB-15] Truck Template.

Application 2

Reallocation of Cross Section

Overview

The following application discusses an approach of reallocating pavement to a different lane configuration. The *Urban Intersection Design Guide*, Chapter 4, Section 1 <link> provides discussion on through lanes.

Background

An old city with a population of approximately 200,000 has two minor arterial streets that consistently have higher-than-average accident rates. Washington Street is a four-lane, undivided street with a pavement width of 43 ft [13 m] (face-of-curb to face-of-curb) that predominately serves an older section of the city. Most adjacent development is commercial with some multifamily residential. There are several elementary schools, a junior high school, and two large public parks that are located either adjacent to or in close proximity to the roadway. Traffic volumes on the street are about 15,000 vehicles per day. The percentage of trucks on the street is very low. The speed limit on Washington Street is 35 mph [56 km/h].

Brock Avenue is a four-lane, undivided street with a pavement width of 40 ft [12 m] (face-of-curb to face-of-curb) that serves a variety of developments, including both commercial and industrial properties. This street has a higher percentage of large vehicles (trucks) compared to other arterial streets in the city. Traffic volumes on the street are about 13,000 vehicles per day. The speed limit on Brock Avenue is 35 mph [56 km/h].

The city engineering staff has reviewed the accident histories of both streets and determined that a large percentage of the accidents involved vehicles making unsafe left turns, or were rear-end collisions involving stopped or slow-moving vehicles attempting to turn left or right from the travel lanes. Review of turning movement counts and observations of traffic flow on both streets indicated that a large number of left and right turns were being made from both streets. The ideal solution to the accident problem for both arterials was to widen the streets and provide either a median with separated left-turn lanes or a continuous, center, left-turn lane. In addition, separate right-turn lanes were desired at specific locations along the streets.

The desired street improvements were quickly eliminated from consideration. Both roadways were developed many years ago with numerous driveways along the streets to serve the adjacent developments. The city's street system was not conducive to providing alternate routes to provide access to the developments from the rear. Hence, the possibilities of installing a median or prohibiting turns along both streets were quickly eliminated from consideration. In addition, many developments adjacent to the streets were positioned very close to the right of way. Existing rights of way outside of the curb lines on both streets were very narrow. Hence, the acquisition of additional right of way for roadway widening would be extremely difficult and expensive.

The city staff eventually determined that any roadway improvements would have to be made within the existing curb lines. Therefore, the number of potential operational improvements was few.

Issues Considered

The city staff recognized that because of the large number of left turns being made along the street, the inside travel lanes were being used essentially as left-turn lanes. Vehicles traveling in opposite directions that were stopped at intersections while attempting to make left turns were laterally offset from one another, which significantly affected the ability of drivers of those vehicles to observe other vehicles approaching from behind the opposing left-turning vehicles. The consistent interaction between through vehicles and turning vehicles (especially with the 10-ft-wide [3 m] travel lanes on Brock Avenue) reduced operational efficiency and available capacity. Ideally, providing separated left-turn lanes was the desired solution to the problem. Neither street had sufficient right of way or existing pavement width, however, to permit the addition of a median or left-turn lane and maintain two travel lanes in both directions.

The only alternative was to reduce the number of lanes on the streets to three lanes, providing a continuous center, left-turn lane and a single travel lane in each direction. This type of alternative, recently termed as a road diet, has been implemented in other cities with some success where conditions are conducive to lane reductions. Generally, four-lane streets can accommodate about 18,000 to 20,000 vehicles per day. These capacity volumes are reduced substantially if there are a large number of turning vehicles, especially left-turning vehicles. Two-lane streets can accommodate about 7000 to 10,000 vehicles per day. Again, these capacity volumes are reduced substantially if there are a large number of turning vehicles.

Providing three travel lanes appeared to be a realistic compromise considering the traffic volumes on the two streets. Both streets had traffic volumes much less than the capacity volumes of a typical four-lane street, so the three-lane cross section would not likely create a serious congestion problem. Obviously, a three-lane street would be inadequate to accommodate volumes greater than 20,000. The three-lane cross section would separate left-turning vehicles from through vehicles and provide drivers of those left-turning vehicles with better visibility conditions to see conflicting vehicles. Hence, the recommended three-lane cross section was considered to be a safer design that likely would reduce the accident rates.

One concern was that drivers may confuse the existing concrete joints for the lane lines. The city decided to include an overlay to cover the joint lines.

Designs Selected

As shown in Figure 4-5, the existing striping on Washington Street provides four travel lanes, each 10.75 ft [3.27 m] in width. The first alternative striping design, also shown in Figure 4-5, considered providing two 15.5-ft-wide [4.7 m] through lanes and a 12-ft-wide [3.7 m] continuous, center, left-turn lane. The wide through lanes created a concern that speeds would increase due to the wide travel lanes. Also, a single wide travel lane possibly would encourage occasional use as two narrow travel lanes or encourage on-street parking. Neither condition would be desirable. Hence, a wider center lane was considered in order to narrow the through lanes.

However, the city staff considered a second alternative, shown in Figure 4-5, that would include narrower travel lanes and bicycle lanes. The 11-ft-wide [3.4 m] travel lanes were considered sufficiently wide for the predominantly passenger-vehicle traffic on the street but sufficiently narrow as to encourage maintenance of the existing typical vehicle speeds. Right-turn movements from the 11-ft-wide [3.4 m] through lanes would benefit with the additional 5 ft [1.5 m] of pavement width from the bicycle lanes. The bicycle lanes would encourage bicycle use to and from the schools (especially the junior high school) and the recreational facilities. The 5-ft-wide [1.5 m] bicycle lanes were 1 ft [0.3 m] narrower than the city staff's preferred 6 ft [1.8 m] width; however, Williams Boulevard is constructed of portland cement concrete so there is no gutter seam. Therefore, the entire 5-ft-wide [1.5 m] bicycle lane would be available for use. The second alternative was preferred by the city staff, the city council, and local citizens and was selected for implementation.

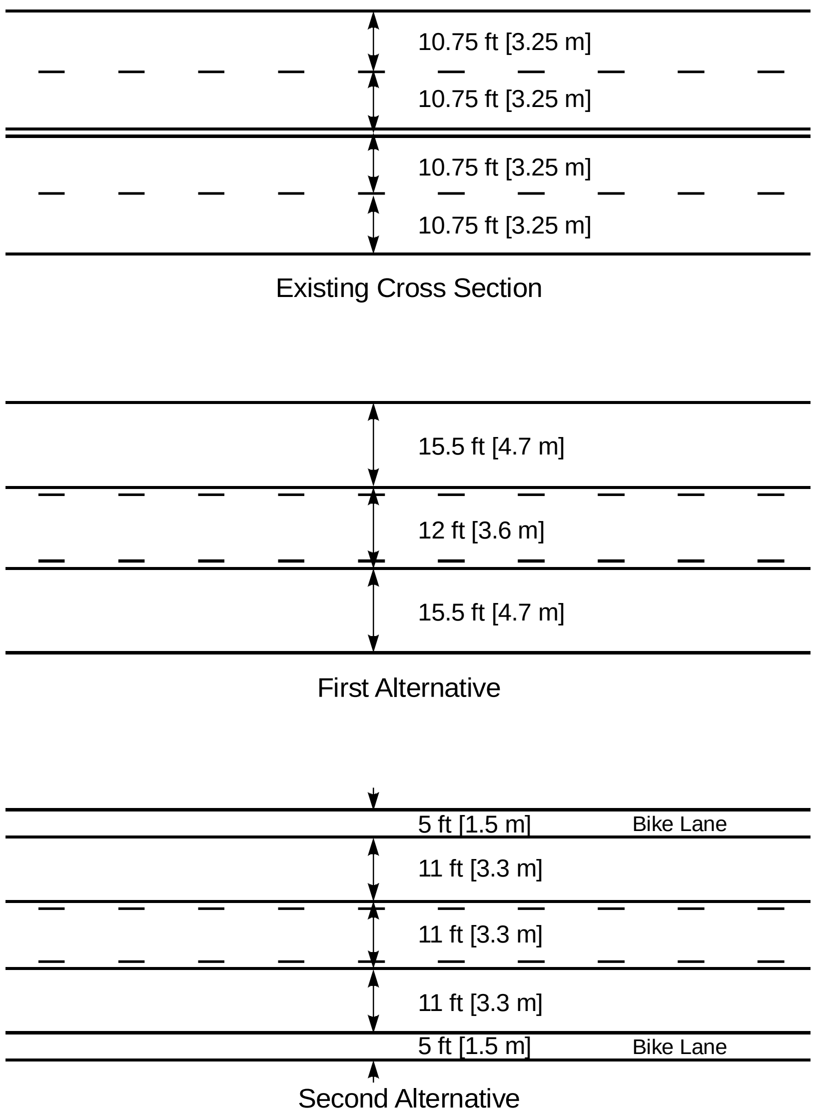


Figure 4-5. Existing and Proposed Alternatives for Williams Street.

As shown in Figure 4-6, the existing striping on Brock Avenue provided four, 10-ft-wide [3 m] travel lanes. The proposed restriping, also shown in Figure 4-6, provided 14-ft [4.3 m] travel lanes and a 12-ft-wide [3.7 m] center two-way left-turn lane. The outside lane widths were considered desirable to accommodate right turns by the numerous large vehicles that use the street. The width of the center lane was considered appropriate for all vehicle sizes. The street was too narrow to consider bicycle lanes; however; considering the minimal bicycle activity in the area, bicycle lanes were not desired. The recommended striping plan was selected for implementation.

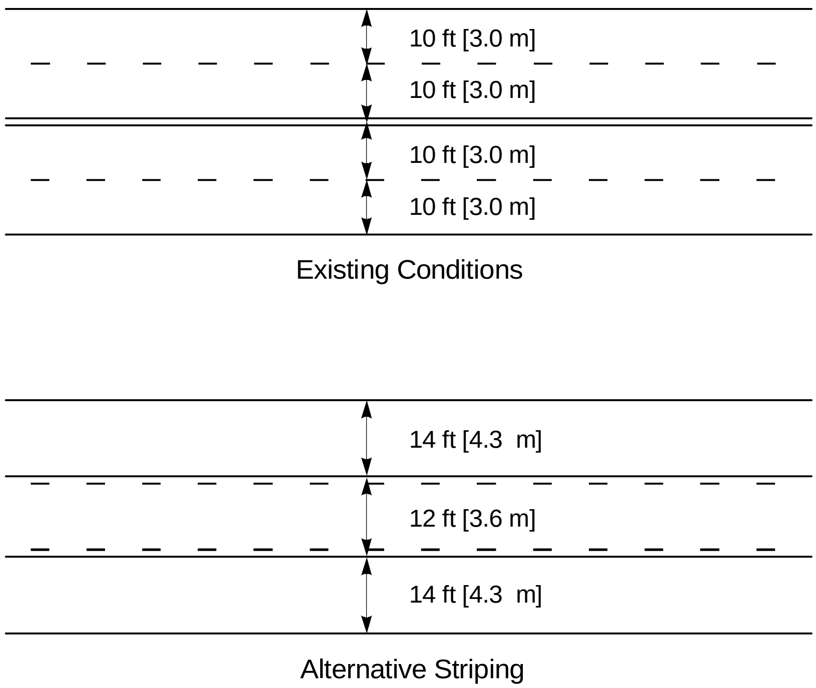


Figure 4-6. Existing and Proposed Alternatives for Brock Avenue.

Application 3
Inclusion of Left-Turn Lane

Overview

The following application explores information available on evaluating when to consider a left-turn lane. The *Urban Intersection Design Guide,* Chapter 4, Section 2 <link> provides information on left-turn lane design.

Effectiveness of Left-Turn Lanes

The inclusion of a left-turn lane can result in a reduction in crashes. A recent Federal Highway Administration (FHWA) study on 280 three- and four-leg intersections found the expected effectiveness on crash reduction as shown in Table 4-2.

Table 4-2. Expected Effectiveness of Left-Turn Lanes on Crash Reduction.

		Crash Reduction (%)	
Intersection Type	**Intersection Traffic Control**	**Left Turn Installed on One Approach**	**Left Turn Installed on Both Approaches**
Rural			
Three-leg intersection	Stop Sign Traffic Signal	44 15	
Four-leg intersection	Stop Sign Traffic Signal	28 18	48 13
Urban			
Three-leg intersection	Stop Sign Traffic Signal	33 7	
Four-leg intersection	Stop Sign Traffic Signal	27 10	47 19

When to Install a Left-Turn Lane

The decision to include a left-turn lane may be governed by a city's thoroughfare plan or guidelines based on function class of the intersecting roadways. For example, the intersection of two major arterials typically includes left-turn lanes (and in some cases dual left-turn lanes). Other factors considered include available sight distances and crash history. TxDOT's *Roadway Design Manual* <link> contains guidance for use in determining when to consider a left-turn lane on two-lane highways (see Table 4-3). A similar table is also present in the AASHTO *Green Book*. Figure 4-7 illustrates the following terms used in the table along with other terms needed for the procedure:

- ***Advancing Volume (V_A)*** – the total peak hourly volume of traffic on the major road approaching the intersection to include through, right- and left-turn volumes.
- ***Left-Turn Volume (V_L)*** – the portion of the advancing volume that turns left at the intersection.

- ***Percent Left Turns (PL)*** – the percentage of the advancing volume that turn left; equal to the left-turn volume divided by the advancing volume (PL = V_L/V_A).
- ***Straight Through Volume (V_S)*** – the portion of the advancing volume that travels straight through the intersection ($V_L + V_S = V_A$).
- ***Opposing Volume (V_O)*** – the total peak hourly volume of vehicles opposing the advancing volume.

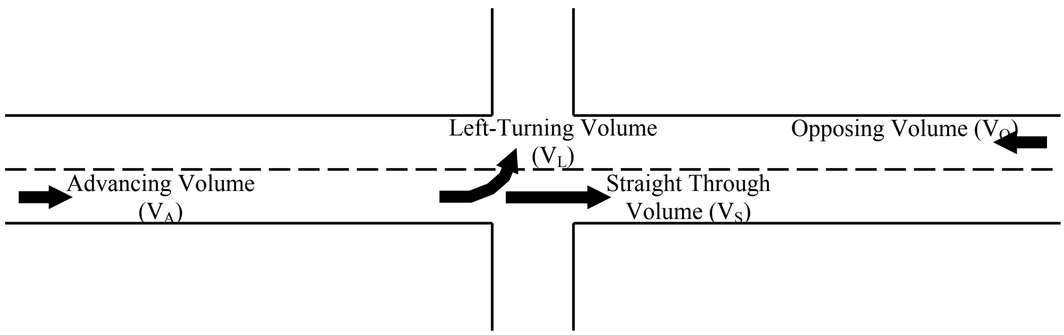


Figure 4-7. Volume Definitions.

Table 4-3. Guide for Left-Turn Lanes on Two-Lane Highways (Reproduction from TxDOT *Roadway Design Manual* Table 3-11 <link>).

Opposing Volume (vph)	Advancing Volume (vph)			
	5% Left Turns	10% Left Turns	20% Left Turns	30% Left Turns
40 mph [64 km/h] operating speed				
800	330	240	180	160
600	410	305	225	200
400	510	380	275	245
200	640	470	350	305
100	720	515	390	340
50 mph [80 km/h] operating speed				
800	280	210	165	135
600	350	260	195	170
400	430	320	240	210
200	550	400	300	240
100	615	445	335	295
60 mph [100 km/h] operating speed				
800	230	170	125	115
600	290	210	160	140
400	365	270	200	175
200	450	330	250	215
100	505	370	275	240

Should a Left-Turn Lane Be Installed?

Problem. In a rapidly developing area, citizens are concerned with the number of cars using the shoulder to pass slow-moving left-turning vehicles (see Figure 4-8). The area is currently considered rural; however, the anticipated development within the next 5 years will change the performance of the roadway. The state highway will provide more access and less mobility. It has already started evolving into a suburban high-speed arterial. The designers noted that the TxDOT *Access Management Manual* contains criteria on connection spacing for Other State Highways <link>. They decided to check both the *Access Manual* and the *Roadway Design Manual* as part of their traffic operations evaluation.

Figure 4-8. Example of Vehicle Using Shoulder to Pass Left-Turning Vehicle.

Known Information. The information known for this site includes:

- Peak hour turning movement counts are shown in Figure 4-9.
- The 85th percentile speed is 59 mph [95 km/h].
- Posted speed is 55 mph [89 km/h].
- Grades at the intersection are level.
- Lane widths are 12 ft [3.7 m].
- Shoulder width on the major road is 10 ft [3.0 m].
- Another left-turn bay is not within 425 ft [130 m] of the site.

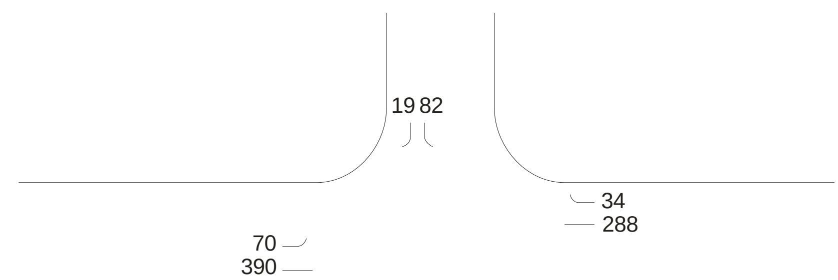


Figure 4-9. Peak Hour Turning Movement Count.

Solution. Following is the solution for this example:

- *Step 1: Determine the opposing, advancing, and percent left-turn volumes.*

Advancing volume consists of those vehicles moving toward the intersection on the same approach as the left-turning vehicles. For this example it is:

390 + 70 = 460 vph

Opposing volume consists of those vehicles that conflict with the left-turning vehicle. Therefore it should include both through and right-turning vehicles. For this example it is:

288 + 34 = 322 vph

The percent left-turn volume is determined based on the approaching volume. Therefore, it is:

70 vehicles turning left / 460 advancing vehicles = 0.152 or 15 percent

- *Step 2: Use table to determine if a left-turn lane should be considered.*

The volumes are used with the guidelines in Table 4-3, reproduced from Table 3-11 in the *Roadway Design Manual* <link> to determine if a left-turn lane should be considered. The operating speed of 59 mph [95 km/h] is near 60 mph [97 km/h]; therefore, the data for 60 mph [97 km/h] are used in this example. Because the exact volumes are not provided in the table, interpolation must be used. Table 4-4 shows the interpolated volumes for this situation.

Table 4-4. Interpolated Volumes.

Advancing Volume (vph)			
Opposing Volume	**10% Left Turns**	***15% Left Turns***	**20% Left Turns**
400	270	***235***	200
322	***293***	***256***	***220***
200	330	***290***	250

Original data are from TxDOT *Roadway Design Manual* Table 3-11 <link> for design speed of 60 mph [97 km/h]. ***Bold and italics values are the interpolated values.***

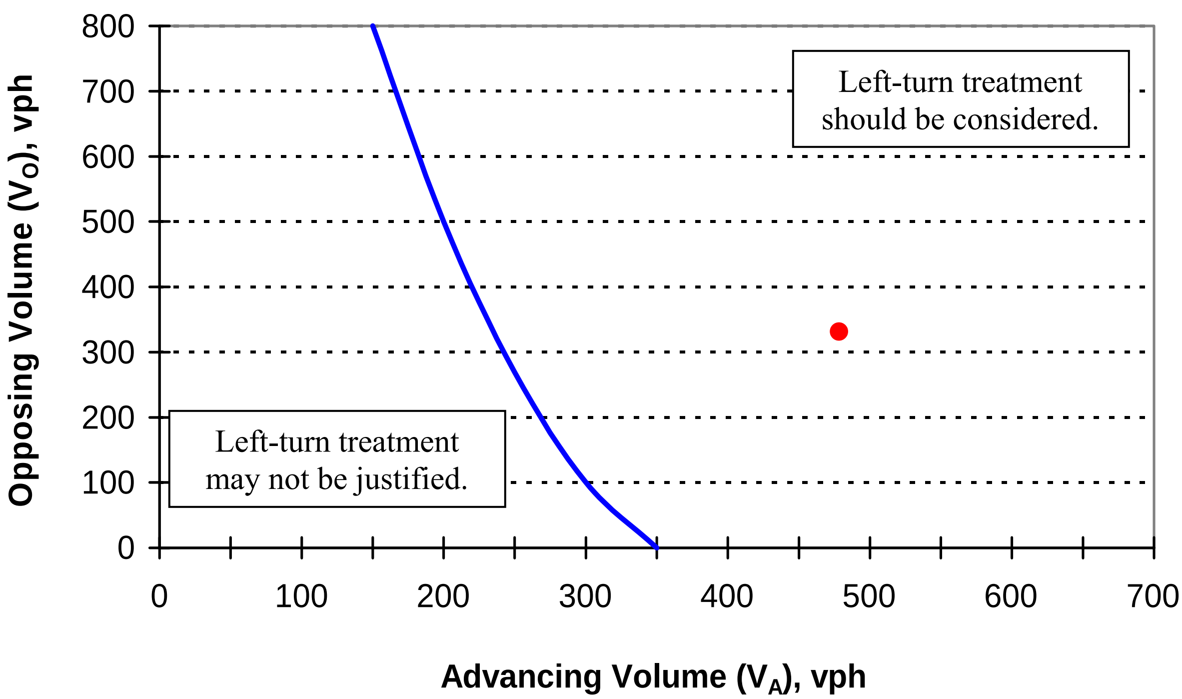
The advancing volume determined from the table is 256 vph. The number of vehicles advancing toward the left-turning vehicles as measured in the field was 460 vph. Because 460 vph exceeds 256 vph, a left-turn lane should be considered.

Another method for evaluating this situation is to use the spreadsheet included in NCHRP 457.[2] Table 4-5 and Figure 4-10 show the results from the evaluation.

[2] Bonneson, J., and M. Fontaine, *Engineering Study Guide for Evaluating Intersection Improvements*, NCHRP Report No. 457. Available Online. <http://trb.org/trb/publications/nchrp/esg.pdf> Accessed: August 2003. Transportation Research Board, Washington, D.C., 2001.

Table 4-5. NCHRP 457[2] Results for Application.

Input	
Variable	**Value**
85th percentile speed, mph	60
Advancing volume (V_A), vph	460
Opposing volume (V_O), vph	322
Output	
Limiting advancing volume (V_A), vph	238
Guidance for determining the need for a major-road left-turn bay:	
Left-turn treatment should be considered.	



• = plot of Advancing Volume and Opposing Volume for the example intersection (see Table 4-5).

Figure 4-10. Results for Application Using Material from NCHRP 457.[2]

♦ *Step 3: Check TxDOT Access Management Manual.*

The *Access Management Manual*, Table 2-2 lists spacing criteria for Other State Highways <link>. With a posted speed in excess of 50 mph [81 km/h], the spacing distance is 425 ft [130 m]. Currently a turn bay for another intersection or driveway is not present within that distance.

A driveway is present approximately 300 ft [91 m] west of the intersection. The design team decided to move forward with the turn lane at the intersection and to inform the property owner that a median opening at the driveway will not be considered when the highway is widened.

Application 4

Left-Turn Lane

Overview

The presence of large numbers of left-turning vehicles can degrade the performance of an intersection. Higher traffic volumes and degraded intersection performance may justify the construction of a left-turn lane. The left-turn storage bay design length can be determined by the projected volumes of left-turn and through traffic volumes and the design speed. The *Urban Intersection Design Guide*, Chapter 4, Section 2 <link> provides design guidelines.

Background

The intersection of Diamond Boulevard and Douglas Street is in an urban area. Diamond Blvd. is a four-lane arterial with a raised median, while Douglas St. is a two-lane collector. Developments on each corner are:

- convenience stores on the northeast and northwest corners,
- a fast-food restaurant on the southwest corner, and
- a small shopping center on the southeast corner.

This intersection has a relatively high left-turn volume. The presence of the left-turning vehicles restricts the traffic flow through the intersection and limits the options available for signalization strategies that could reduce delay in the intersection.

Figure 4-11 illustrates the current intersection layout. The following is known:

- Diamond Boulevard is an urban arterial roadway.
- Douglas Street is an urban collector roadway.
- Design speed on Diamond Boulevard is 45 mph [72 km/h].
- The intersection is signalized.
- Cycle length of the traffic signal is 75 sec.
- Truck percentage is 8 percent.
- Projected design hour traffic volumes in vph are shown in Figure 4-11.
- Median width is 18 ft [5.5 m].
- Median width at crosswalk is 6 ft [1.8 m].

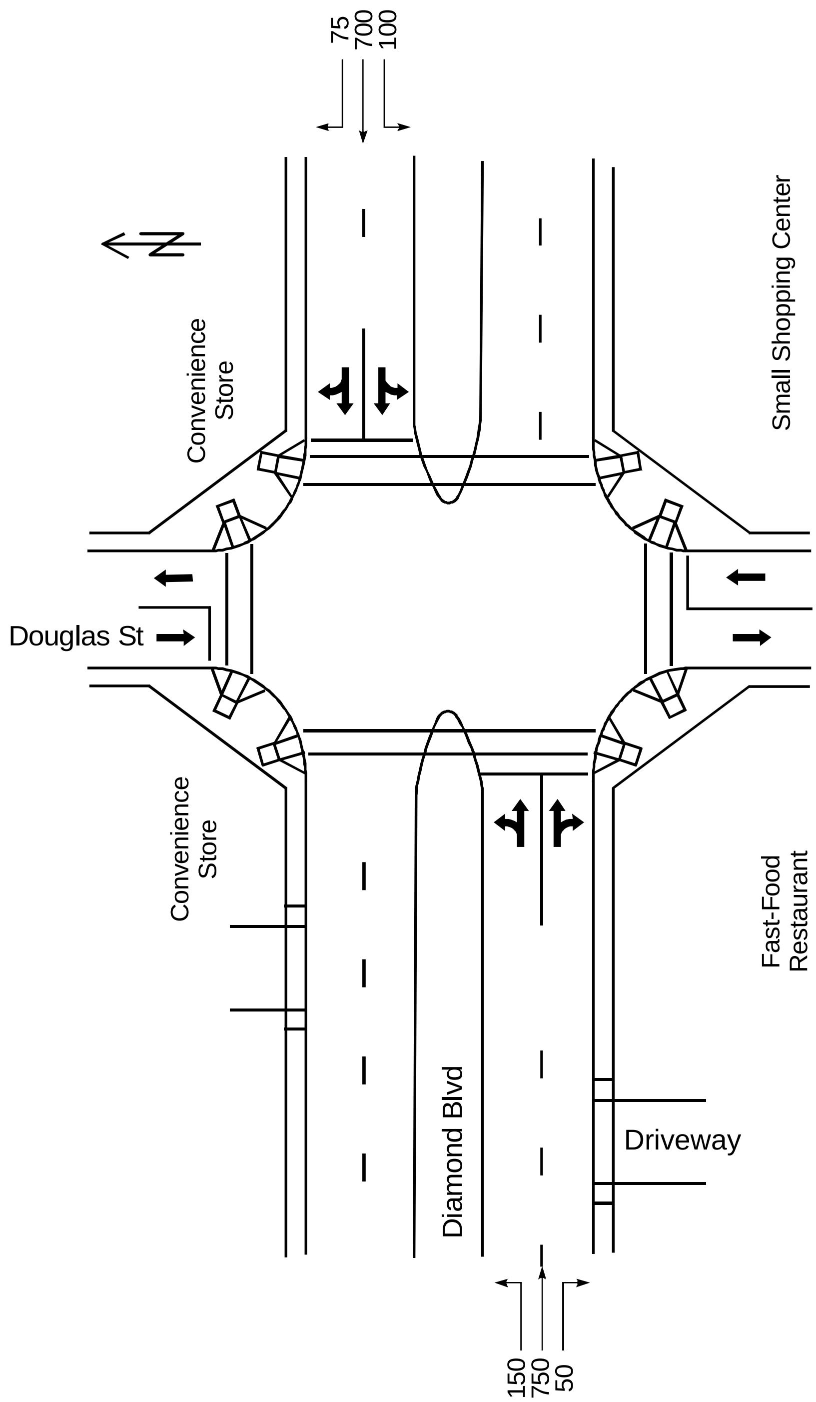


Figure 4-11. Existing Intersection Layout.

Issues Considered

Issues considered during an upgrade to the site include the following:

- ♦ Provide upgraded traffic signal hardware including:
  - longer mast-arms,
  - replacement of foundations and signal poles as necessary, and

- left-turn signal head.

♦ Provide left-turn speed change lanes that:

- accommodate the queues in the left-turn lanes, and
- consider the length of the queues in the through lanes so they do not block the entrance to the left-turn bays.

Proposed Design

The design of the left-turn lane includes both deceleration and storage. The design of the storage available for left-turning vehicles depends on the queues projected to develop in the turn lanes and the adjacent through lanes. The through lane queues should be estimated because of the possibility of their blocking the entrance to the turn lanes. Other characteristics of the design include the width of the median and the width of the turn lane.

♦ *Step 1: Determine left-turn storage length.*

The left-turn storage length is determined according to Table 3-3 of the *Roadway Design Manual* (reproduced in Table 4-6).

The required storage length is a calculated length based on the queue (with a minimum of 100 ft [30 m]). The calculated length may be obtained using an acceptable traffic model such as the latest version of the HCM software (HCS), SYNCHRO, VISSIM, or other acceptable simulation models, as suggested in the *Roadway Design Manual*. However, if those techniques have not been employed, then the queue may be estimated by the following *storage length* equation:

$$L = (V/N)(2)(S)$$

Where:

L = storage length, ft

V = left-turn volume per hour, vph

N = number of cycles/hour for the traffic signal,

2 = factor that provides for all left-turning vehicles on most cycles; a value of 1.8 may be acceptable on collector streets,

S = queue storage length per vehicle, ft.

Table 4-6. Lengths of Single Left-Turn Lanes on Urban Streets (Reproduction of *Roadway Design Manual* Table 3-3 <link>)

(US Customary)						
Speed (mph)	**Deceleration Length[2] (ft)**	**Taper Length (ft)**	**Storage Length**			
			Signalized		**Non-Signalized**	
			Calculated	**Minimum[4]**	**Calculated[5]**	**Minimum[4]**
30	160	50	See footnote 3	100	See footnote 5	100
35	215	50	See footnote 3	100	See footnote 5	100
40	275	50	See footnote 3	100	See footnote 5	100
45	***345***	***100***	***See footnote 3***	***100***	***See footnote 5***	***100***
50	425	100	See footnote 3	100	See footnote 5	100
55	510	100	See footnote 3	100	See footnote 5	100
Metric						
Speed (km/h)	**Deceleration Length[2] (m)**	**Taper Length (m)**	**Storage Length**			
			Signalized		**Non-Signalized**	
			Calculated	**Minimum[4]**	**Calculated[5]**	**Minimum[4]**
50	50	15	See footnote 3	30	See footnote 5	30
60	65	15	See footnote 3	30	See footnote 5	30
70	85	30	See footnote 3	30	See footnote 5	30
80	105	30	See footnote 3	30	See footnote 5	30
90	130	30	See footnote 3	30	See footnote 5	30

[1]The minimum length of a left-turn lane is the sum of the deceleration length plus queue storage. In order to determine the design length, the deceleration plus storage length must be calculated for peak and off-peak periods; the longest total length will be the minimum design length.

[2]See Deceleration Length discussion immediately following Table 3-3.

[3] ***See Storage Length Calculations discussion immediately following Table 3-3A.***

[4] ***The minimum storage length shall apply when: 1) the required queue storage length calculated is less than the minimum length, or 2) there is no rational method for estimating the left-turn volume.***

[5]The calculated queue storage at unsignalized location using a traffic model or simulation model or by the following:

L = (V/30)(2)(S)

Where: (V/30) is the left-turn volume in a two-minute interval and other terms are as defined in the Storage Length Calculations discussion immediately following Table 3-3A.

The storage length of vehicles, S, is determined by the percentage of trucks. The *Roadway Design Manual* provides the following:

% of Trucks	*S, ft [m]*
<5	25 [7.6]
5 to 9	***30 [9.1]***
10 to 14	35 [10.7]
15 to 19	40 [12.2]

Because the percent trucks on Diamond Blvd. is 8, S is 30 ft [9.1 m]. The number of cycles per hour is determined by the cycle length used at the intersection, 75 sec, or 48 cycles per hour.

Substituting in the equation for left-turning vehicles approaching from the east on Diamond Blvd.:

L = (150 vph/48)(2)(30)

L = 188 ft [57 m]

Substituting in the equation for left-turning vehicles approaching from the west on Diamond Blvd.:

L = (100 vph/48)(2)(30)

L = 125 ft [38 m]

- *Step 2: Check through lane queue.*

The queue lengths should be compared to the estimated through-lane queue, to see if that queue will extend back far enough to block vehicles from entering the left-turn lane. The same technique is used to estimate the through-lane queue. The volume used in the equation is the number of through vehicles per lane for eastbound and westbound through traffic on Diamond Blvd., 800 and 775 vph, respectively. The volumes are split evenly between the two through lanes available in each direction.

Substituting in the equation for through vehicles approaching from the east on Diamond Blvd.:

L = (400 vph/48)(2)(30)

L = 500 ft [152 m]

Substituting in the equation for through vehicles approaching from the west on Diamond Blvd.:

L = (388 vph/48)(2)(30)

L = 485 ft [148 m]

Because the through-lane queue is estimated to be longer than the left-turn lane queue, its length is used for the design of the left-turn lane. The left-turn lane design is shown in Figure 4-12. This design obviously occupies a considerable length of roadway, and may exceed the block spacing in some locations. Practical constraints such as this may necessitate the installation of turn bays that are shorter than those otherwise desired.

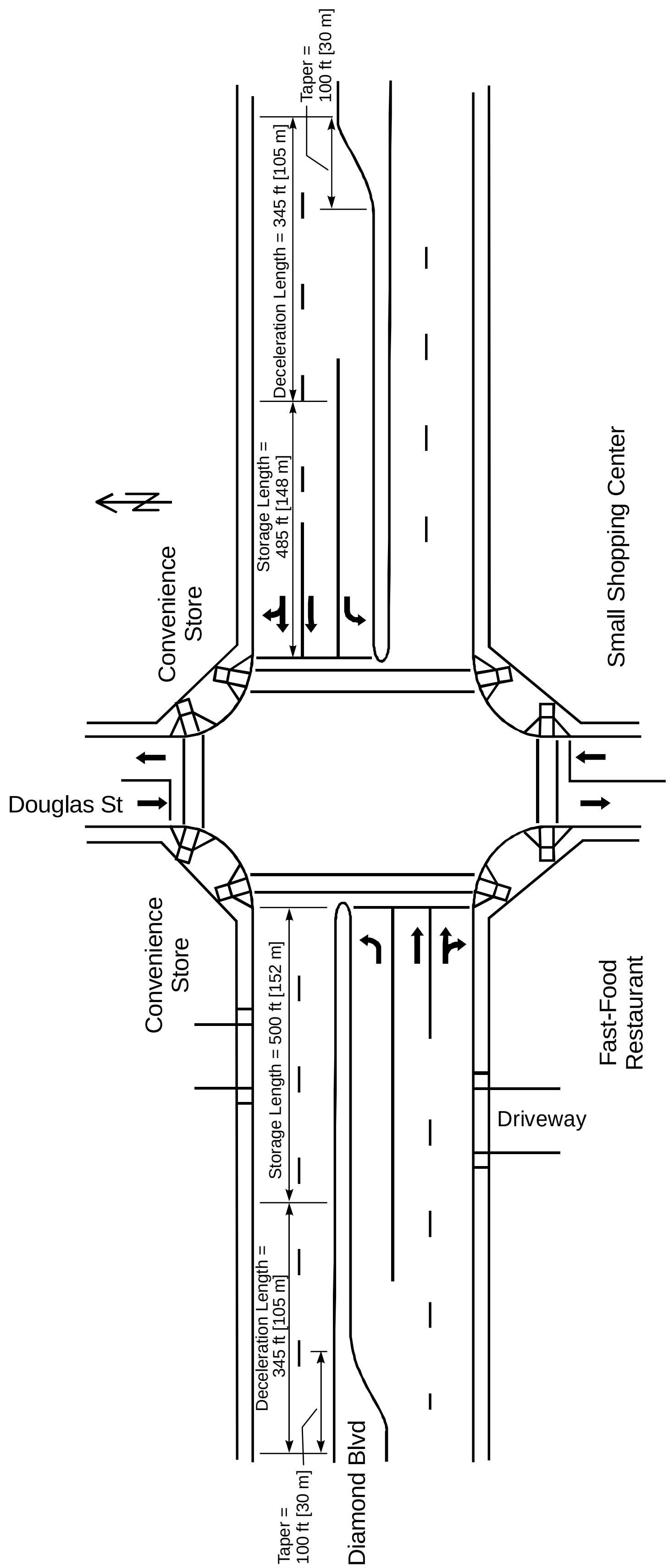


Figure 4-12. Proposed Intersection Layout.

- *Step 3: Determine left-turn deceleration and taper length.*

As shown in Table 4-6, the deceleration length and taper length are provided as 345 ft [105 m] and 100 ft [30 m], respectively.

- *Step 4: Determine median and turn lane width.*

The width of the left-turn lane was selected from Table 3-1 of the *Roadway Design Manual*. The range allowed is 11 to 12 ft [3.4 to 3.7 m] desirable and 10 ft [3 m] minimum; a 12-ft [3.7 m] lane width was selected. The width of the median prior to the inclusion of a turn lane was 18 ft [5.5 m], greater than the minimum width of 16 ft required for the design of a single left-turn lane as discussed in the *Roadway Design Manual*. The use of a 12-ft [3.7 m] lane allows the retention of a 6-ft [1.8 m] median adjacent to the turn lane, meeting pedestrian refuge width requirements (see *Roadway Design Manual*, Chapter 4, Section 5 <link>).

- *Step 5: Relocate crosswalk and update traffic signals.*

The addition of the left-turn lanes requires the end of the median lines to be moved back to allow the same turning radius as used previously (50 ft [15 m]). A bullet nose shape was used for the median end to minimize the distance the nose was set back from the intersection. For further information, see Chapter 4, Section 5, Median End Treatment Design <link> and Figure 4-24 <link> of that chapter of the *Roadway Design Manual*.

The crosswalk across Diamond Blvd. was placed in approximately the same location as the previous design; no refuge area is provided in the median. If the crosswalks were moved far enough back to provide pedestrian refuge areas within the median, the stop lines would be too far back from the intersection to meet *TMUTCD* requirements (stop lines should be placed 4 ft [1.2 m] prior to crosswalks, and should be no more than 30 ft [9 m] from the face of the curb on the intersecting roadway). The pedestrian curb ramps were relocated to match the new crosswalk locations.

The traffic signal will be updated to provide a signal head with a left-turn indication. The additional mast-arm length will require a larger signal pole and pole foundation.

Application 5
Offset Left-Turn Lanes

Overview

Left-turn lanes are used to provide space for the deceleration and storage of turning vehicles.[1] They may be used to improve safety and/or operations at intersections. However, vehicles in opposing left-turn lanes can limit each other's views of conflicting traffic. Benefits of offset left-turn lanes include:

- better visibility of opposing through traffic,
- decreased possibility of conflict between opposing left-turn movements within the intersection, and
- more left-turn vehicles served in a given period of time (particularly at signalized intersections).

Guidelines[3] were developed for offsetting opposing left-turn lanes at 90-deg intersections on level, tangent sections of divided roadways with 12-ft (3.7 m) lanes <link to Table 4-3 of the *Guide*>. The guidelines presented in Table 4-3 of the *Urban Intersection Design Guide* would typically involve reconstructing the left-turn lanes. Increasing the width of the lane line between the left-turn lane and the adjacent through lanes can also improve the sight distance by encouraging the driver to position the vehicle closer to the median. For new location and full reconstruction projects, wider offsets are suggested with provisions for pedestrian refuge.

Example

The view of oncoming vehicles available to left-turning vehicles can be improved by reallocating the existing median to provide an offset left-turn lane.

Problem. An existing signalized intersection with a 6-ft [1.8 m] median adjacent to the left-turn bay is shown in Figure 4-13; the full median width is 18 ft [5.5 m]. The figure shows the visual blocking caused by a vehicle present in the opposing left-turn lane. As shown, oncoming vehicles are blocked from view of left-turning vehicles. An accident pattern of left-turning vehicles turning in front of oncoming traffic has become apparent, with a presumed cause of impaired sight distance.

[3] Tarawneh, M.S., and P.T. McCoy. Guidelines for Offsetting Opposing Left-Turn Lanes on Divided Roadways. In *Transportation Research Record 1579*, TRB, National Research Council, Washington, D.C., 1997, pp. 43-52.

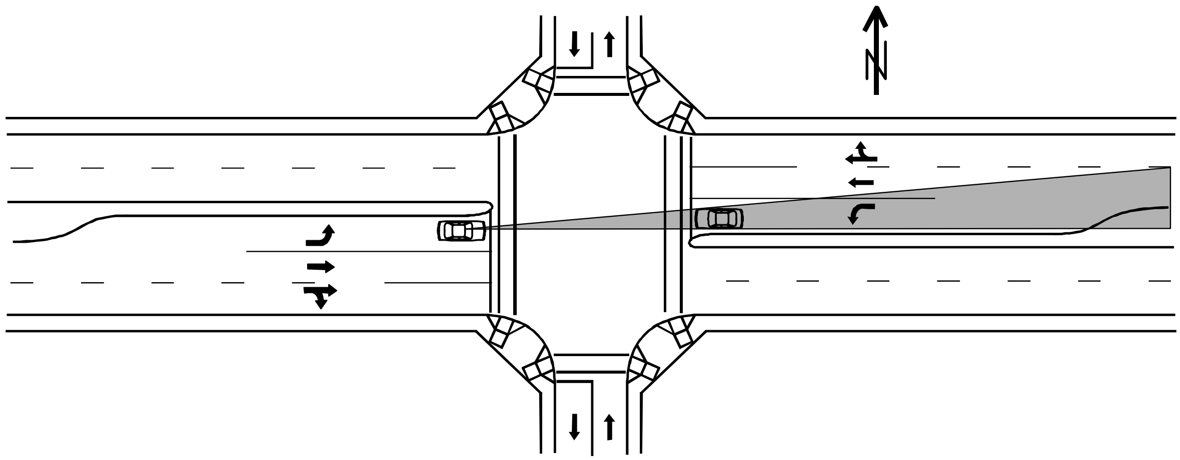


Figure 4-13. Existing Intersection Showing Visual Blocking.

The questions to be answered are as follows:

1. How wide should the left-turn lane line be?
2. How wide should the median be?
3. What improvement in sight distance can be expected from the wider lane line?

Solution. Left-turn lanes should desirably be 12-ft wide [3.7 m], while medians on urban arterials should be at least 2 ft [0.6 m] to avoid recurring damage to the divider.[1] Although the reduced median width will not be adequate to provide a pedestrian refuge, the signal timing provided is such that pedestrians may cross the intersection without stopping in the median.

Figure 4-14 shows the suggested design of a 4-ft [1.2 m] white line and a 2-ft [0.6 m] divider. In the proposed design the left-turning drivers' vision is not impaired. Figure 4-15 shows that vision is not impaired for left-turning drivers even if the opposing vehicle is a city transit bus.

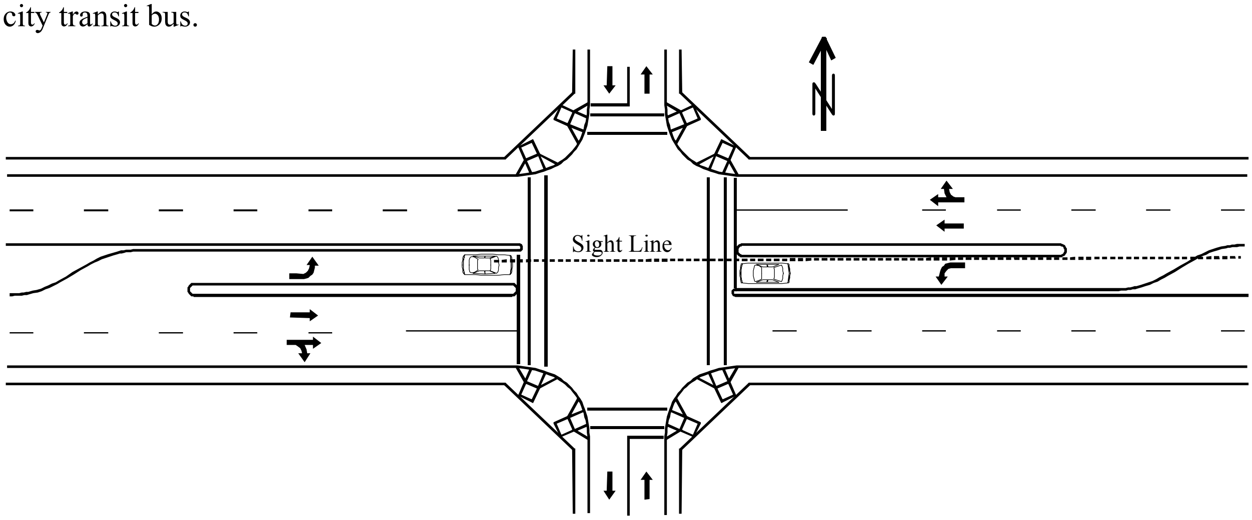


Figure 4-14. Proposed Design for Offset Left-Turn Lane.

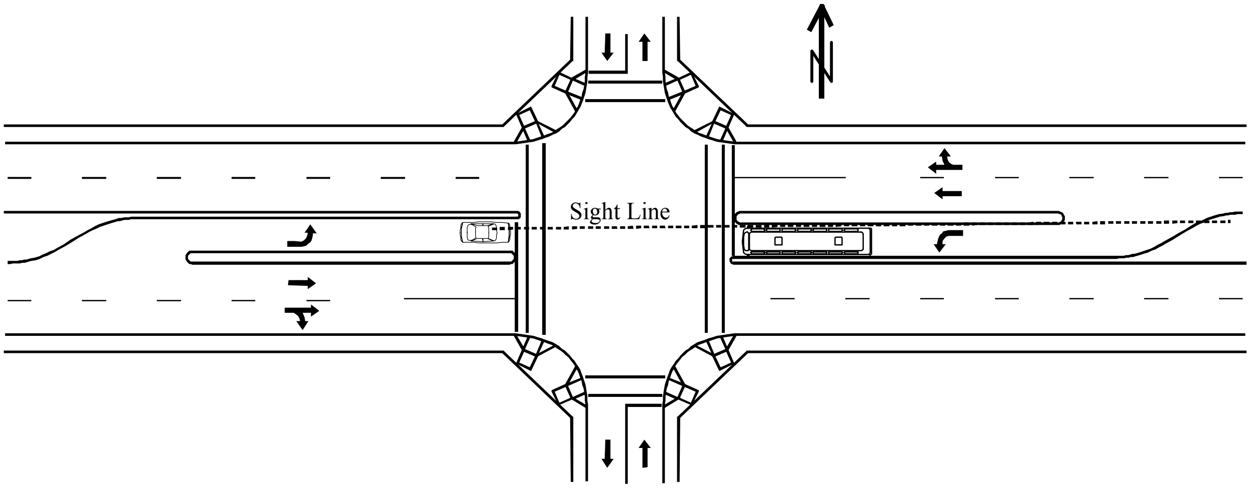


Figure 4-15. Proposed Design for Offset Left-Turn Lane with Bus.

Application 6
Adding Right-Turn Lane

Overview

Significant volumes of right-turning traffic can adversely affect the performance of an intersection. Higher turning volumes may warrant the addition of a right-turn lane to expedite turning movements and improve traffic signal operations. Right-turn lanes are discussed in the *Urban Intersection Design Guide*, Chapter 4, Section 3 <link>.

Background

An urban intersection has a substantial amount of right-turning traffic on a particular approach. Queues in the right-hand lane become lengthy during certain times of day, increasing delay and driver frustration.

The intersection of Jackson Road and Park Drive is in an urban area, near a large hospital and medical park. Jackson Road is a four-lane arterial with a raised median, while Park Drive is a two-lane collector. Developments on each corner are:

- a large parking area for the hospital on the southeast corner,
- a park area/green space adjacent to part of the medical park on the northeast corner,
- a fast-food restaurant on the northwest corner, and
- a free-standing pharmacy/variety store on the southwest corner.

The southwest corner is the location of the problem: eastbound right-turning vehicles on Jackson Road share the right-hand lane with eastbound through vehicles, causing delays. This southwest corner contains a driveway to the pharmacy.

Figure 4-16 illustrates the current intersection layout. The following is known:

- Jackson Road is an urban arterial roadway.
- Park Drive is an urban collector roadway.
- Design speed on Jackson Rd. is 45 mph [72 km/h].
- The intersection is signalized with a traffic signal cycle length of 90 sec.
- Truck percentage is 4 percent.
- Projected approach volume eastbound on Jackson Rd. is 720 vph.
- Projected right-turn volume from Jackson Rd. eastbound to Park Dr. southbound is 160 vph.
- Median width is 16 ft [4.9 m].

- Median width at crosswalk:
  - West side: 4 ft [1.2 m] and
  - East side: 7 ft [2.1 m].

Issues Considered

Issues to consider during an upgrade to the site include the following:

- Acquire right of way.
- Consider need to move utility lines.
- Move signal poles.
- Tie into existing sidewalk, but ensure grades are appropriate for usage by disabled pedestrians.
- Accommodate current traffic flow during construction.
- Accommodate moving of pharmacy driveway during construction.

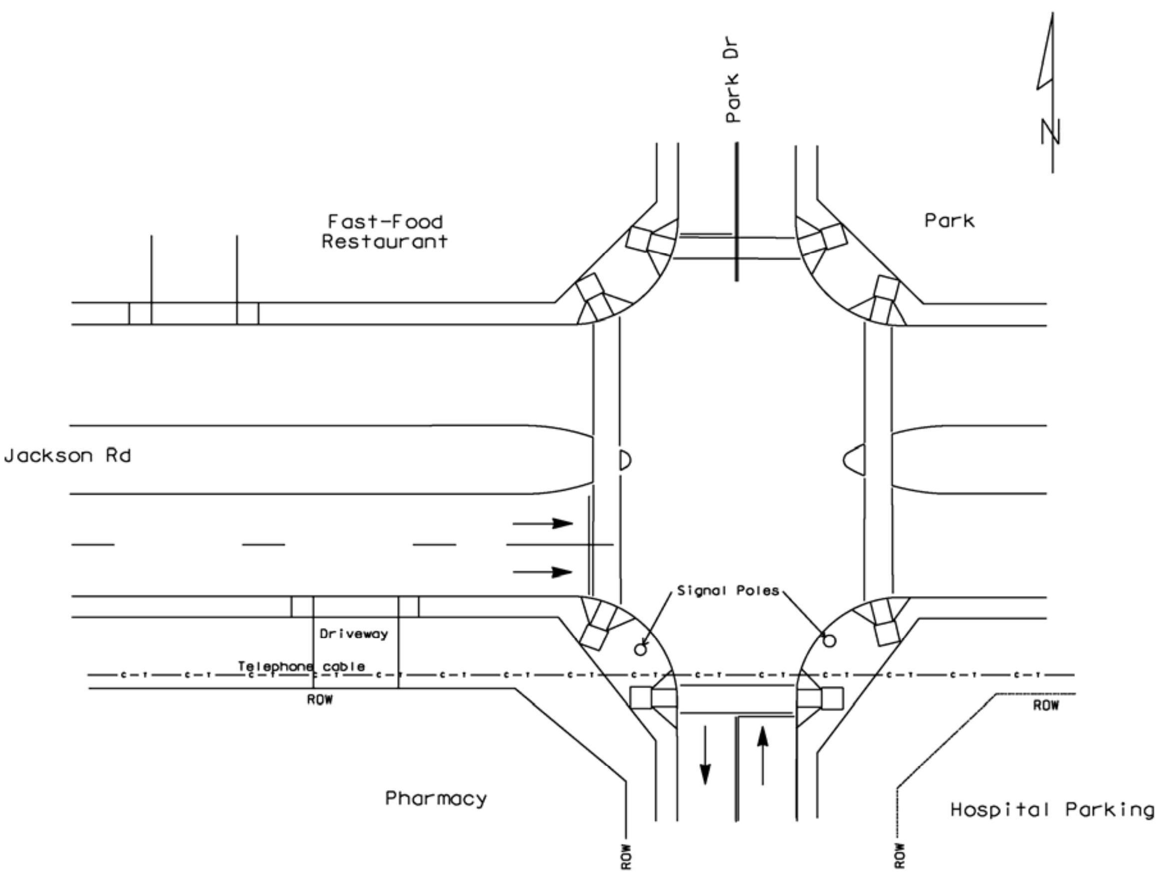


Figure 4-16. Existing Intersection Layout.

A range of options are available to enhance the operation of the intersection. The designer has chosen to focus on:

- Add a right-turn lane to the eastbound approach of Jackson Road to better distribute traffic approaching the intersection.

Other issues that were considered in the design include:

- Relocate the sidewalk to accommodate the new lane.
- Relocate pharmacy driveway to reduce conflicts from exiting vehicles.
- Relocate traffic signal poles to avoid the utility line, curb ramps, and the increased intersection area.
- Ensure that adequate width is provided for pedestrian refuge in the median.

Proposed Design

- *Step 1: Determine right-turn bay design.*

The right-turn bay design is determined according to Table 3-3 of the *Roadway Design Manual* (reproduced as Table 4-7). As shown in Table 4-6, the deceleration length and taper length are 345 ft [105 m] and 100 ft [30 m], respectively.

Table 4-7. Lengths of Single Left-Turn Lanes on Urban Streets Used in Right-Turn Bay Example (From *Roadway Design Manual*, Table 3-3).

(US Customary)						
Speed (mph)	**Deceleration Length[A,B] (ft)**	**Taper Length (ft)**	**Storage Length**			
			Signalized		**Non-Signalized**	
			Calculated	**Minimum[D]**	**Calculated[E]**	**Minimum[D]**
30	160	50	See footnote C	100	See footnote E	100
35	215	50	See footnote C	100	See footnote E	100
40	275	50	See footnote C	100	See footnote E	100
45	***345***	***100***	***See footnote C***	***100***	***See footnote E***	***100***
50	425	100	See footnote C	100	See footnote E	100
55	510	100	See footnote C	100	See footnote E	100
Metric						
Speed (km/h)	**Deceleration Length[A,B] (m)**	**Taper Length (m)**	**Storage Length**			
			Signalized		**Non-Signalized**	
			Calculated	**Minimum[D]**	**Calculated[E]**	**Minimum[D]**
50	50	15	See footnote C	30	See footnote E	30
60	65	15	See footnote C	30	See footnote E	30
70	***85***	***30***	***See footnote C***	***30***	***See footnote E***	***30***
80	105	30	See footnote C	30	See footnote E	30
90	130	30	See footnote C	30	See footnote E	30

[A]The minimum length of a left-turn lane is the sum of the deceleration length plus queue storage. In order to determine the design length, the deceleration plus storage length must be calculated for peak and off-peak periods, the longest total length will be the minimum design length.

[B]See Deceleration Length discussion immediately following Table 3-3.

[C]***See Storage Length Calculations discussion immediately following Table 3-3A.***

[D]***The minimum storage length shall apply when: 1) the required queue storage length calculated is less than the minimum length, or 2) there is no rational method for estimating the left-turn volume.***

[E]The calculated queue storage at unsignalized location using a traffic model or simulation model or by the following:

L = (V/30)(2)(S)

Where: (V/30) is the left-turn volume in a two-minute interval and other terms are as defined in the Storage Length Calculations discussion immediately following Table 3-3A.

The required storage length is based on the anticipated queue with 100 ft [30 m] being the minimum (see Table 4-6). Because right turns on red are prohibited, the queue should be determined. The required storage may be obtained using an acceptable traffic model such as the latest version of the HCM software (HCS), CORSIM, SYNCHRO, VISSIM, or other acceptable simulation models, as suggested in the *Roadway Design Manual*. However, if those techniques have not been used, then the queue may be estimated by the following equation:

L = (V/N)(2)(S)

Where:

L = storage length, ft

V = turning volume per hour, vph

N = number of cycles/hour for the traffic signal

2 = factor that provides for all left-turning vehicles on most cycles; a value of 1.8 may be acceptable on collector streets,

S = queue storage length per vehicle, ft.

The storage length of vehicle, S, is determined by the percentage of trucks. The *Roadway Design Manual*[1] provides the following:

% of Trucks	*S, ft [m]*
<5	**25 [7.6]**
5 to 9	30 [9.1]
10 to 14	35 [10.7]
15 to 19	40 [12.2]

Because the percent trucks on Jackson Rd. is 4, S is determined to be 25 ft [7.6 m]. The number of cycles per hour is determined by the cycle length used at the intersection, 90 sec, or 40 cycles per hour. Substituting in the equation:

L = (160 vph/40)(2)(25)

L = 200 ft [61 m]

♦ *Step 2: Check through lane queue.*

The queue length of 200 ft [61 m] should be compared to the estimated through-lane queue, to see if that queue will extend far enough to block vehicles from entering the right-turn lane. The same technique is used to estimate the through-lane queue.

The approach volume of 720 vph should be reduced by the number of vehicles turning right, 160, leaving 560 vehicles. Assuming that the remaining traffic is distributed evenly in the left lane (through and left-turning vehicles) and the right lane (through vehicles), this volume should be divided by two to determine the number of vehicles per lane of 280 vph. This volume of 280 vph is then used in the equation:

L = (280 vph/40)(2)(25)

L = 350 ft [107 m]

Because the through-lane queue is estimated to be longer than the right-turn lane queue, its length is used for the design of the right-turn lane.

The right-turn deceleration lane consists of a 345-ft [105 m] deceleration length and a 350-ft [107 m] storage length, for a total length of 695 ft [212 m]. Using a 100-ft [30 m] taper and 25-ft [7.6 m] radius, the full width length is 570 ft [174 m].

The lengths determined for the right-turn lane may not always be achievable because of factors such as the block length; it may not always be practical to accommodate the through-lane queue.

The downstream end of a right-turn lane is normally calculated to end at the face of the curb on the cross street as shown in Figure 3-4 of the *Roadway Design Manual* <link>. This design is shown in Figure 4-17. In this case, however, the city has requested that the overall length be calculated to end at the stop bar of the intersection so that the design does not depend on drivers stopping past the stop line and blocking the crosswalk. The completed right-turn lane design is shown in Figure 4-18.

The width of the right-turn lane was selected from Table 3-1 of the *Roadway Design Manual*. The range allowed is 11 to 12 ft [3.4 to 3.7 m] desirable and 10 ft [3 m] minimum; a 12-ft [3.7 m] lane width was selected.

- *Step 3: Relocate signal poles, sidewalks, and pharmacy driveway.*

As shown in Figure 4-17, the pharmacy driveway has been relocated onto Park Drive. This reduces the conflicts between the traffic queues at the traffic signal and vehicles entering the pharmacy driveway (see *Urban Intersection Design Guide*, Chapter 11, Section 3 <link>). This type of solution may not always be practical; TxDOT's *Access Management Manual* should be consulted for further guidance.

Although the telephone cable appears to be located in an acceptable location in Figure 4-17, its location should be confirmed in the field to determine any need for increased burial depth or other modification to the line.

The traffic signal poles have been relocated to avoid conflicts with the curb ramps and to relocate them for the widened roadway. This will result in the use of longer traffic signal mast arms, larger support poles, and larger pole foundations (see *Urban Intersection Design Guide*, Chapter 8, Section 3 <link>).

The width of the median at the west side of the intersection was originally 4 ft [1.2 m]. This is less than the preferred 6 ft [1.8 m] or minimum 5 ft [1.5 m] for pedestrian refuge (see *Urban Intersection Design Guide*, Chapter 4, Section 5 <link>) so the crosswalk and ramps were relocated, and 6 ft [1.8 m] was provided. The east side was satisfactory without modification.

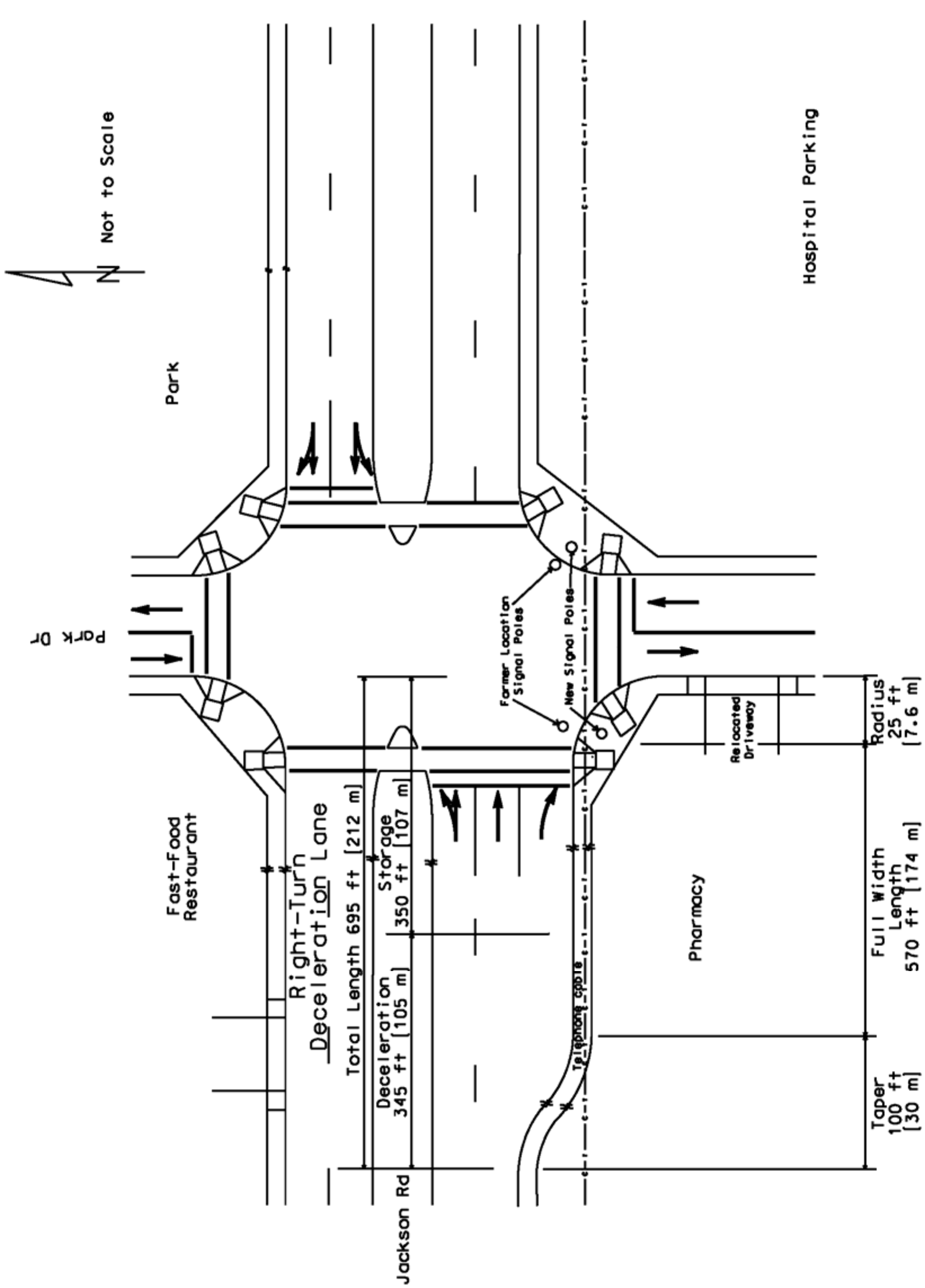


Figure 4-17. Design of Right-Turn Lane; Right-Turn Lane Design Ending at Cross-Street Curb.

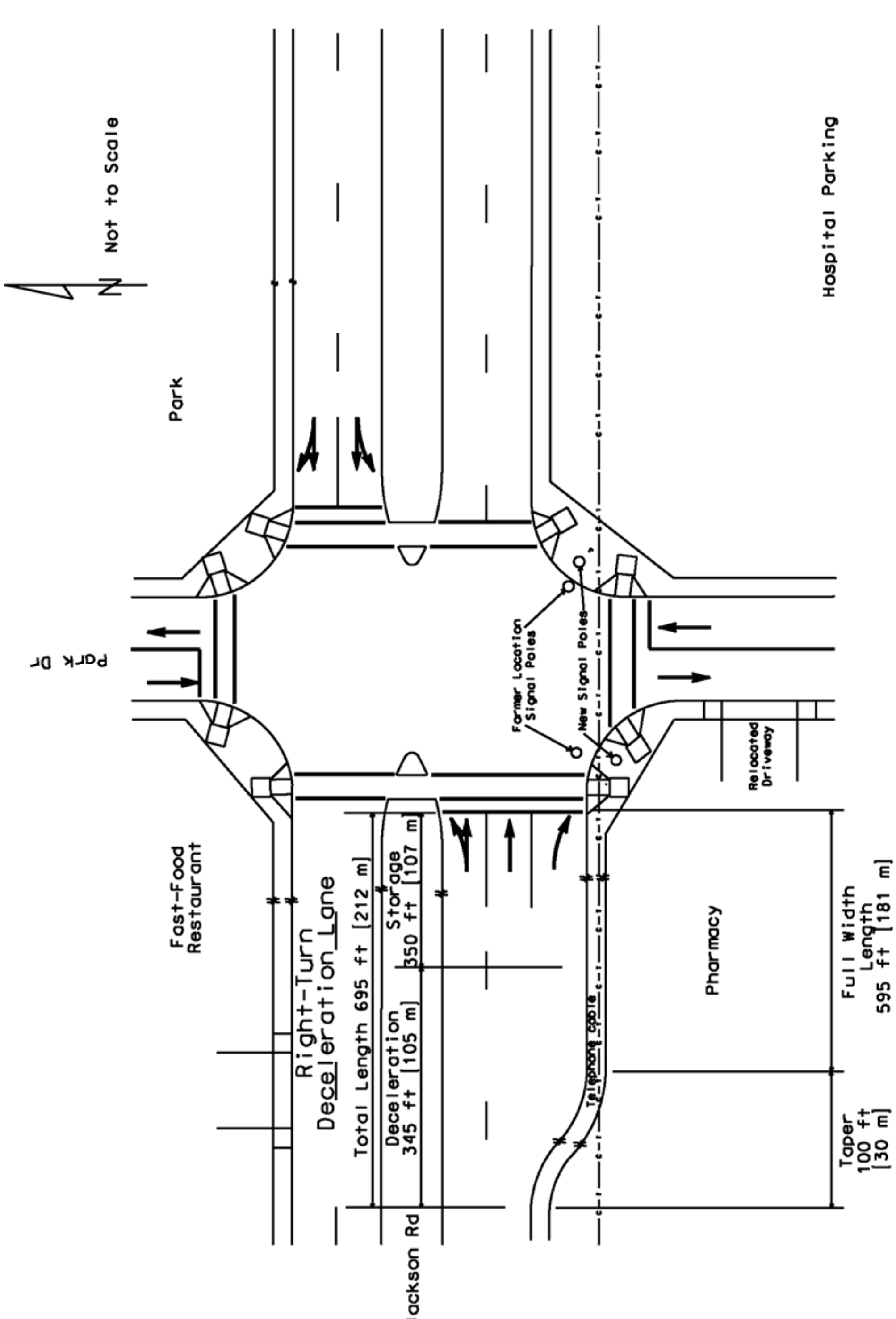


Figure 4-18. Design of Right-Turn Lane; Right-Turn Lane Design Ending at Stop Bar.

Application 7
Auxiliary Lane Improvements

Overview

The following application presents a situation where a right-turn lane is being added. The *Urban Intersection Design Guide*, Chapter 4, Section 3 <link> provides information on right-turn lane design.

Background

An intersection of two arterials exists within a developed area of a city of approximately 100,000. (See Figure 4-19.) Pine Road is a 62-ft-wide [19 m], five-lane arterial with a continuous center, two-way left-turn lane. A traffic signal exists at the intersection of Pine Road and David Boulevard. At this intersection, Pine Road has left-turn lanes on both approaches. The daily traffic volume on Pine Road is about 17,000.

David Boulevard is an old city street that originated as a collector street between the city's downtown area and its original residential developments, but it slowly evolved into an arterial street as traffic volumes increased and as the street continued to be extended from its original design length. Several years ago, David Boulevard was widened east of Pine Road from its original 40-ft-wide [12 m] cross section to a 55-ft-wide [17 m] cross section consisting of two travel lanes in each direction and a continuous center two-way left-turn lane. Right-of-way constraints limited the width of the widening project. West of Pine Road, David Boulevard maintained its 55-ft-wide [17 m] cross section for a distance of 150 ft [46 m], and then tapered back to its original 40-ft-wide [12 m] cross section.

Currently, David Boulevard has a daily traffic volume of about 15,000 vehicles. Extensive redevelopment northwest of the intersection of David Boulevard and Pine Road is expected within the next two to 4 years, partially due to an existing medical complex expanding its facilities and an existing junior college campus growing from an enrollment of about 6000 to 12,000. In order to accommodate the expected growth in traffic volumes, city officials plan to widen David Boulevard west of Pine Road to provide additional roadway capacity, make additional operational efficiency improvements, improve transit operations, and provide for expected increases in pedestrian traffic.

In anticipation of the future widening of David Boulevard, the city obtained right-of-way dedications from new developments as they occurred adjacent to the north and south side of the street. In addition, because Bobcat Drive is the only entrance to the junior college from David Boulevard, the city obtained additional right of way from the landowner to eventually construct a right-turn lane on the westbound David Boulevard approach to Bobcat Drive. Bobcat Drive also provides access to part of the medical complex as well.

The city is prepared to design the David Boulevard widening project and is attempting to determine the most cost-effective design that will incorporate as much available right of way as possible and maximize operational efficiency.

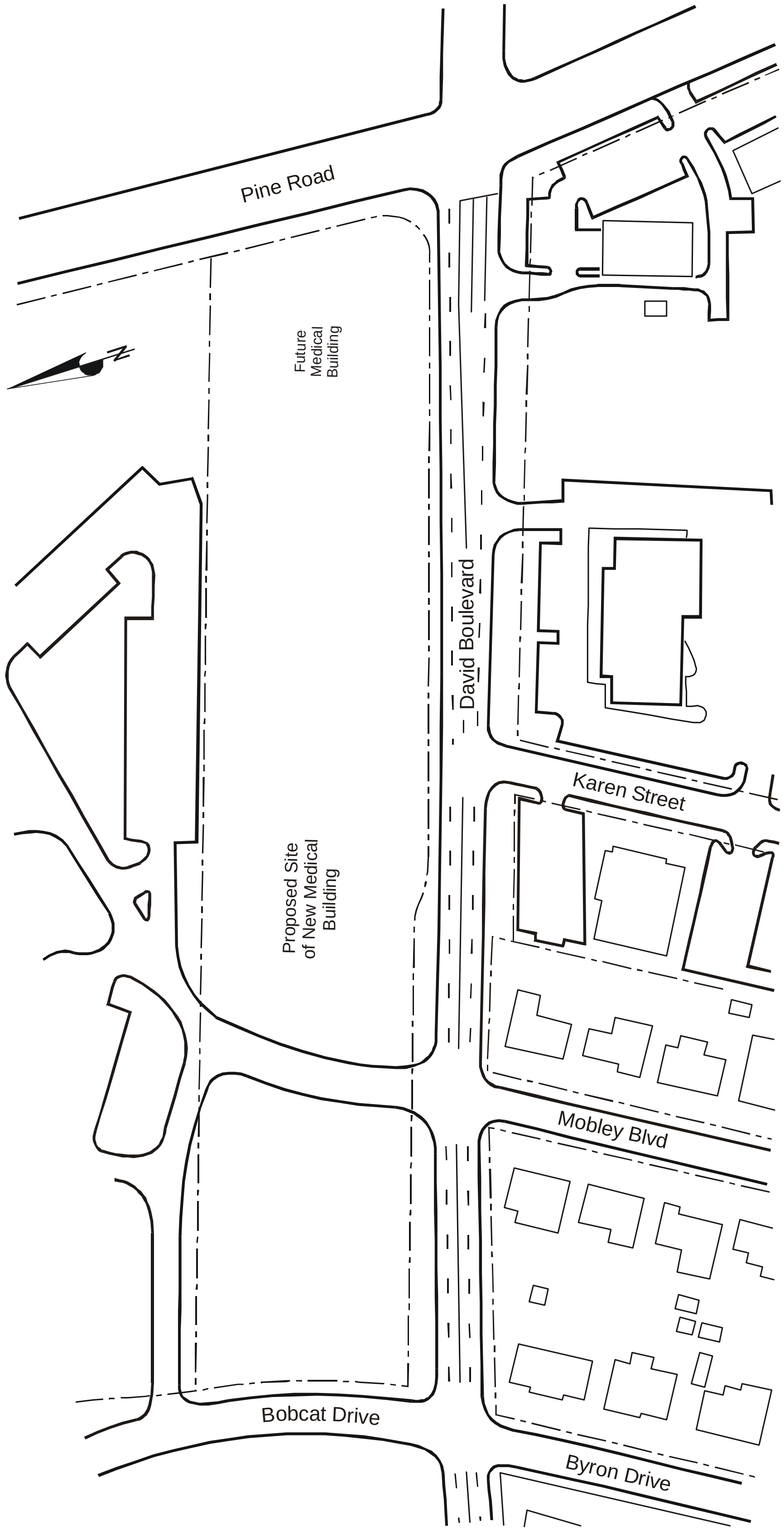


Figure 4-19. Existing Conditions.

Issues Considered

As shown in Figure 4-19, the properties south of David Boulevard and west of Karen Street are primarily residential properties that have rights of way very close to the existing curb lines. Existing houses also are located relatively close to David Boulevard. Obtaining right of way from these residential properties will be difficult, and purchasing these homes would be costly. Also, an overhead power line is located along the south side of David Boulevard that would have to be removed or relocated if the arterial is widened along that side of the street. Hence, widening David Boulevard on the south side would likely be very costly.

The property along the north side of David Boulevard between Pine Road and Bobcat Drive is undeveloped; however, two tracts have planned medical buildings and access to those properties has already been promised, as illustrated in Figure 4-19. There is little doubt that future development along the north side of David Boulevard between these two streets will attract a substantial number of vehicles. In contrast, the existing properties along the south side of David Boulevard are expected to generate only a minimal amount of traffic.

Ultimately, a traffic signal will be installed at the intersection of David Boulevard and Bobcat Drive. This signal will be justified due to the large number of vehicles entering and exiting Bobcat Drive to and from the college campus and the medical complex. The roadway intersecting David Boulevard on the south side across from Bobcat Drive, Byron Drive, is a low-volume, local street. Signalizing a low-volume, local street would encourage additional traffic onto that residential street.

The city's decision to obtain right of way to provide a right-turn lane on the westbound David Boulevard approach to Bobcat Drive was commendable. However, as shown in Figure 4-20, the right of way would provide a right-turn lane that would begin a short distance east of the northwest hospital entrance. Therefore, it would not serve the entrance to the hospital. The city made the decision that the right-turn lane should be extended further to the east. Again, the additional extension of the right-turn lane to serve the hospital would not serve the entrance to the future medical building on the corner of the intersection of Pine Road and David Boulevard. The logical conclusion is that a right-turn lane (or essentially an additional travel lane used primarily for right turns into and out of adjacent properties) would be desirable along David Boulevard from the intersection of Pine Road to Bobcat Drive.

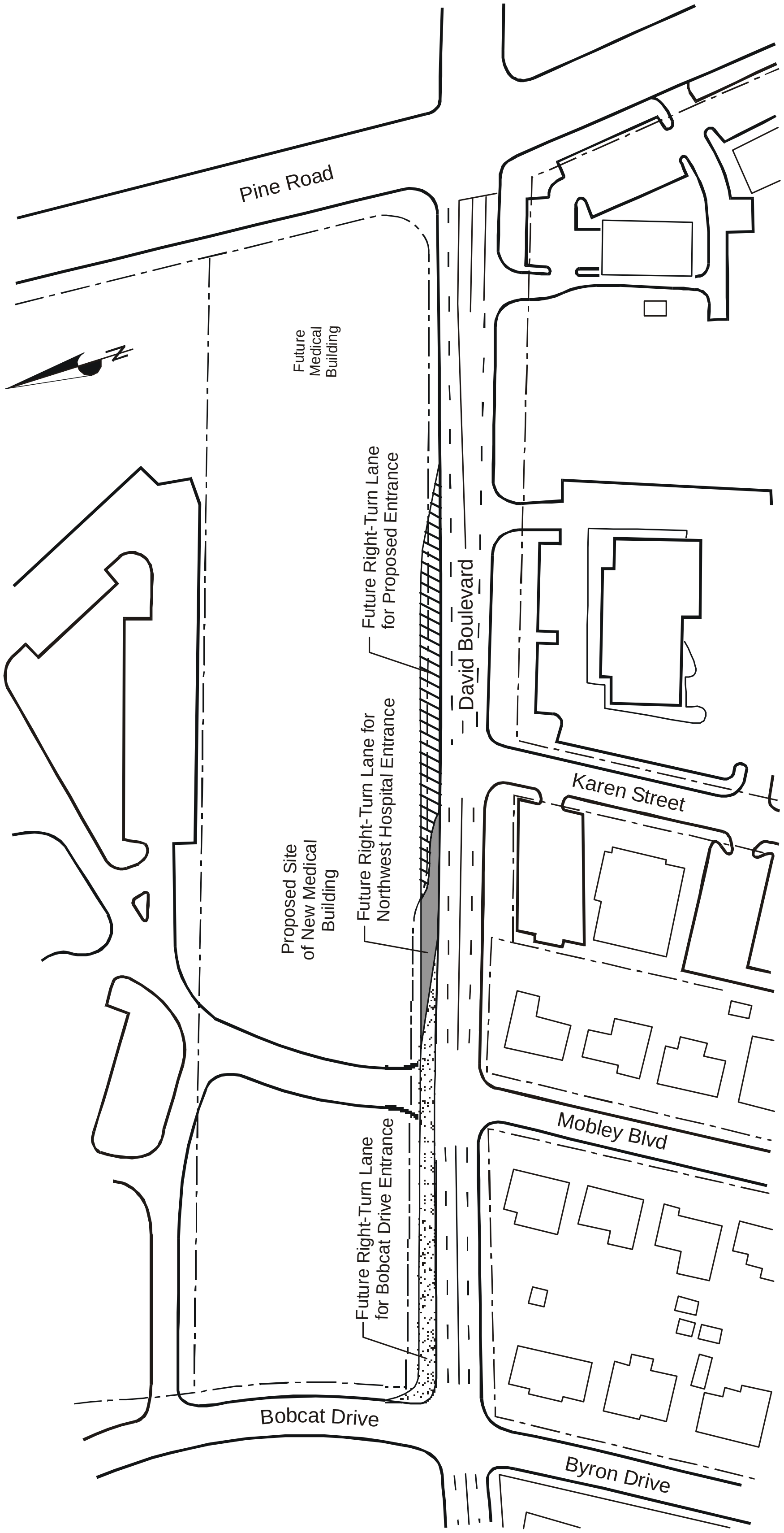


Figure 4-20. Turn-Lane Recommendations.

Design Selected

The widened section of David Boulevard west of Pine Road required design features for intersections of two arterials and for several intersections of an arterial with numerous local streets and driveways. While it is desirable to limit intersections of arterials with driveways and restrict intersections of arterials with local streets, real world conditions require compromises. The primary design goal was to maximize operational efficiency on David Boulevard. The widening of the roadway to a 55-ft-wide [17 m] cross section to provide two lanes in each direction and a continuous center, two-way left-turn lane was the primary design element to accomplish this objective. This selected cross section (which was limited to a 55-ft-wide [17 m] cross section because of minimal right of way availability) widened existing travel lanes and provided an additional center lane for left-turning vehicles. Both of these geometric improvements increased roadway capacity and operational efficiency. The widening was designed to occur solely on the north side of David Boulevard because right of way could be most easily obtained from undeveloped land, and the proposed widened section was continued along the north side of David Boulevard west of Bobcat Drive for another 0.5 mi [0.8 km]. (See Figure 4-21.)

Because future development would generate high volumes of vehicles turning right from westbound David Boulevard into the developments (and right-turn exits onto David Boulevard), a right-turn lane was designed along the north side of the widened David Boulevard. This right-turn lane provided numerous operational benefits for David Boulevard. Vehicles could use the right-turn lane to decelerate before turning into the several driveways along David Boulevard and to accelerate after turning from the driveways onto David Boulevard. Because these diverging and merging movements could be made at higher speeds, there would be less interference with the westbound “through” vehicles on David Boulevard, which would maintain operational efficiency for through traffic.

The auxiliary right-turn lane provides storage areas for right-turning vehicles regardless of turning demands. Without this lane, large numbers of right-turning vehicles accessing one or more of the driveways would slow down or block the outside traffic lane, which would significantly affect operational efficiency on both David Boulevard westbound travel lanes. Large, slow-moving vehicles making turns from travel lanes have much more negative impact on traffic flow efficiency. By providing long return radii at the driveways, larger vehicles could use the right-turn lane without interfering with traffic on the two through lanes.

The auxiliary right-turn lane also provided the opportunity for construction of a continuous right turn from southbound Pine Road onto westbound David Boulevard. The continuous right turn from southbound Pine Road onto westbound David Boulevard also will increase the traffic signal operational efficiency at the intersection of the two streets. The continuous right turn allows these right-turning vehicles to merge into the westbound through lanes of David Boulevard with greater efficiency as well.

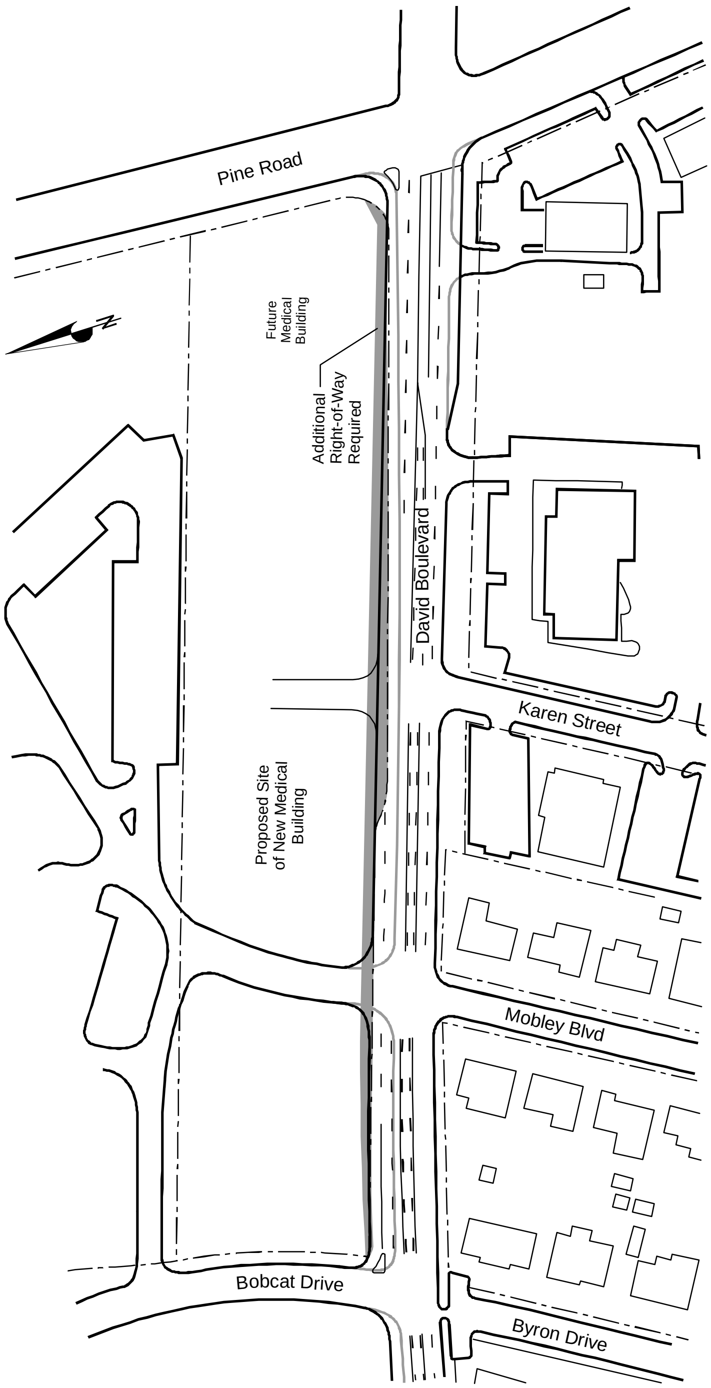


Figure 4-21. Selected Design.

Because the right-turn lane would be used primarily by vehicles entering or leaving the properties along David Boulevard, a bus stop could be located along the lane an adequate distance from Pine Road. The additional travel lane would provide westbound buses with the opportunity to pull into the lane to decelerate to its stop and then accelerate before returning to the westbound through travel lanes. A bus stop for eastbound buses could be established at the intersection of David Boulevard and Bobcat Drive. Pedestrian signals at the intersection will provide assistance for transit riders who desire to cross David Boulevard near the bus stop. Bus transit operations are expected to benefit from these improvements and have minimal effect on David Boulevard traffic flow conditions.

There was some discussion in the design phase of the project about constructing islands along the right-turn lane to force vehicles to turn right into the driveways. These islands could be painted or raised. The decision concerning painted islands was quickly resolved. Painted islands would have little or no effect as a method of forcing vehicles to turn right. Motorists would determine quickly that the pavement continues past the painted islands and would travel across the island if they considered this action convenient. Construction of raised islands would, however, force the right turns to be made. However, the raised islands would interfere with bus operations, minimize lengths available for vehicle acceleration and deceleration, reduce storage capacity for right-turning vehicles, and reduce overall operational capacity. Hence, it was determined that the only raised island that would be constructed would be at the end of the deceleration lane at the Bobcat Drive intersection.

The disadvantages of the auxiliary right-turn lane included additional cost for construction and right of way. However, the disadvantages associated with the additional costs for construction and right of way were determined to be minimal and more than offset by the improvement to operational efficiency. A negative result from the roadway widening project was the need to increase pedestrian crossing times. The crossing distance for pedestrians increased from 40 ft to 55 ft, with the amount of additional time required for the crossing being relatively small. The pedestrian crossings at the signalized intersections of David Boulevard with Pine Road and Bobcat Drive will have pedestrian signals to increase pedestrian safety. Hence, provisions were made to accommodate pedestrians along the corridor.

In regards to the pedestrian crossing concerns, it was readily apparent that anticipated developments along the south side of David Boulevard likely would not generate a substantial amount of pedestrian crossings within the street’s five-lane cross section. Should the land use on the south side of David Boulevard change or if an increase in pedestrian crossings between Pine and Bobcat is observed, an additional marked pedestrian crossing could be installed at Karen Street or Mobley Boulevard.

Accommodation of bus transit was considered to determine how transit could be incorporated into the project’s design. The junior college had a small bus shuttle operation that transported students from the interior of the campus to nearby parking lots and apartment complexes. Experience with the shuttle bus system indicated that few students rode the city transit buses to and from the campus. The city also had a good paratransit system for older residents and individuals with disabilities. Hence, many of the patients traveling to the medical complex (and the rehabilitation center) would be able to receive door-to-door service. It was anticipated that bus service to the area would be desirable but ridership levels in city transit buses likely would remain moderate at best.

Because additional right of way was available along the south side of David Boulevard near the intersection of Pine Road, a right-turn lane also was designed for the eastbound David Boulevard approach to Pine Road. The additional right of way presented other geometric options for consideration. One option was to widen the intersection approach and provide a median storage area for pedestrians. This option was not selected primarily because greater overall operational improvements were anticipated with the additional right-turn lane.

The installation of traffic signals at the intersection of David Boulevard and Bobcat Drive would create an interesting operational problem for Byron Drive, the local street located opposite of Bobcat Drive. It is unusual for a local street to intersect an arterial street. It is also unusual for an intersection of an arterial street and a local street to be signalized. If Byron Drive remains accessible from David Boulevard, traffic volumes on Byron Drive likely will increase as neighborhood traffic would be attracted to the signalized intersection. Hence, Byron Drive would begin to operate more like a collector street than a local street. Byron Drive does not have the cross section or pavement structure necessary to accommodate higher traffic volumes; therefore, additional treatment of the intersection of Byron Drive and David Boulevard was necessary.

The two options considered for intersection treatment were turn restrictions or street closure. The intersection could be redesigned to allow right turns into and out of Byron Drive. This treatment would reduce the amount of accessibility to Byron Drive, but the right turns would affect the intersectional traffic flow. Closure of Byron Drive would be the preferred treatment, because it would restrict all vehicular traffic from accessing David Boulevard via Byron Drive.

The street closure could be designed as a circular cul-de-sac, or it could be constructed as shown in Figure 4-21. The closure could be designed to permit bicycle and pedestrian access to David Boulevard. The closure of Byron Drive would allow the street to function as a local street, as it was intended. Also, traffic volumes on Byron Drive would remain low and residents along the street would not have to contend with increased traffic volumes, which would exist if the street was not closed.

The street closure also would permit the intersection of David Boulevard and Bobcat Drive to function as a T-intersection, which can operate more efficiently than a signalized four-legged intersection. Also, T-intersections have fewer conflict points created by turning vehicles. Fewer conflict points result in less vehicle interaction and fewer accidents. Hence, the closure of Byron Drive would result in more operational efficiency and increased safety.

Application 8
Island Offsets

Overview

The design of corner islands at intersections is presented in the *Urban Intersection Design Guide,* Chapter 4, Section 5 <link>. The designs have offsets to the curb lines of the roadway depending on their characteristics.

Background

This example will review the effects of corner radius and pedestrian facilities on the design of corner islands. A turning roadway width of 14 ft [4.3 m] is used in each of the three cases examined.

Issues Considered

The design of corner islands depends on a number of issues, including:

- corner radius or more complex curvature (see *Urban Intersection Design Guide,* Chapter 3, Section 3, Turning Radius <link>, and *Urban Intersection Design Applications,* Chapter 3, Application 9 <link>;
- island size (see *Urban Intersection Design Guide,* Chapter 4, Section 4, Channelization <link>, and Section 5, Island and Median Design <link>);
- design vehicle (see *Urban Intersection Design Guide,* Chapter 2, Section 1, Motorized Vehicles <link>; and
- pedestrian facility characteristics (see *Urban Intersection Design Guide,* Chapter 7, Sections 1 and 2 <link>, and *Urban Intersection Design Guide,* Chapter 4, Section 5, Island and Median Design).

Figure 4-16 of the *Urban Intersection Design Guide* <link> provides details regarding curb offsets on urban streets. Some island dimensions depend upon its classification as “large,” “intermediate,” or “small.” The *Green Book* provides the following guidance on island classification:

- Small: area of approximately 50 ft^2 [5 m^2] normally or 100 ft^2 [9 m^2] preferable
- Large: side dimension of at least 100 ft [30 m]

Proposed Design, 100-ft [30 m] Turning Radius

- *Step 1: Establish island outer boundary and size.*

As shown in Figure 4-22, the island was first sketched using the corner radii and offsets indicated in Figure 4-16 of the *Urban Intersection Design Guide* <insert link to *Guide* Figure 4-16>.

The initial estimates of its size indicated either a large or intermediate classification, so the island was designed in a manner consistent with those requirements shown in Figure 4-16 of the *Urban Intersection Design Guide*. As shown, the island has the following characteristics:

- Area: 584 ft^2 [54 m^2]
- Edge dimensions: approximately 43 ft [13 m] by 35 ft [11 m] by 35 ft [11 m]

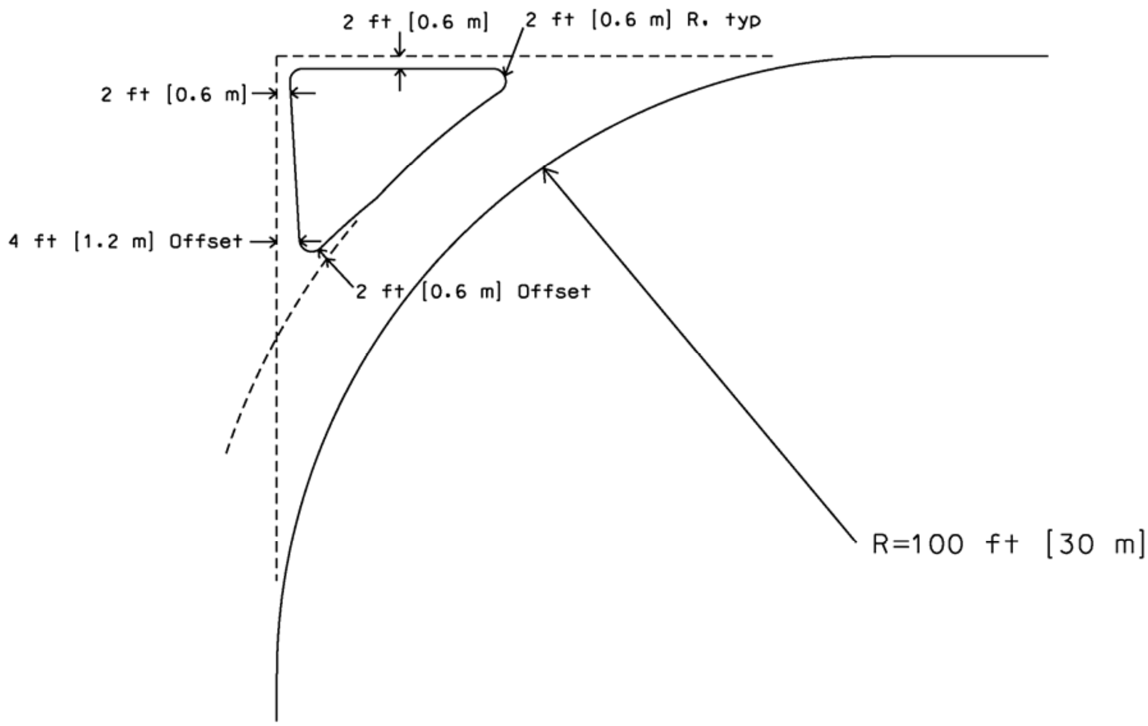


Figure 4-22. 100-ft [30 m] Turning Radius and Island.

Reviewing the classification guidelines from the *Green Book*,[4] the area is considerably larger than the minimum island size (584 ft^2 [54 m^2] compared to a preferred minimum of 100 ft^2 [9 m^2]), indicating either a "large" or "intermediate" island. To be classified as a large island, the island's edge dimensions must be greater than 100 ft [30 m]. The edge dimensions for the island are less than the requirement, so it is classified as an intermediate island.

The design as initially developed is consistent with the intermediate island dimensions and offsets shown in Figure 4-16 of the *Urban Intersection Design Guide* <insert link to *Guide* Figure 4-16>. The island will be curbed to provide delineation for the traffic movements at the intersection. This is acceptable because it exceeds the preferred minimum area of 100 ft^2 [9 m^2] for a curbed island.[1]

The island is offset from the projected through lane face of curb by 2 to 3 ft [0.6 to 0.9 m]; the nose of the island on the approach end is offset an additional amount for a total 4 to 6 ft [1.2 to 1.8 m] offset. The nose of the island is also offset from the right-turn traffic by 2 to 3

[4] American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets.* AASHTO, Washington, D.C., 2001.

ft [0.6 to 0.9 m]. The radii used for the corners of the islands may be 2 to 3 ft [0.6 to 0.9 m] on the island noses and 2 to 5 ft [0.6 to 1.5 m] on the 90-deg corner. Figure 4-22 shows the offsets selected for this particular design.

♦ *Step 2: Design pedestrian crossing.*

Pedestrian crossings of curbed islands can use curb ramps to rise to the surface of an island if sufficient width is available to accommodate the curb ramps and their associated landing areas. The curb ramps are 4 ft [1.2 m] wide, while the landing areas are 5 ft by 5 ft [1.5 m by 1.5 m]. If the available island width is inadequate for curb ramps, 5-ft [1.5 m] cuts may be provided through the island to allow passage for pedestrians.

As shown in Figure 4-23, space is adequate to provide curb ramps and a landing on the island. The curb ramps should be aligned perpendicular to the curb and end within the provided crosswalks. The curb ramps are each shown with a 5 ft by 5 ft [1.5 m by 1.5 m] landing area blocked out at the top of the curb ramp; the curb ramps would actually be constructed to the top of a uniformly surfaced island. Overlapping the landing areas in this manner is permissible.

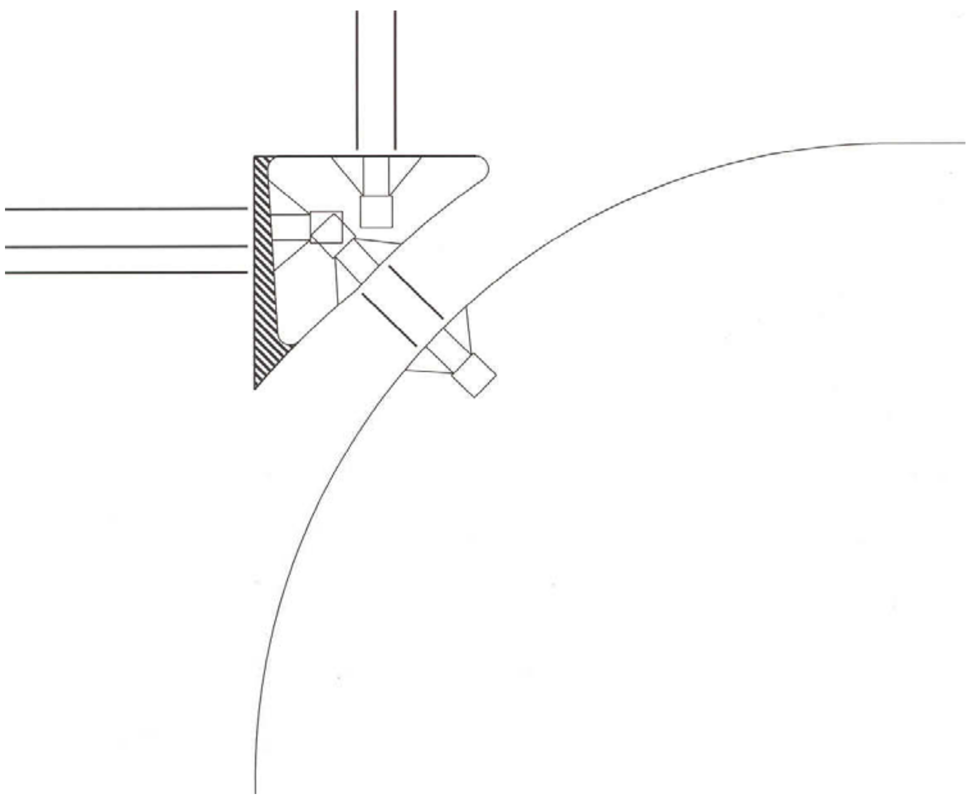


Figure 4-23. 100-ft [30 m] Turning Radius Island with Pedestrian Elements.

Figure 4-23 also includes the pavement markings used at the intersection, and includes crosswalk and stop line markings. For further information regarding crosswalks see the *Urban Intersection Design Guide*, Chapter 7, Section 2 <link>. Transverse markings are also provided on the through side approaching the nose of the island, as shown in Figure 4-16 of the *Urban Intersection Design Guide* “Pedestrian and Bicyclist Accommodation” <link>.

Proposed Design, 60-ft [18 m] Turning Radius

♦ *Step 1: Establish island outer boundary and size.*

As shown in Figure 4-24, the island was first sketched using the corner radii and offsets indicated in Figure 4-16 of the *Urban Intersection Design Guide* <link>. Some of the dimensions for the island depend upon its classification as “large,” “intermediate,” or “small.” The initial estimates of its size indicated that it probably met requirements for a small classification, so the island was designed in a manner consistent with those requirements. As shown, the island has the following characteristics:

- Area: 140 ft^2 [13 m^2]
- Edge dimensions: approximately 19 ft [6 m] by 13 ft [4 m] by 13 ft [4 m]

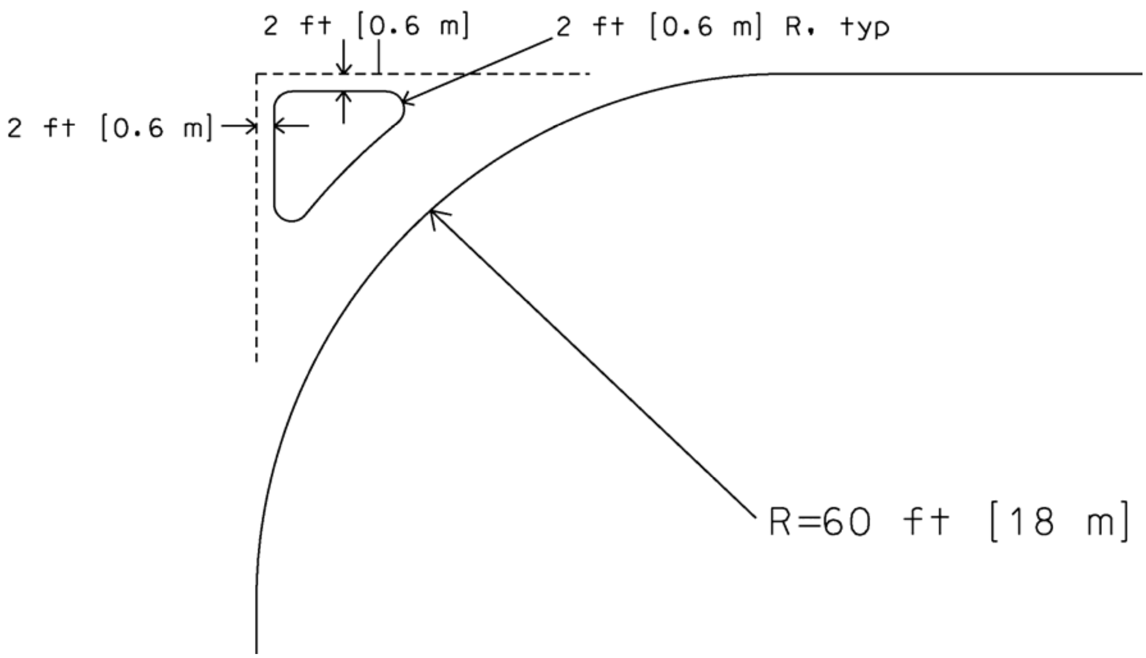


Figure 4-24. 60-ft [18 m] Turning Radius and Island.

Reviewing the classification guidelines from the *Green Book*, the area is near the minimum island size (140 ft^2 [13 m^2] compared to the preferred minimum 100 ft^2 [9 m^2]) and its outer dimensions are considerably less than 100 ft [30 m]. The island is thus classified as small.

The design as initially developed is consistent with the small island dimensions and offsets shown in Figure 4-16 of the *Urban Intersection Design Guide*. This size is acceptable because it exceeds the minimum area of 50 ft^2 [5 m^2] for a curbed island.[1] The island will be curbed to provide delineation for the traffic movements at the intersection, with 2-ft [0.6 m] offsets from the through traffic lanes and 2-ft [0.6 m] radii on the corners.

♦ *Step 2: Design pedestrian crossing.*

The small island size is not sufficient to provide room for the pedestrian curb ramps and their landing areas, so 5-ft [1.5 m] cuts were provided through the island to allow passage. The cuts are aligned with the crosswalks as shown in Figure 4-25.

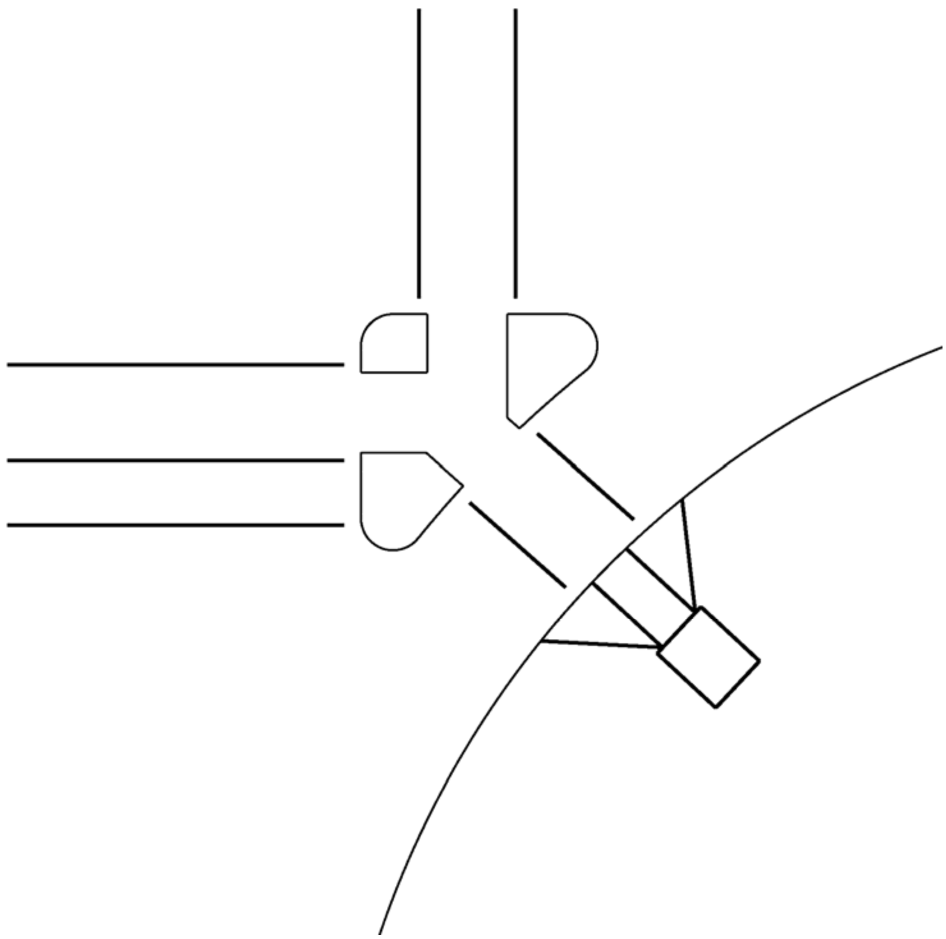


Figure 4-25. 60-ft [18 m] Turning Radius Island with Pedestrian Elements.

Proposed Design, 60-ft [18 m] Simple Curve Turning Radius with Taper

♦ *Step 1: Establish island outer boundary and size.*

As shown in Figure 4-26, the island was first sketched using the corner radii and offsets indicated in Figure 4-16 of the *Urban Intersection Design Guide* <link>. The initial estimates of its size indicated that it probably met requirements for a small classification, so the island was designed in a manner consistent with those requirements. As shown, the island has the following characteristics:

- Area: 180 ft^2 [17 m^2]
- Edge dimensions: approximately 22 ft [7 m] by 16 ft [5 m] by 16 ft [5 m]

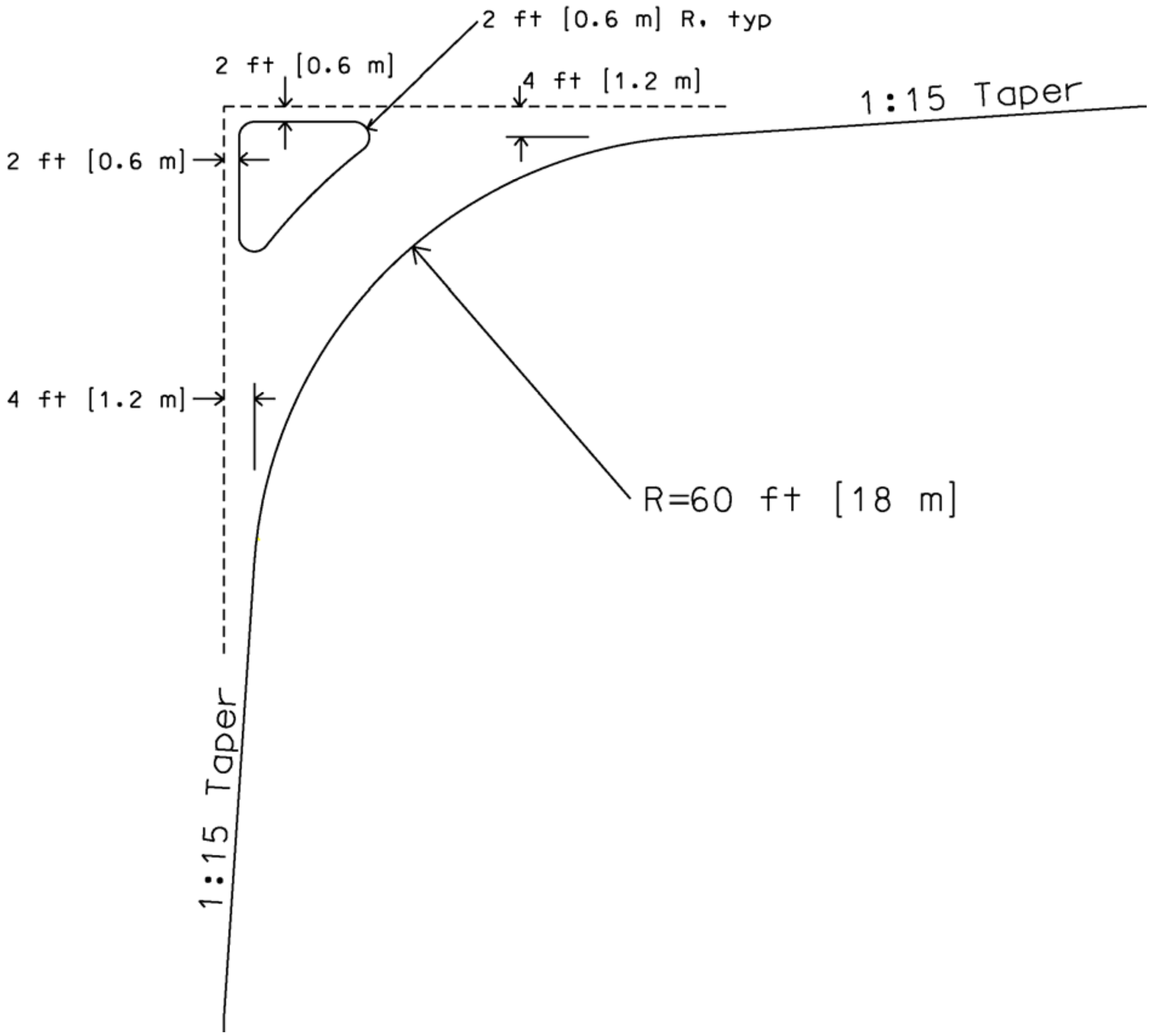


Figure 4-26. 60-ft [18 m] Simple Curve Turning Radius with Taper and Island.

Reviewing the classification guidelines from the *Green Book*,[4] the area is near the minimum island size (180 ft^2 [17 m^2] compared to a preferred minimum of 100 ft^2 [9 m^2]) and its outer dimensions are considerably less than 100 ft [30 m]. The island is thus classified as small.

The design as initially developed is consistent with the small island dimensions and offsets shown in Figure 4-16 of the *Urban Intersection Design Guide*. This size is acceptable because it exceeds the preferred minimum area of 100 ft^2 [9 m^2] for a curbed island.[1] The island will be curbed to provide delineation for the traffic movements at the intersection, with 2-ft [0.6 m] offsets from the through traffic lanes and 2-ft [0.6 m] radii on the corners.

- *Step 2: Design pedestrian crossing.*

The small island size is not sufficient to provide room for the pedestrian curb ramps and their landing areas, so 5-ft [1.5 m] cuts were provided through the island to allow passage. The cuts are aligned with the crosswalks as shown in Figure 4-27.

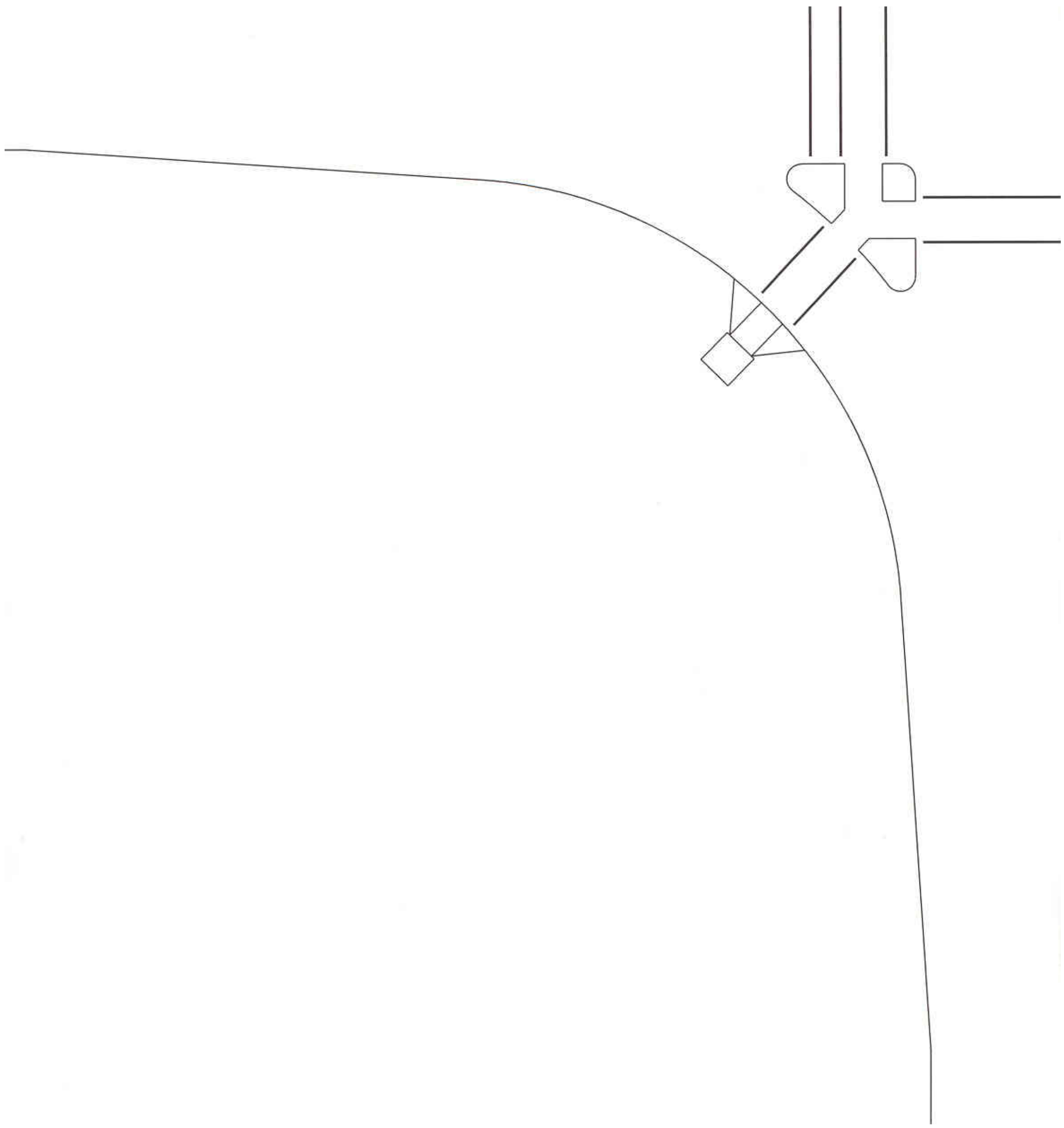


Figure 4-27. 60-ft [18 m] Simple Curve Turning Radius Island with Taper with Pedestrian Elements.

Application 9
Median Design for Large Vehicles

Overview

The following application presents a situation where a design vehicle impacts design decisions. The *Urban Intersection Design Guide,* Chapter 4, Section 5 <link> provides information on island and median design.

Background

A city of over 400,000 is planning the widening of an existing arterial street, Morgan Avenue, that is 33 ft [10 m] in width from edge of pavement to edge of pavement and has no curbs, to a completely curbed-and-guttered cross section having four lanes and a raised median. The city plans to construct the arterial with a basic cross section of two, 28-ft-wide [9 m] roadway sections (measured face-of-curb to face-of-curb) with an 18-ft-wide [5 m] median. Some of the intersections along the arterial will have more traffic volumes than others, some will have more turning movements than others, some will have more large truck traffic than others, and some will have more pedestrian use than others. However, each redesigned intersection will have to be designed to accommodate pedestrians. The city prefers to design each intersection as required to accommodate the unique conditions for each intersection, but remain essentially consistent with the preferred cross section. Right of way is more than sufficient for the widening project, but the city prefers to keep the cost of roadway construction as low as possible.

Morgan Avenue currently intersects Stanton Drive, a four-lane divided arterial, at an acute angle (see Figure 4-28). It will not be practical to realign either roadway to change the intersecting angle. The proposed new intersection is expected to accommodate a moderate to high amount of traffic with twice the average percentage of buses found at the other intersections. Bus stops currently are located on the near corners of each approach leg. Pedestrian use is expected to be moderate but high during peak hours of operation. The area near the intersection is relatively flat, and there are no obstructions to sight distance at and in the vicinity of the intersection. Furthermore, the intersection's accident history does not indicate any unusual operational or safety problems; however, there have been complaints about the large number of city transit buses interfering with or blocking vehicular traffic at the intersection. The intersection is signalized.

The intersection of Morgan Avenue and Stanton Drive has some unique conditions that are dissimilar to the other intersections along Morgan Avenue. Hence, this intersection generated more interest and was selected for special design considerations. A concern specifically mentioned by the transit agency was in regard to the ability of the city's buses being able to comfortably turn through the intersection.

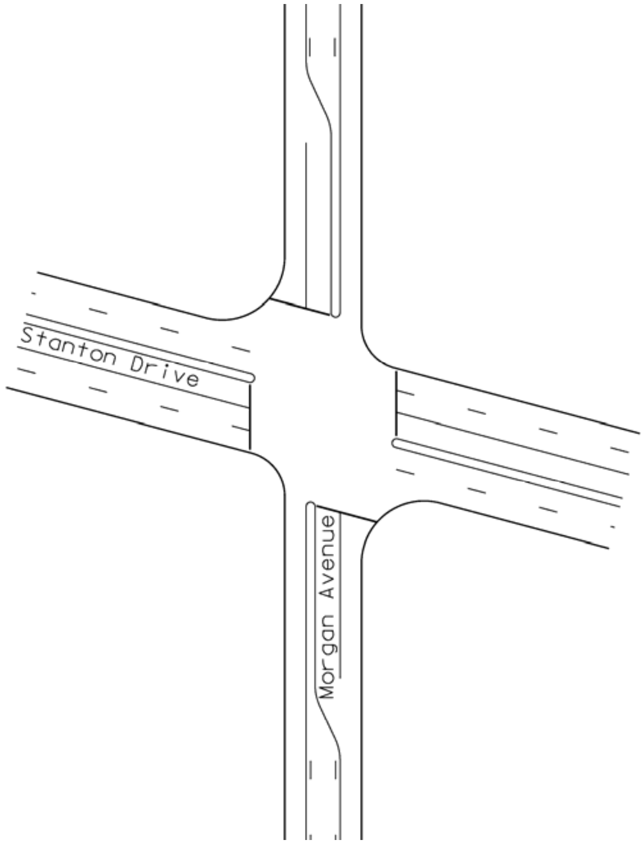


Figure 4-28. Existing Conditions at Morgan Avenue and Stanton Drive.

Issues Considered

In urban areas, intersections on divided roadways need to be designed with operational efficiency in mind but able to accommodate all travel modes. Operational efficiency can be maximized by keeping the intersectional area as small as possible, which minimizes both vehicle clearance times and pedestrian crossing times. Hence, confining the size of the intersection is preferred in urban areas.

Selecting a design for an urban intersection includes the selection of a design vehicle. When designing for a large vehicle, intersections become larger to accommodate the large turning radii required by large vehicles. This larger size is detrimental to efficient operation. At the same time, designing a more confined intersection affects the ability of larger vehicles to make turns at the intersection. The design vehicle chosen for this intersection design is a city transit bus.

The design selected for the intersection of Morgan Avenue and Stanton Drive requires consideration of large vehicle operation (which means a large intersectional area), consideration of pedestrian crossings (which benefit from a small intersectional area), and an attempt to provide operational efficiency for the moderate to high amount of traffic (which can best be accommodated with a small intersectional area). The decision that must be made is whether to design for large vehicles and accommodate pedestrians and the moderate to large traffic volumes, or design for the pedestrians and moderate to large traffic volumes and accommodate the larger vehicles. Obviously, the final design must be a compromise that addresses each of these design considerations.

Proposed Design to Accommodate Turning Buses

There is no absolute right or wrong design decision for this intersection. Because sight distance is not an issue and accidents have not been a problem, then the question that must be answered is whether the intersection should be designed to be slightly more advantageous to operational efficiency and pedestrian movements, or slightly more advantageous for large vehicle operations. Also, the cost considerations were a factor. It is more cost-efficient to build a smaller intersectional area rather than a large intersectional area. The design selected for the median, as shown in Figure 4-29, incorporated aspects of operational efficiency for large vehicles, including buses and pedestrian movements. The intersection was designed to accommodate the turns of buses, and special bus stop locations were provided on each of the downstream sides of the intersection to allow buses to exit the travel lanes to board passengers. An 8 ft by 5 ft [2.4 m by 1.5 m] bus boarding area has been added at each bus stop to comply with ADAAG requirements.[5] Chapter 5, Section 6 <link> of the *Urban Intersection Design Guide* should be consulted for further information regarding bus stop design.

The design of the median was the primary design concern for the intersection at this stage; hence the signal pole and inlet locations are not shown for this example. With the acute angle of intersection, the median had to be "cut back" to accommodate the large vehicle turning maneuvers. Therefore, the resulting design included a mountable median that could be used by the larger vehicle if needed. The mountable median was 10 ft [3 m] in length and was constructed with cast-in-place concrete. The sides of the mountable median were 2 inches [5.1 cm] high at the edges adjacent to the travel lanes, and the median was sloped gradually to its center where its height was 4 inches [10.2 cm]. The design did not permit any vegetative growth in this section of the median, and it allowed the occasional large vehicle to complete its left turn by mounting the median area (Figure 4-30 illustrates the turning path of the design vehicle as it crosses over the mountable median).

[5] U.S. Access Board, *Americans with Disabilities Act Accessibility Guidelines* (ADAAG). September 2002. http://www.access-board.gov/adaag/html

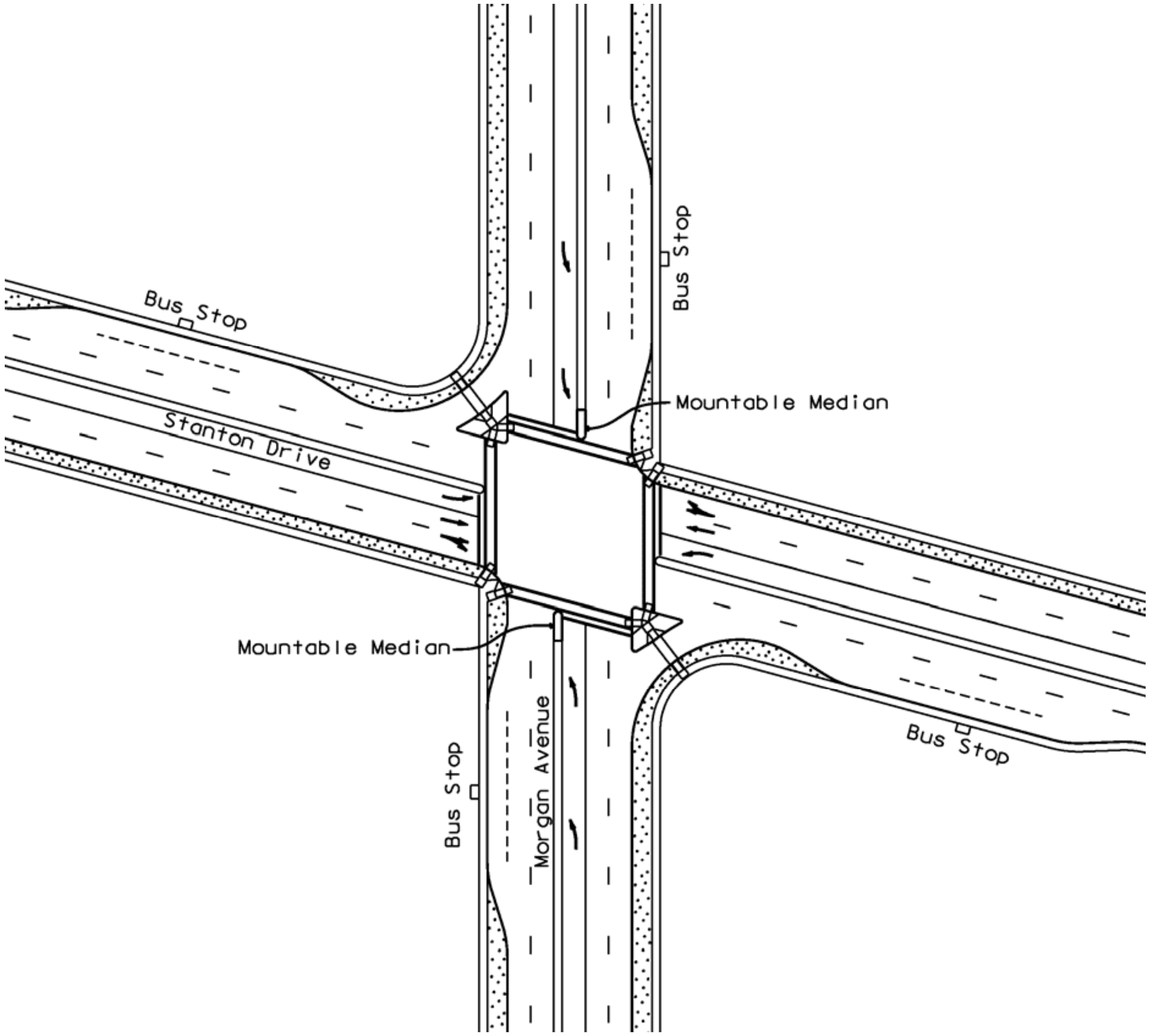


Figure 4-29. Proposed Intersection Design for Morgan Avenue and Stanton Drive.

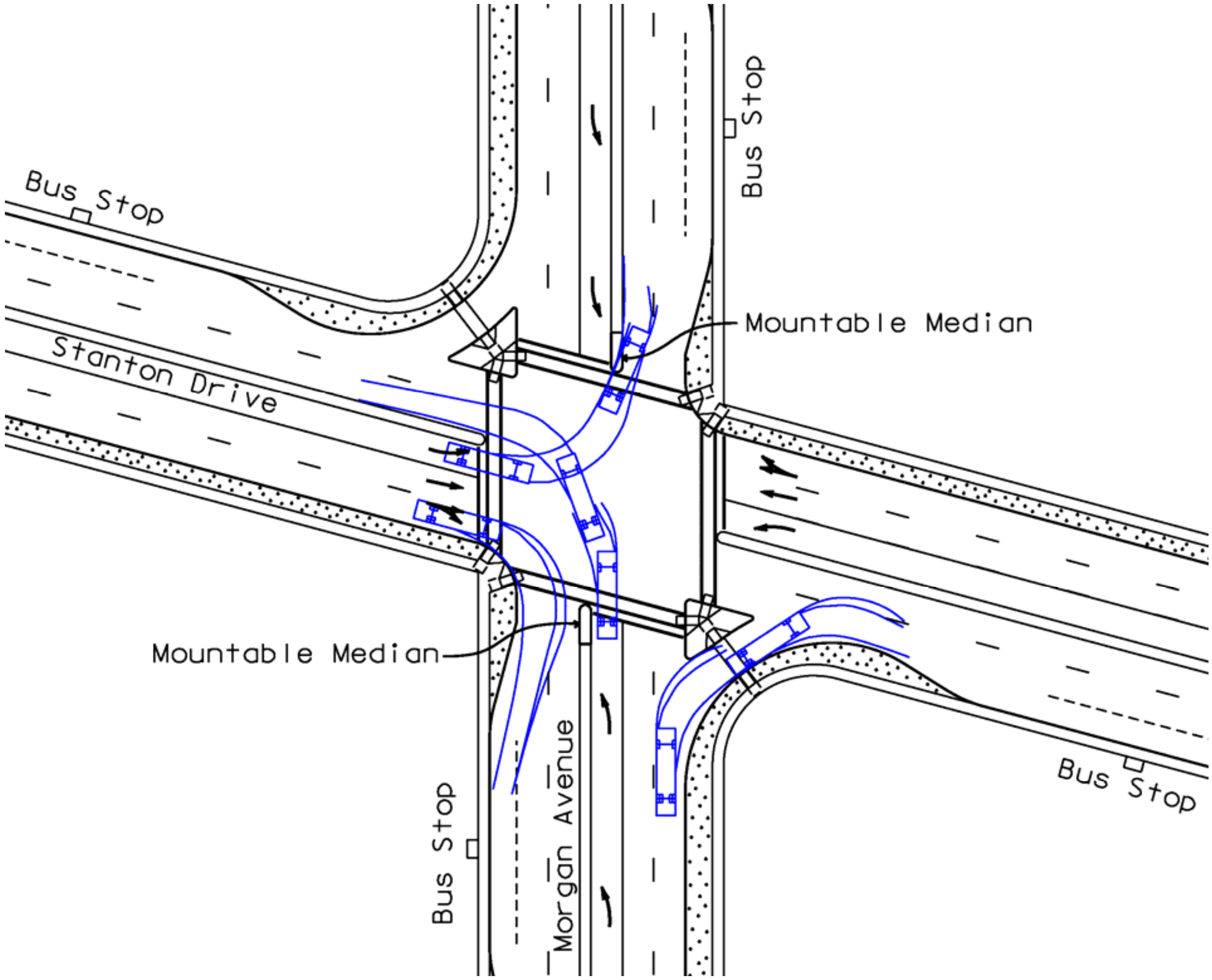


Figure 4-30. Proposed Intersection Design with City Transit Bus Turning Template.

Application 10

Temporary and Ultimate Medians and Outside Curbing

Overview

This application provides a review of some of the issues related to median design in a situation that considers the staged development of a roadway and its median. The *Urban Intersection Design Guide,* Chapter 4, Section 5 <link> provides information on island and median design.

Background

An intersection of a two-lane state highway with a four-lane divided major collector street that serves residential subdivisions currently exists on the suburban edge of a city of approximately 250,000. The state highway (called Stagecoach Road) has the typical rural design, consisting of 12-ft-wide [3.7 m] travel lanes, paved shoulders, no curbs, and open ditches to accommodate drainage. The collector street (Pin Oak Drive) has curbs and gutters that end on the approaches to Stagecoach Road. At the intersection, Stagecoach Road has separate left-turn lanes on both approaches. Traffic signals already exist at the intersection. Figure 4-31 shows the existing condition.

Major improvements (widening project) have been planned for Stagecoach Road and at its intersection with Pin Oak Drive. Stagecoach Road will be widened to a four-lane, divided cross section with curbs and gutters. Left-turn lanes will be provided at the intersection of Pin Oak Drive, and also to both Pin Oak Drive approaches to the intersection. Sidewalks will be provided on both sides of both roadways. The right of way for Stagecoach Road provides room for an additional lane for both directions (or a six-lane, divided roadway); however, the need for more than four lanes has not been justified for construction in the immediate future. Stagecoach Road is expected, however, to eventually be widened to six lanes due to its designation as a principal arterial and the number of lanes and the traffic volume on other, more heavily urbanized segments of the roadway.

The design of the intersection improvements also was affected by the positioning of the sidewalks and traffic signal hardware. A primary consideration in the design involved allowing for the future expansion of Stagecoach Road to six lanes.

Issues Considered

The initial design of the four-lane divided section of Stagecoach Road obviously will be altered when it is widened to its ultimate six-lane divided cross section. The initial design consideration was whether to design the initial cross section (1) with the ultimate median in place and then widen the roadway to the outside (which would include removing the curbing on the outside of the roadway), or (2) with the ultimate outside curbing in place, providing initially a wide median, and then adding the additional lanes in the inside or median area.

The design engineer recognized that more compact intersections operated more efficiently because less time is required for both vehicles and pedestrians to travel through the intersections. Hence, a narrow median would be preferred over a wider median from an operational perspective. A wider median (initially) obviously would increase intersection clearance times.

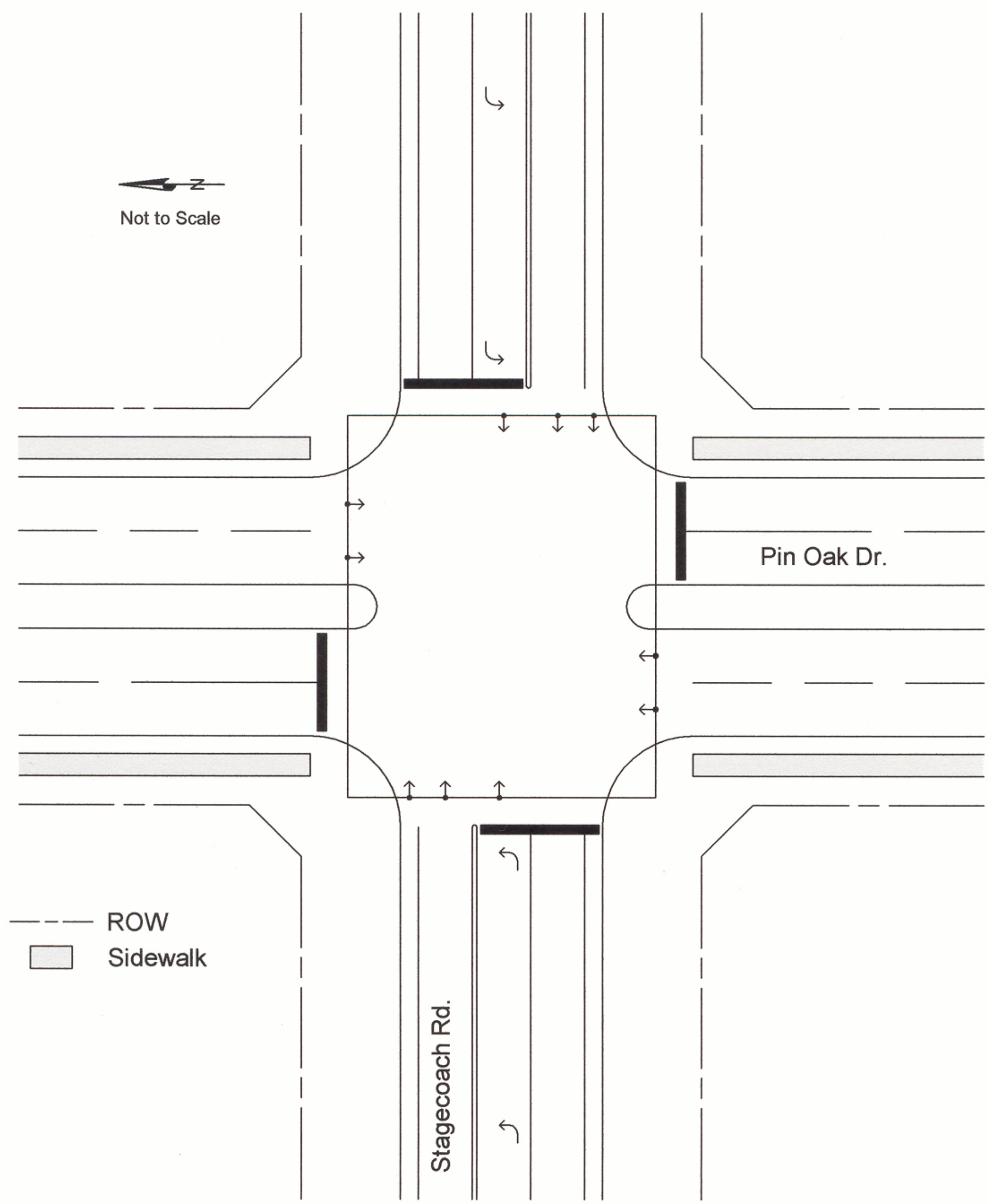


Figure 4-31. Existing Conditions at Stagecoach Road and Pin Oak Drive.

The design engineer recognized that construction of the ultimate median and temporary outside curbing would require more unique drainage design (to accommodate the ultimate cross section). Construction of the ultimate outside curbing initially would permit a more typical construction of the ultimate drainage facilities, minimizing the need to relocate storm sewer inlets and lines. In addition, by constructing the outside curbing initially and maintaining a wide median, the existing roadway could remain in place and accommodate traffic during the widening project. If the ultimate narrower median was constructed initially, then maintaining traffic during construction would be more difficult.

The design engineer considered how the future construction project (that would take place when the six-lane cross section was constructed) would be affected by the initial design. If the ultimate outside curbs were constructed initially, then the future construction project could be staged totally within the median area with less disruption of traffic. If the ultimate median is constructed initially, then the future construction project would require activity on both sides of the roadway with more disruption of traffic.

The design engineer also recognized that construction of the ultimate outside curbs would allow installation of utilities in the right of way that would not have to be disturbed when the ultimate cross section is constructed. Furthermore, if the ultimate outside curbs were constructed initially, then development (and the associated access points) that occurs along the roadway would not be affected significantly when the future widening project occurs.

Construction of the ultimate median and temporary outside curbs would be less costly than the construction of the ultimate outside curbs with a temporary wide median. However, because the ultimate cross section was considered to be viable in the future and sufficient right of way was available, the benefits associated with building the ultimate outside curbs initially was considered greater than the disadvantages (including additional costs) associated with constructing the ultimate median initially.

Design Selected

The interim and final designs selected are shown in Figure 4-32 and Figure 4-33, respectively.

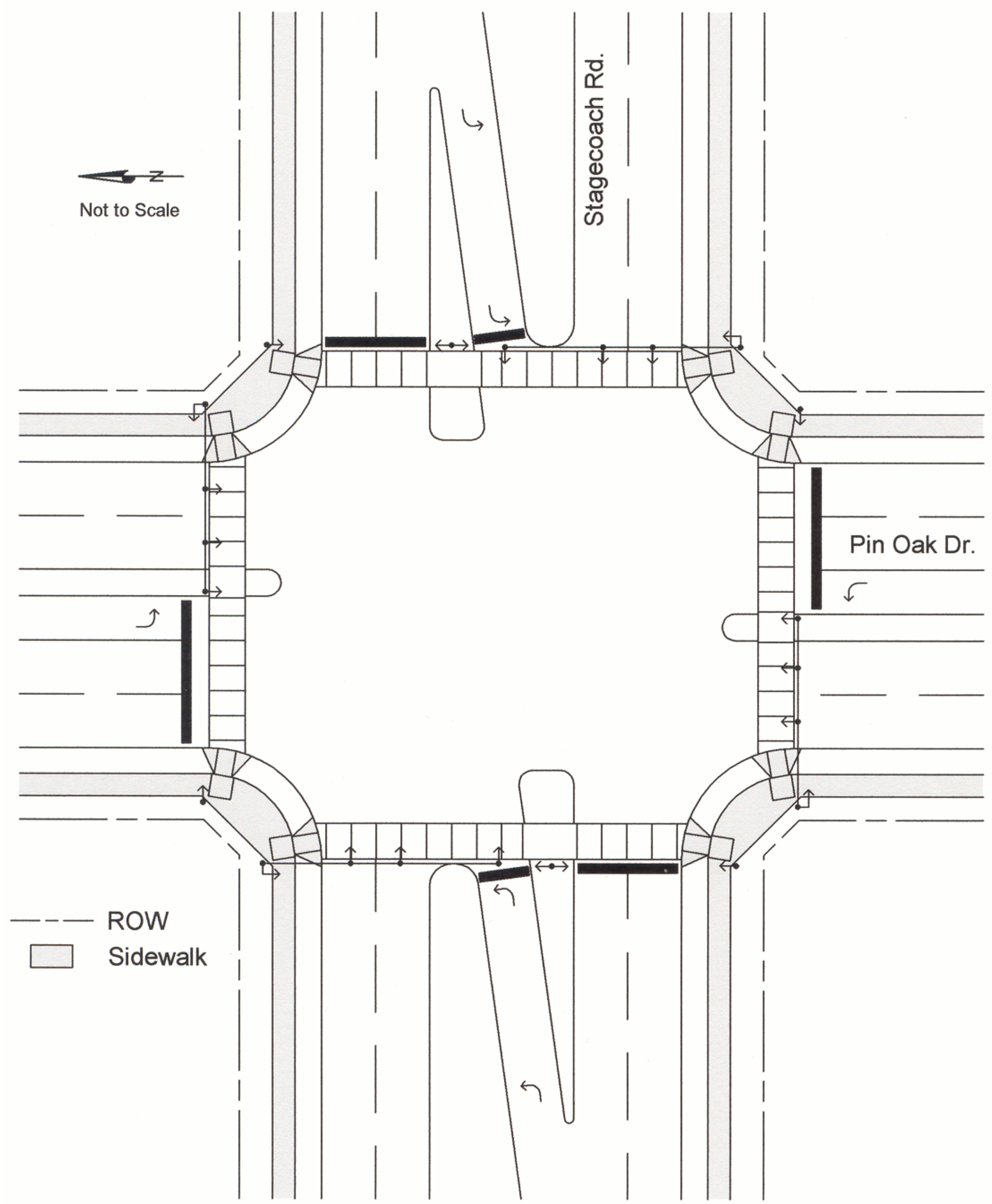


Figure 4-32. Selected Interim Design at Stagecoach Road and Pin Oak Drive.

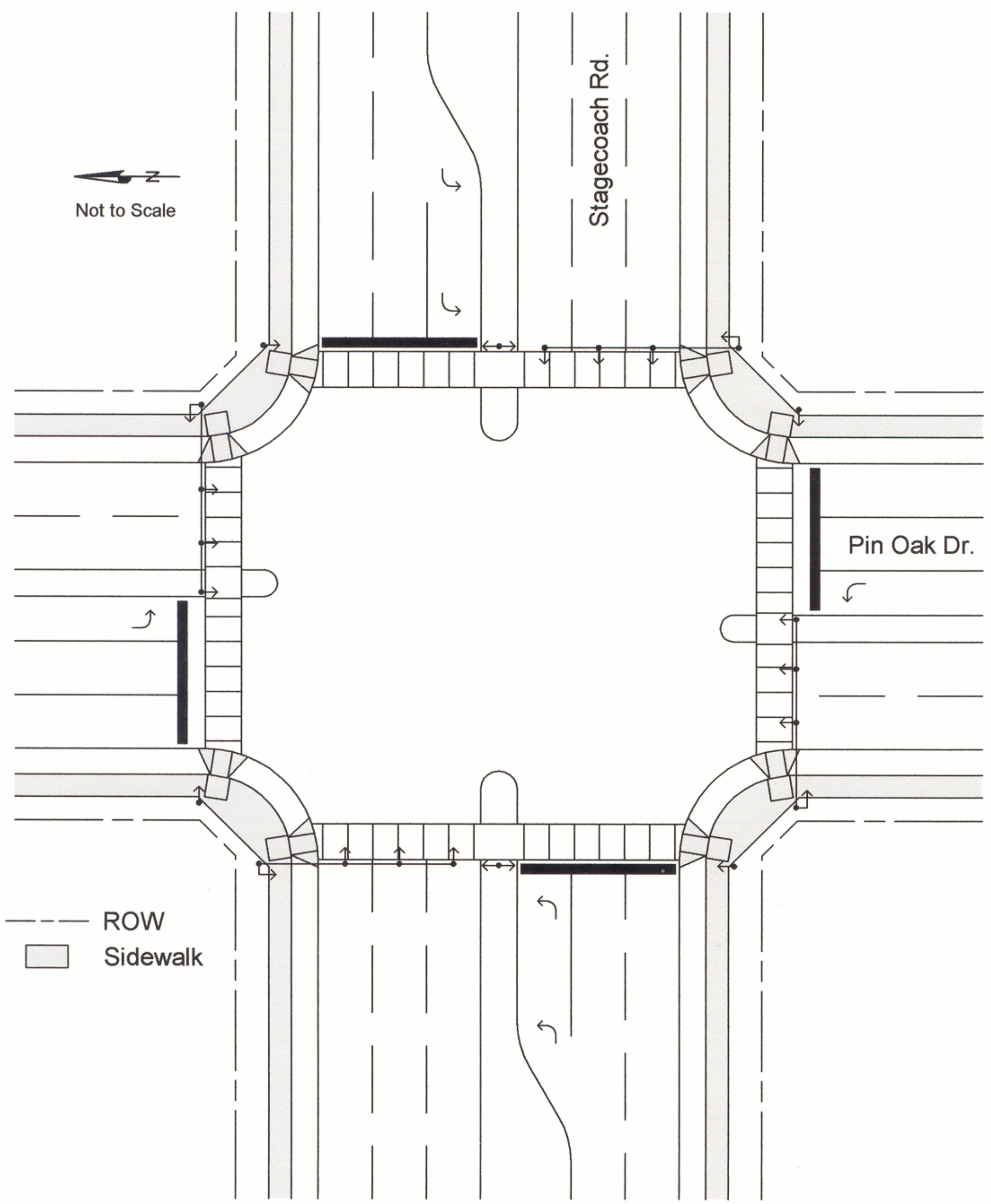


Figure 4-33. Final Design at Stage Coach Road and Pin Oak Drive.

The design engineer decided to build the four-lane, divided cross section with the ultimate outside curbs (see Figure 4-32). Once this decision was made, there were three more important design considerations associated with the intersection of Stagecoach Road with Pin Oak Drive. These three design issues included the design of the left-turn lanes on Stagecoach Road, the design of the crossings of the pedestrian crossing, and the design of the new traffic signal installation.

One of the disadvantages of designing a wide median is the increase in intersection clearance times for both vehicles and pedestrians. Hence, the design of the intersection should incorporate those design features that would reduce clearance times. Also, wide medians make the design of left turns more difficult because there is the potential for negative offsets of opposing left-turn lanes. Hence, a more unique design is required to provide positive left-turn lane offsets or at least minimize negative offsets. Once the position of the left-turn lanes and pedestrian crossings were established, the final design for the traffic signal installation and the intersection itself was determined.

In the ultimate six-lane configuration of Stagecoach Road (see Figure 4-33) the installation of the additional lanes will eliminate the offset left-turn lanes present in the selected design shown in Figure 4-32.

As shown in Figure 4-32, the intersection of Stagecoach Road and Pin Oak Drive had the following design characteristics:

- ♦ The four-lane cross section of Stagecoach Road had a 42-ft-wide [12.8 m] raised median.
- ♦ Tapered left-turn lanes were constructed on the Stagecoach lane approaches to create positive offsets.
- ♦ Left-turn lanes were added in the existing medians of both Pin Oak Drive approaches.
- ♦ Pedestrian crosswalk markings were included at the intersection.
- ♦ Median islands were used to provide pedestrian refuge areas.
- ♦ Traffic signals were installed in the median islands for the left-turning vehicles on the Stagecoach Road approaches.
- ♦ Pedestrian signals were installed on the same median signal poles so that pedestrian crossings could be timed so that pedestrians would cross half of the roadway at a time to minimize disruption of traffic on Stagecoach Road.
- ♦ Long curb return radii were included on all four corners to expedite right-turning vehicles.
- ♦ Sidewalks were offset 6 ft [1.8 m] from the edge of the streets in order to accommodate slopes for curb ramps.

Chapter 5
Roadside

Contents:

Application 1

Redevelopment Near an Intersection

Overview

The following application discusses sidewalk considerations along with other concerns during a redevelopment. The *Urban Intersection Design Guide*, Chapter 5, Section 1 <link> presents information on sidewalks; Chapter 5, Section 4 <link> presents information on street furniture and fixtures; and Chapter 5, Section 6 <link> provides information on bus stops.

Background

An intersection of two 40-ft-wide [12.2 m] streets exists near the central business district of a very large city. Bluebonnet Drive (the east/west street) is striped for four narrow travel lanes and is the major street at the intersection. Its average daily traffic volume is about 9000. Dawn Avenue (the north/south street) is striped for two travel lanes with permitted parking. Stop signs are installed on both Dawn Avenue approaches to Bluebonnet Drive. The average daily traffic on Dawn Avenue is about 5000. (See Figure 5-1.)

The city has had significant redevelopment within and near its central business district, including the area near the Bluebonnet Drive/Dawn Avenue intersection. The general area is beginning to develop into an upscale neighborhood as old homes are being either renovated or replaced with expensive larger homes. New commercial developments, especially along Bluebonnet Drive, have generated additional traffic volumes. Off-street parking areas have been constructed to serve these businesses, and pedestrian volumes also have increased. The city has recognized the potential of the area as a vibrant residential and commercial development and has responded to numerous requests by residents and business owners to make major street improvements in the area.

At the present time, sidewalks are located adjacent to Bluebonnet Drive but are not constructed with curb ramps. Dawn Avenue has no sidewalks. Power poles are located along the north side of Bluebonnet Drive and are located within the sidewalk itself. Curb return radii are relatively short by modern standards (about 20 ft [6.1 m]). Existing street hardware also includes fire hydrants and street lights. The city desires to install traffic signals at the intersection (which have been warranted), construct sidewalks, improve intersection lighting, and provide aesthetic streetscaping. Two major constraints exist: additional right of way will be difficult to obtain (only 10 ft [3 m] exists behind the back of the curb) and the overhead electric power lines and poles cannot be replaced for at least 3 years. The city's bus transit system operates a route along Bluebonnet Drive, and bus stops are made on the near sides of both approaches to Dawn Avenue.

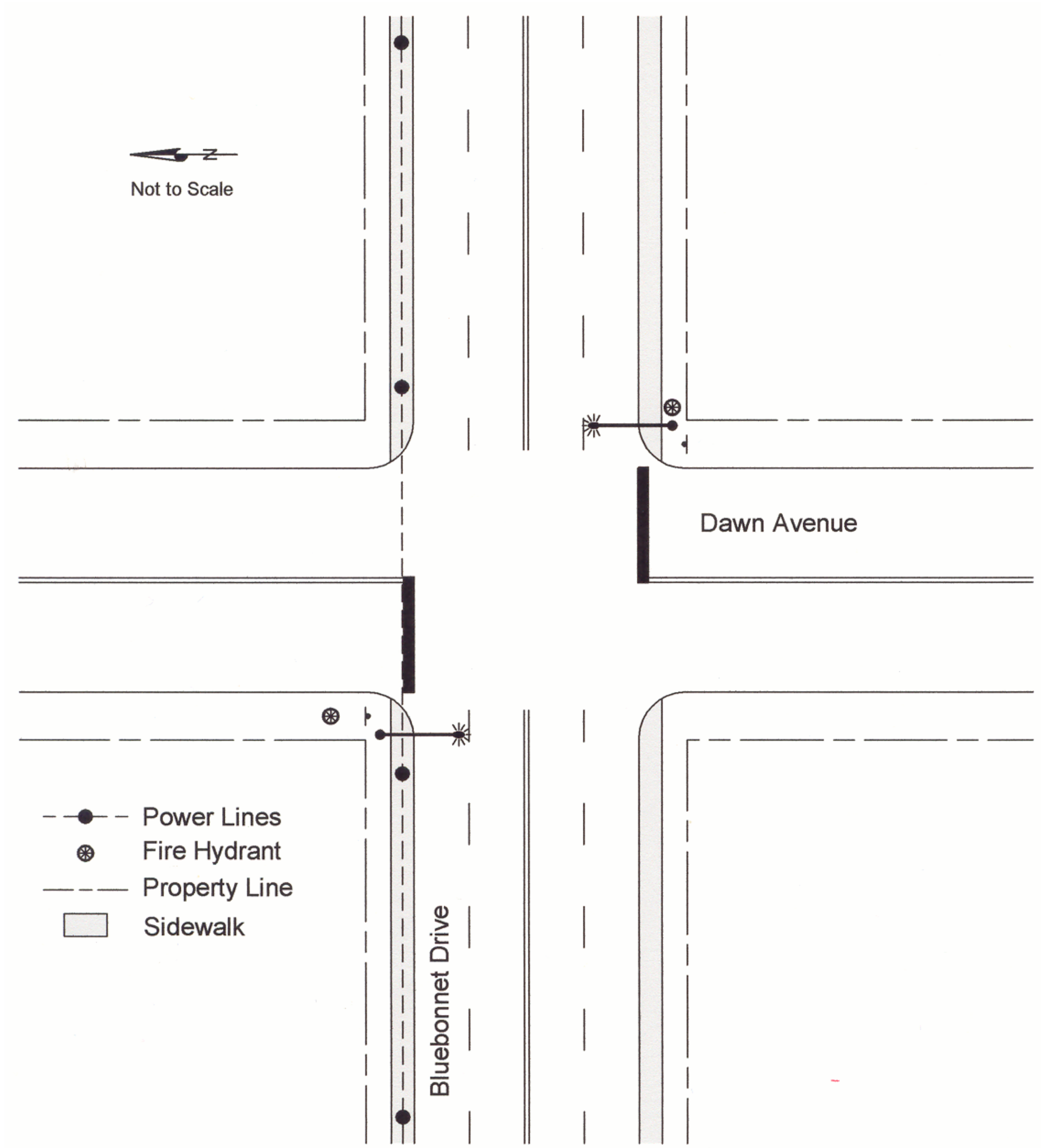


Figure 5-1. Existing Conditions at Bluebonnet Drive and Dawn Avenue.

Issues Considered

Traffic counts at the intersection revealed a relatively high volume of left turns, especially on the Bluebonnet Drive approaches. Hence, because the inside lanes were essentially being used as left-turn lanes, it was determined to provide separated left-turn lanes with no offset. Because of the numerous driveways that exist along Bluebonnet Drive that serve the off-street parking areas, a continuous center, two-way left-turn lane was incorporated into the new striping of Bluebonnet Drive. The operational capacity of a four-lane, undivided street versus a three-lane street (with the continuous two-way left-turn lane) is about the same if there are numerous left-turning vehicles. Converting an undivided four-lane street to a three-lane street will help reduce rear-end accidents, and will increase travel lane widths or provide additional space for bicycle or pedestrian facilities. The wider lanes allow more efficient right turns because more room is available for maneuvering.

All of these advantages were appealing to the city, especially to the manager of the bus transit system. The lane used by the buses could be increased in width from 10 to 14 ft [3 to 4.3 m].

Because of the recent increases in traffic volumes on Dawn Avenue (and expected additional future increases as well), the city elected to remove the parking on Dawn Avenue. Removal of parking allowed the street to be striped for three travel lanes, matching the striping used on Bluebonnet Drive.

The existing sidewalk on Bluebonnet was in a state of disrepair, and the presence of wood power poles in the sidewalk on the north side of the street seriously affected the usefulness of the sidewalk. Because the power poles were planned for removal sometime after 3 years, it was decided to construct the new sidewalk away from the power pole locations. It was determined that a 6-ft-wide [1.8 m] sidewalk would be constructed on both sides of Bluebonnet Drive adjacent to its right-of-way lines. The remainder of the right-of-way area (between the new sidewalk and the curb) would be lined with inlaid bricks. The bricks could be removed for streetscape hardware installation, and new bricks could be placed where the power poles exist after poles are removed.

Sidewalks along Dawn Avenue were planned to be 5 ft [1.5 m] in width and located 1 ft [0.3 m] from the right-of-way line. Due to the required lengths for ramps and size of the landings, additional right of way had to be obtained near the corners of the intersection. Signal poles will be located adjacent to these landings so that pedestrian push buttons could be installed adjacent to the landings. Luminaires are planned for installation on the four signal poles to increase intersectional lighting.

In a confined area, the positioning of a signal cabinet may be difficult. Because of the location of the signal poles near the landings, there was insufficient space for a pole-mounted cabinet. A ground-mounted cabinet has several desirable location design features:

- The cabinet should be located such that the cabinet door opens away from the roadway.
- The cabinet should be positioned so that the technician can stand on a firm foundation (preferably concrete) while working inside the cabinet.
- The cabinet should be located away from the street, if possible, but close to the intersection.
- When facing the controller, the technician should be able to view the signal heads without having to "turn around."
- The cabinet should not be placed in a sidewalk.

After studying the geometry and right-of-way restrictions at the intersection of Bluebonnet Drive and Dawn Avenue, the most logical location for the controller was on the southeast corner.

With a protective/permissive signal operation, only two signal heads per approach would be needed. Pedestrian signals were included in the design, and crosswalks were provided. Additional pedestal poles were installed at the intersection for pedestrian push buttons.

Design Selected

The final design of the intersection (see Figure 5-2) included the following:

- Make changes to existing right of way or existing street and curbs, except for additional right of way at intersection corners and curb reconstruction due to installation of curb ramps.
- Install sidewalks 6 ft [1.8 m] in width along Bluebonnet Drive adjacent to the edge of the right-of-way lines, and install sidewalks 5 ft [1.5 m] in width along Dawn Avenue, offset 1 ft [0.3 m] from the back of the right-of-way line.
- Install inlaid bricks along the north and south sides of Bluebonnet Road at a width of 4 ft [1.2 m], placed between the edge of the sidewalk and the curb.
- Stripe both streets for three lanes, each with a center, continuous two-way left-turn lane. The two-way left-turn lane was discontinued in advance of the intersection so that separate left-turn lanes would be provided on each intersection approach.
- Install traffic signals (overhead on mast arms) and pedestrian signals, with pedestrian push buttons on all four signal poles and on four pedestal poles.
- Remove existing street lights and poles and install luminaires (with mast arms) on all four signal poles.
- Relocate a fire hydrant on the southeast corner into the inlaid brick area.
- Relocate a fire hydrant on the northwest corner of the intersection into the grassy area.
- Install the signal controller in the inlaid brick area on the southeast corner of the intersection, positioning the controller so that the door opens toward the sidewalk.
- Beneath the new sidewalks, the city planned to install several conduits for electrical, telephone, cable, and any other utility that may be positioned within the right of way. On-ground connections (boxes) can be provided at specific locations within the inlaid brick areas (along Bluebonnet Drive) or within the grassy areas (along Dawn Avenue).
- The city also planned to place plants and trees (in containers), and benches on top of the inlaid bricks at various sites. Periodic inspections will be required to ensure that vegetation does not protrude into the pedestrian envelope or create undesirable sight obstructions.
- Provide pad for bus stop landing on nearside approaches of Bluebonnet Drive.

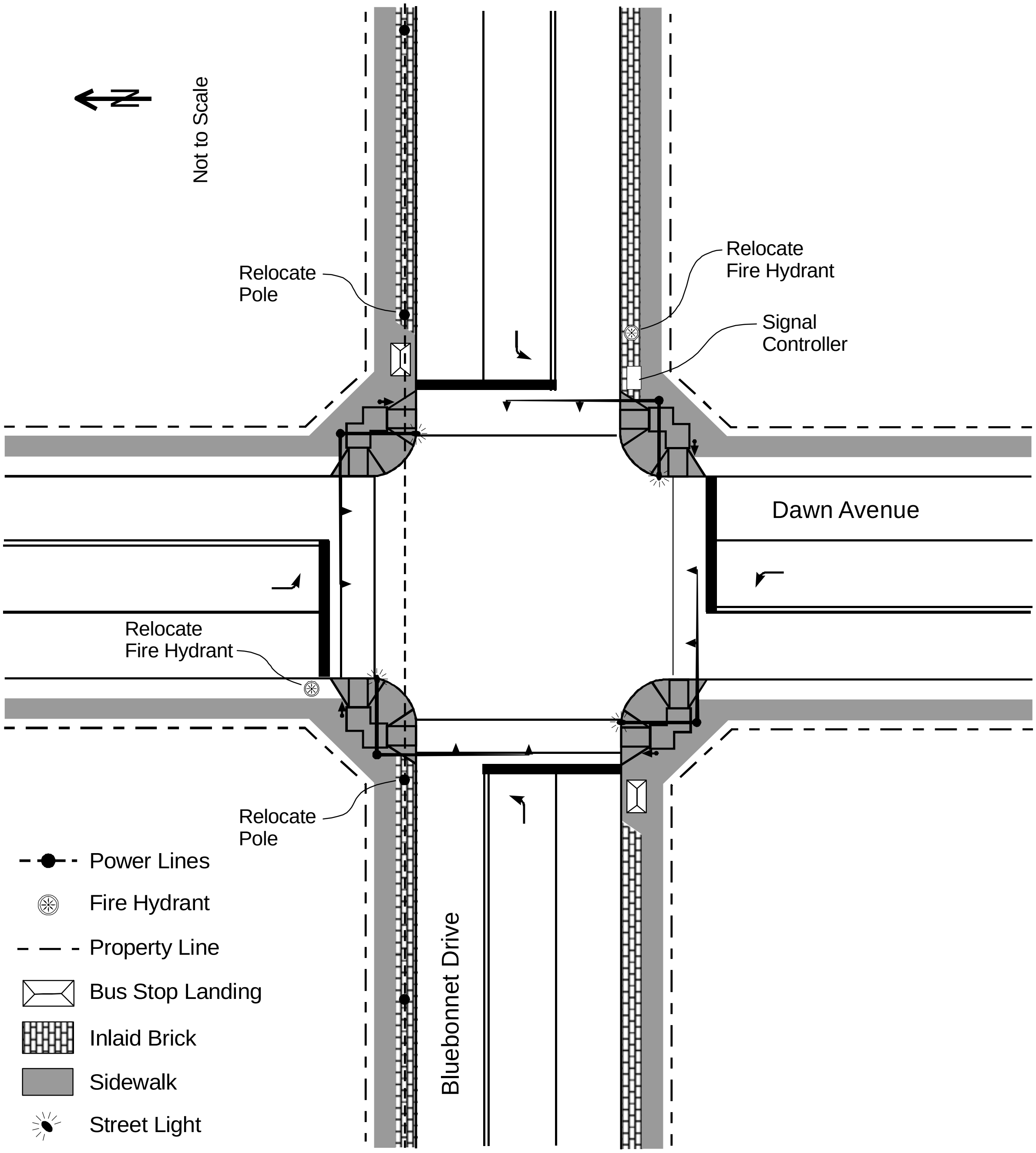


Figure 5-2. Proposed Design for Bluebonnet Drive and Dawn Avenue.

Application 2
Addition of Bus Bay

Overview

The operation of bus stops can significantly affect the performance of an intersection. A stopped bus at a nearside location can prevent vehicles from proceeding through the intersection. At these locations a bus bay can expedite turning movements and improve traffic signal operations; however, disadvantages include longer bus travel times and potential conflicts as the bus reenters the traffic. Bus bays are discussed in Chapter 5, Section 6 <link> of the *Urban Intersection Design Guide*.

Background

An urban intersection has a substantial amount of right-turning traffic on a particular approach. Queues in the right-turn lane are frequently blocked by stopped buses at a bus stop on the nearside of the intersection.

The intersection of Colgate Road and Fordham Drive is in an urban area, near a large hospital and medical park. Colgate Road is a four-lane arterial with a raised median, while Fordham Drive is a two-lane collector. The bus stop is located in the right-turn lane on eastbound Colgate Road. Developments on each corner are:

- a large parking area for the retirement home on the southeast corner,
- convenience stores on the northeast and northwest corners, and
- a small grocery store on the southwest corner.

The southwest corner is the location of the problem: eastbound right-turning vehicles in the right-turn lane are occasionally stopped by buses at the bus stop. When buses stop to board and alight riders, traffic in the right lane is stopped, causing increased delay.

Figure 5-3 illustrates the current intersection layout. The following is known:

- Colgate Road is an urban arterial roadway.
- Fordham Drive is an urban collector roadway.
- Design speed on Colgate Rd. is 45 mph [72 km/h].
- The intersection is signalized.

Issues Considered

Issues to consider during an upgrade to the site include the following:

- Move signal poles to accommodate redesign.
- Move the bus bench and waiting area during and after construction.

- Tie into existing sidewalk, but ensure grades are appropriate for usage by disabled pedestrians.
- Accommodate current traffic flow during construction.

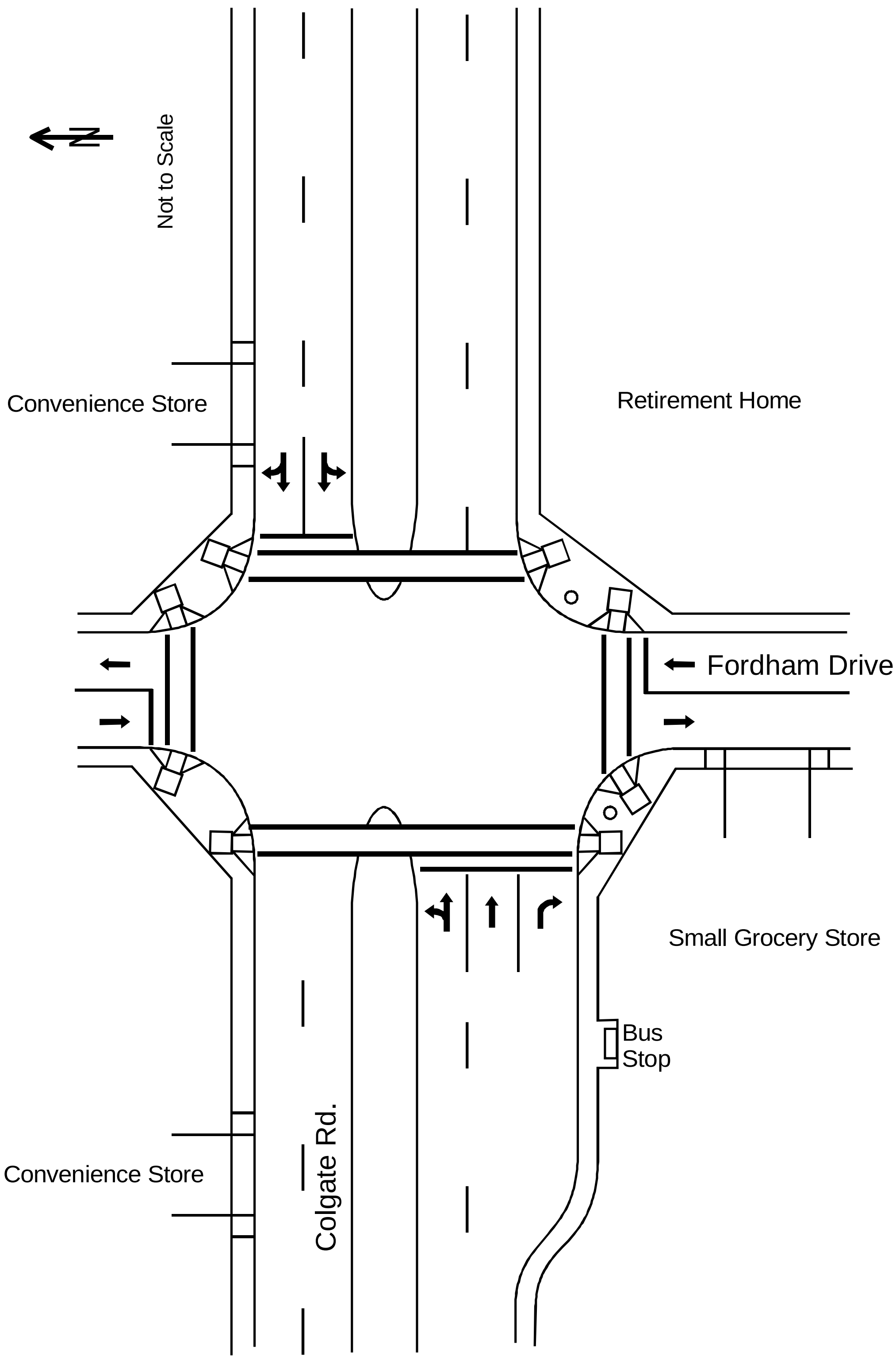


Figure 5-3. Existing Intersection Layout for Colgate Road and Fordham Drive.

In consultation with the local transit agency, the bus stop will be relocated to the far side of the intersection. This move will minimize delay to drivers while the bus is stopped and reduce conflicts with turning vehicles. It will also provide more direct access to users from the retirement home. A partial open bus bay will be used to provide a protected area away from moving vehicles for the bus and its patrons.

Other issues that were considered in the design include:

- ♦ Relocate the sidewalk to accommodate the new lane.
- ♦ Relocate a traffic signal pole due to the addition of the partial open bus bay.

- ♦ *Step 1: Determine bus stop design.*

The operation of the bus stop presents a number of challenges at the intersection due to conflicts with right-turning vehicles and the inability of the bus to stop out of the travel lane while patrons board and alight. The original design, with the bus stop on the west side of the intersection, has the bus blocking other vehicles while it is stopped at the bus stop. Because the bus stop serves a hospital and the surrounding medical community the potential for both increased numbers of bus patrons and older or disabled bus riders is relatively high, potentially taking longer for bus stop operations. Because of these concerns, a partial open bus bay design was selected for the far side of the intersection, shown in Figure 5-4. This location eliminates the conflicts between the bus and turning and through vehicles, reduces the use of the bus bay as an acceleration lane by right-turning vehicles from Fordham Drive, and provides a sheltered area for bus patrons to board and alight.

The use of the partial open bus bay allows the bus to decelerate as it crosses the intersection, and shortens the crossing time for pedestrians through the provision of the curb extension, enhancing signal operations (see *Urban Intersection Design Guide*, Chapter 5, Section 5 <link>). The partial open bus bay also prevents right-turning traffic from south Fordham Drive from using the bus bay as an acceleration lane.

A disadvantage of using a bus bay is that bus drivers may have problems re-entering the traffic stream. The presence of the signal-controlled intersection, however, will provide gaps that the driver can use when exiting the stop.

An 8 ft by 5 ft [2.4 m by 1.5 m] bus boarding area has been added at the bus stop to comply with ADAAG requirements. Chapter 5, Section 6 <link> of the *Urban Intersection Design Guide* should be consulted for further information regarding bus stop design.

- ♦ *Step 2: Relocate signal pole and sidewalks.*

A traffic signal pole has been relocated to remove it from the roadway. This relocation will result in the use of a longer traffic signal mast arm, larger support pole, and larger pole foundations (see *Urban Intersection Design Guide*, Chapter 8, Section 3 <link>).

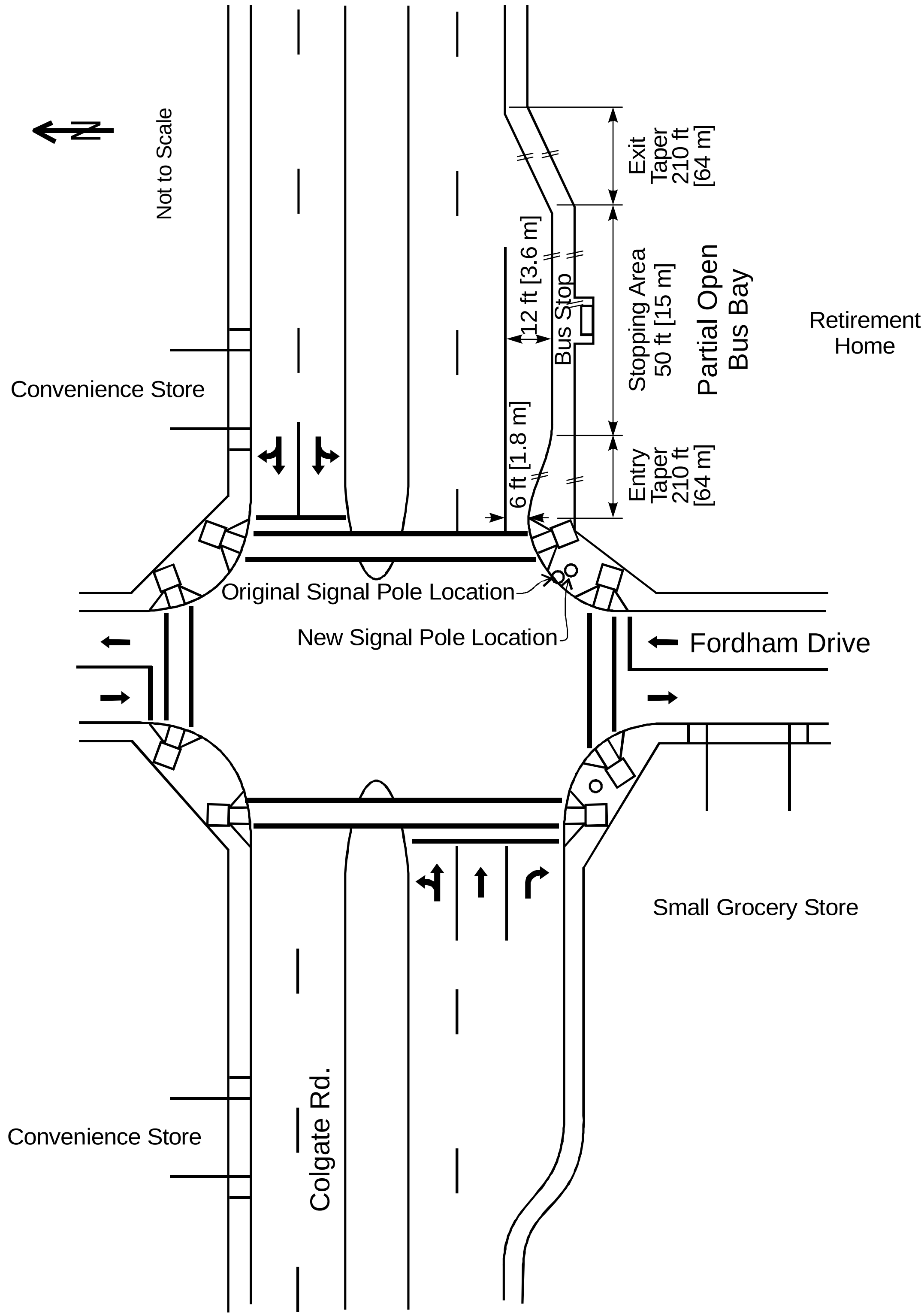


Figure 5-4. Design of Bus Stop and Adjoining Sidewalk.

Chapter 6
Drainage

Contents:

Application 1
Warped Profile and Cross Section

Overview

The following application discusses sidewalk considerations along with other concerns during a redevelopment. The *Urban Intersection Design Guide,* Chapter 6, Section 3 <link> presents information on drainage and roadway profiles.

Background

The intersection of Drake Avenue (an arterial roadway) and Fir Street (a local roadway) is in a small city. The roadways, shown in Figure 6-1, have the following characteristics:

- Drake Avenue
  - four 12-ft [3.7 m] travel lanes;
  - 14-ft [4.2 m] two-way left-turn lane;
  - curb and gutter cross section with 2-ft [0.6 m] curb offsets;
  - 2 percent cross slope; and
  - 40 mph [64 km/h] design speed.
- Fir Street
  - two 11-ft [3.4 m] travel lanes,
  - curb and gutter cross section with 1-ft [0.3 m] curb offsets,
  - 2 percent cross slope, and
  - 30 mph [48 km/h] design speed.

The intersection is being designed as part of a construction project that is reconstructing Drake Avenue and includes a storm drain system. Stop signs are installed on Fir Street at both approaches to Drake Avenue.

Pedestrians are frequently observed in the area of the intersection. Crosswalks are present across Fir Street but not across Drake Avenue. Pedestrians are encouraged instead to cross Drake Avenue at a nearby signalized intersection with pedestrian indications and crosswalks.

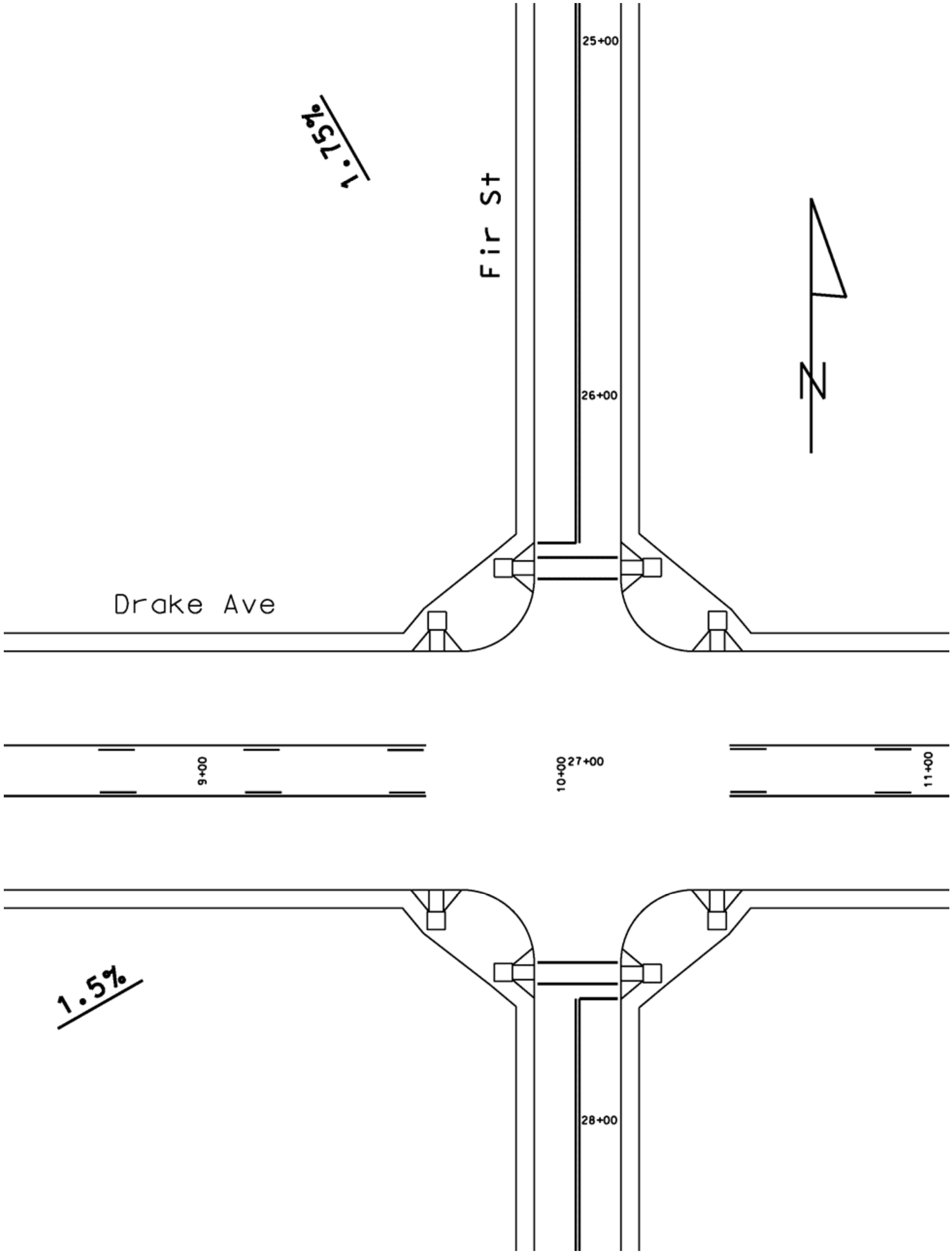


Figure 6-1. Drake Avenue and Fir Street.

Issues Considered

A principal concern at the intersection is the vertical profile present. The intersection is expected to remain stop-controlled on Fir Street. The speeds of vehicles crossing or turning onto Drake Avenue will be relatively low because of the stop condition. Drainage at the intersection has been a problem in the past, with water from Fir Street ponding at the intersection with occasional overflows crossing Drake Avenue. The present vertical alignment of the intersection was achieved by intersecting the centerline gradelines of the two roadways in a similar manner to that shown in Figure 6-7 of the *Urban Intersection Design Guide* <link>. The resulting roadway surface is uncomfortable to drive and results in water ponding in the corners of the intersection.

Another concern at the intersection is the design of the pedestrian elements. Pedestrians are common in the area, and pedestrian crossing points on both Fir Street and Drake Avenue frequently are flooded and have standing water present after storm events because of the vertical alignment.

Proposed Design

The design proposed for the intersection includes realigning the vertical profile on Fir Street and relocating the present storm drain inlets. The new vertical profile on Fir Street will help manage the stormwater runoff without allowing water to enter the intersection and impede the traffic on Drake Avenue. The relocated storm drain inlets will help keep water out of the intersection and help prevent water from ponding near the pedestrian curb ramps.

- *Step 1: Realignment of the vertical profile of Fir Street.*

The present vertical alignment on Fir Street north of Drake Avenue is shown in Figure 6-1. Because of the stop control on Fir Street, a new alignment of the general form shown in Figure 6-3 of the *Urban Intersection Design Guide* was selected <link>. The new alignment will insert two new vertical curves on Fir Street north of Drake Avenue to allow matching Fir Street's grades with the gutterline on Drake Avenue. Shown in Figure 6-2 and Figure 6-3, the alignment has a crest vertical curve at 23+49 [0+716] and a sag vertical curve at 25+37 [0+773] that allow Fir Street's alignment to match the cross slope on Drake Avenue.

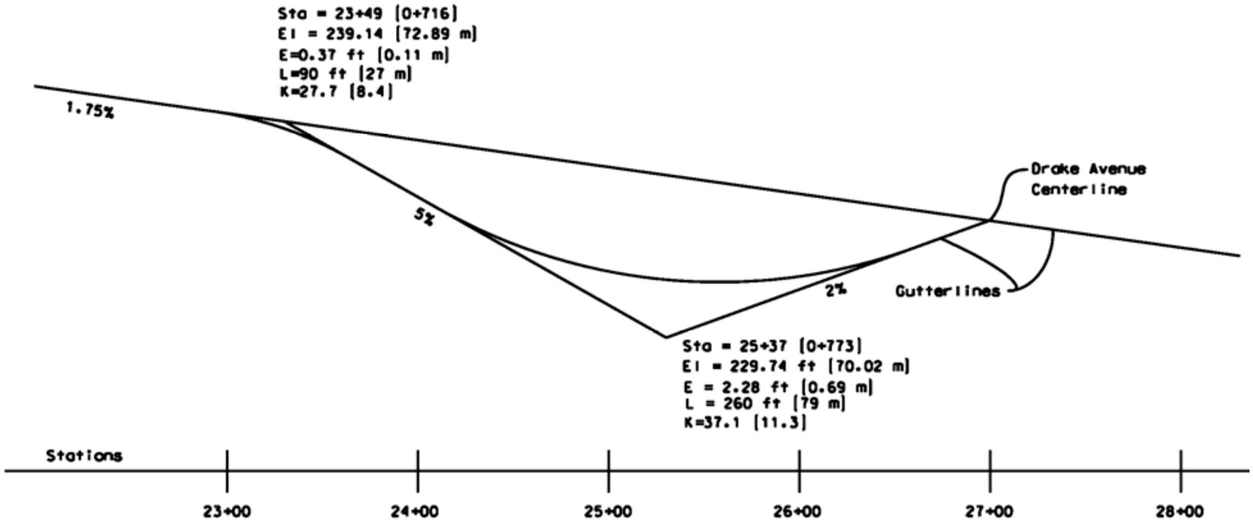


Figure 6-2. Vertical Profile of North Section of Fir Street.

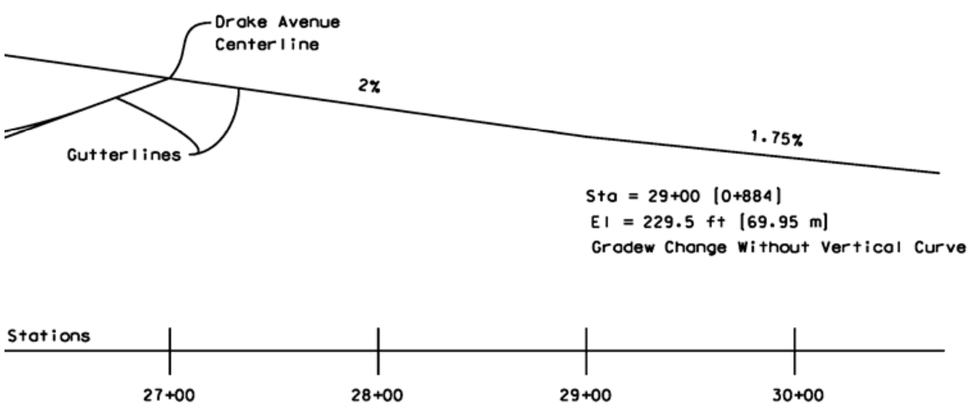


Figure 6-3. Vertical Profile of South Section of Fir Street.

The vertical curves on the north side of Drake Avenue were designed according to the design speed on Fir Street, 30 mph [48 km/h]. The K-factors for the curves were selected from Figures 2-6 and 2-9 [2-7 and 2-10 for metric units] of the *Roadway Design Manual* <link>. From the figures, minimum K-factors of 19 [11] and 37 [18] were determined for crest and sag curves, respectively.

The length of the crest vertical curve at 23+49 [0+716] was determined by the following equation:

$$L = K \times A$$

where:

L = length of the vertical curve, ft

A = algebraic differences in grade, percent

K = design control for the curve

Substituting in the equation:

$L = 19 \times 3.25 = 61\text{ ft }[18.6\text{ m}]$

The minimum length of a vertical curve is three times the design speed, however. In this case the minimum length is three times 30 mph [48 km/h], or 90 ft [27 ft].

The length of the sag vertical curve at 25+37 [0+773] was found in a similar manner:

$L = 37 \times 7 = 260\text{ ft }[79\text{ m}]$

The sag vertical curve length exceeded the minimum length, so 260 ft [79 m] was used in the design.

Proceeding to the south side of Drake Avenue, the gradeline was again matched to the crossfall on Drake Avenue. The alignment matched the existing street elevation at station 29+00 [0+884]. The grade change at the PI was very small, 0.25 percent. Because the grade change is less than 1 percent, no vertical curve is required at this location (see the *Roadway Design Manual* Chapter 2, Section 5, Grade Change Without Vertical Curve) <link>.

The addition of the sag vertical curve at 25+37 [0+773] will increase the right of way and require additional excavation because the new roadway gradeline will be below the present grade in the area of the vertical curve.

- *Step 2: Warp pavement cross section on Fir Street.*

The next step in the design was to match the cross section on Fir Street to the gutterline on Drake Street. To accomplish this, Fir Street's cross section was warped as shown in Figure 6-4. The rotation from the normal cross slope of a 2 percent crown to a constant 1.5 percent up to the east was accomplished over 90 ft [27 m], as shown in the figure. The transition section length was selected to match the rotation rate typically used for superelevated roadway sections (see the *Roadway Design Manual's* guidelines on transition length in its Chapter 2, Section 4 <link>). This criterion was used in the absence of firmly established guidance regarding the development of warped cross sections for drainage purposes.

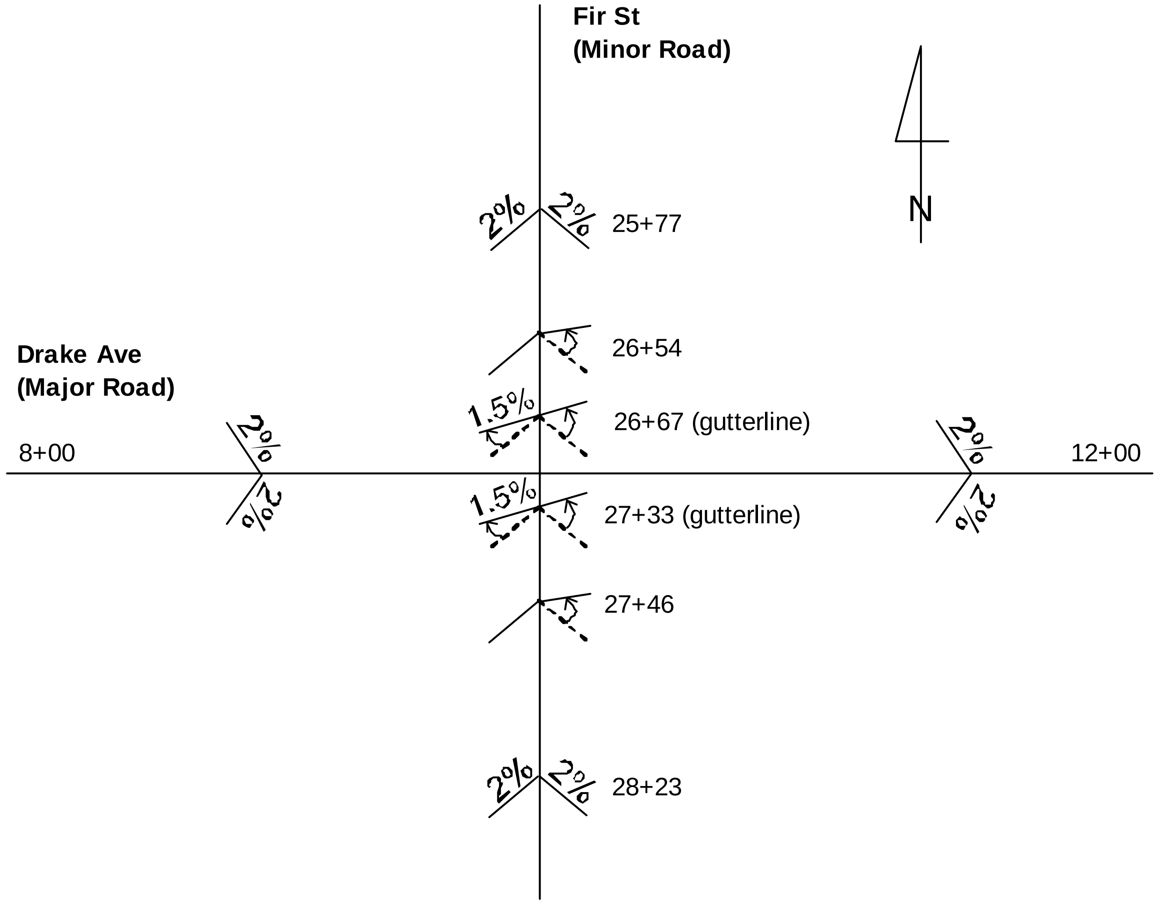


Figure 6-4. Fir Street Cross Section Transition.

- ♦ *Step 3: Develop intersection contour plot to review drainage.*

The next step in the design was to develop a contour plot of the intersection. Shown in Figure 6-5, the contour plot allowed the designer to determine where any low spots were located in the alignment so that the alignment could be adjusted if necessary to eliminate any undesirable "bird baths" or irregularities. Because of the way the pavement was warped and the presence of the vertical curves at the intersection, it is critical that the design be reviewed in this manner. The contour plots (shown at 0.5-ft [0.2 m] intervals for clarity in this example—normally, a smaller interval would be used for design) allow the determination of the locations for curb inlets in the low points on Fir Street.

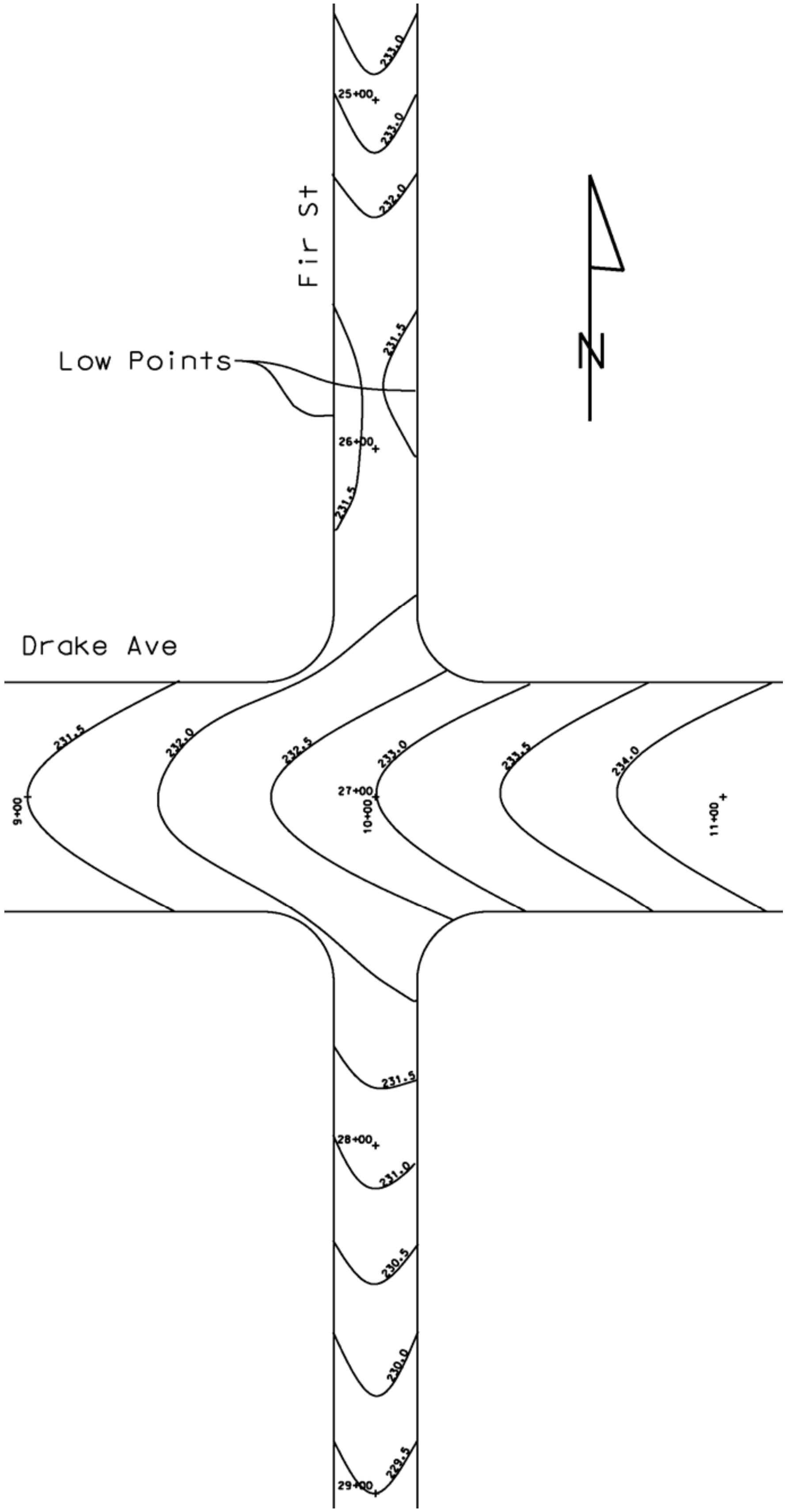


Figure 6-5. Contour Plot of Intersection.

- *Step 4: Locate curb ramps and remainder of curb inlets.*

The final step in the design was to locate the curb ramps and upstream curb inlets at the intersection.

Although a marked crosswalk across Drake Avenue is not present at this location, crossings may nevertheless occur. Accordingly, curb ramps are provided for pedestrians. Shown in Figure 6-6, the curb ramps are located within the crosswalks (or at the location a marked crosswalk would be placed, in the case of the Drake Avenue crossing point); further information about curb ramps and crosswalks can be found in the *Urban Intersection Design Guide* Chapter 7, Sections 1 and 2 <link>.

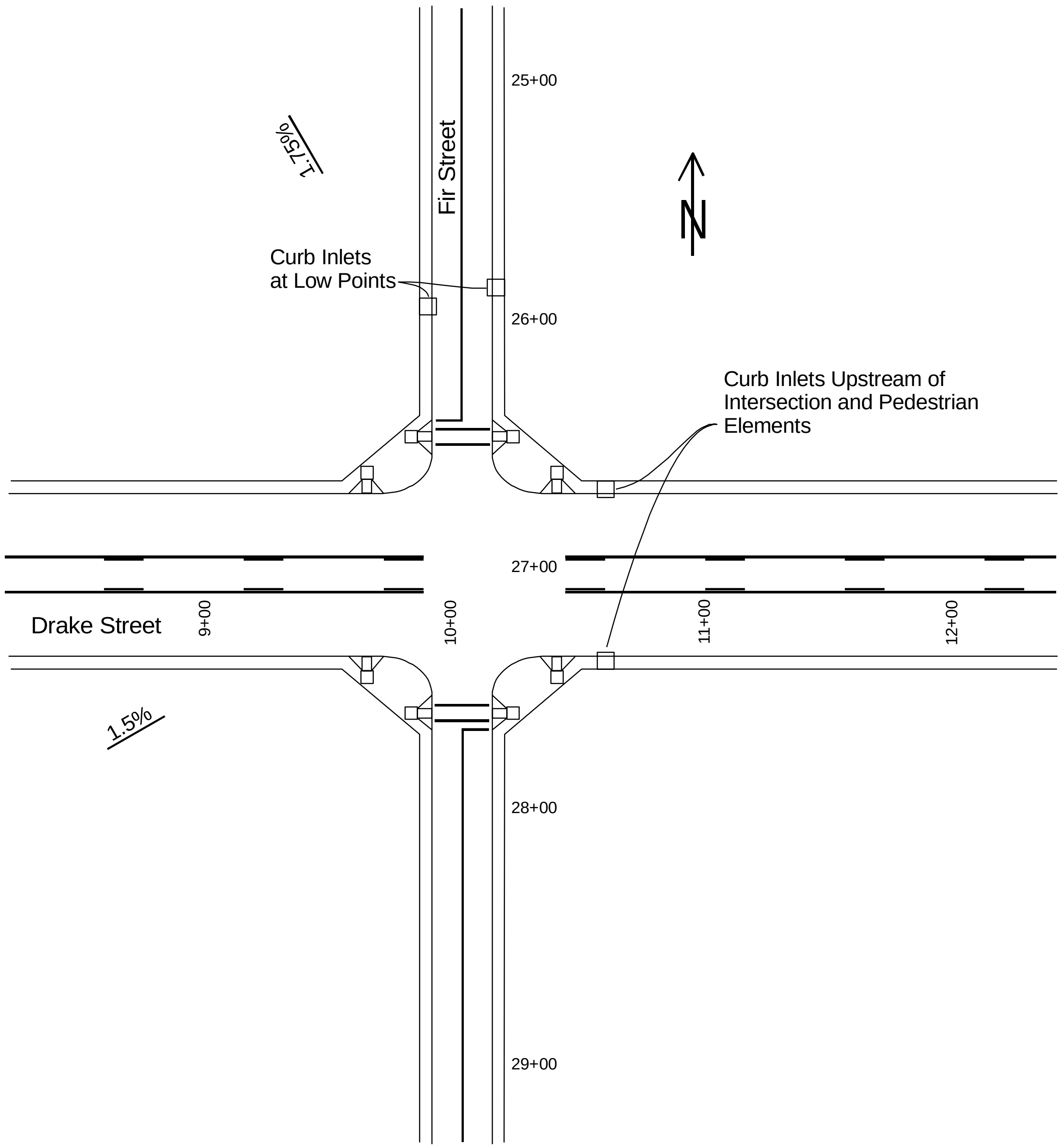


Figure 6-6. Final Intersection Layout.

Curb inlets were placed on the upstream side of the intersection on Drake Avenue. This prevents concentrations of water from entering the intersection. The curb inlets were placed upstream of the curb ramps, avoiding interference with pedestrian crossings and the construction of the ramps.

Chapter 7
Street Crossing

Contents:

Application 1

Suggestions for Making an Intersection Accessible

Background

The use of transportation facilities by disabled persons is increasingly an important concern in the design of those facilities. In this application an urban intersection, with moderate to heavy pedestrian traffic, is examined. It was built many years before current accessibility requirements were established. Information on street crossings including discussion on pedestrian considerations is in the *Urban Intersection Design Guide*, Chapter 7 <link>.

The intersection is shown by a sketch in Figure 7-1. Figure 7-2 shows the locations of the photographer and the direction the pictures were taken for the photos included in this application. Figure 7-3 and Figure 7-4 are overview photos of the intersection. The intersection is in an urban area, close to shopping, convention centers, and tourist attractions. The occupants of the corners immediately adjacent to the intersection are: a mall/hotel, a diner restaurant, a city public works building, and a parking garage. Main Street is a five-lane urban arterial running one way west. James Street is also five lanes wide at the intersection, with a combination of through and turning lanes.

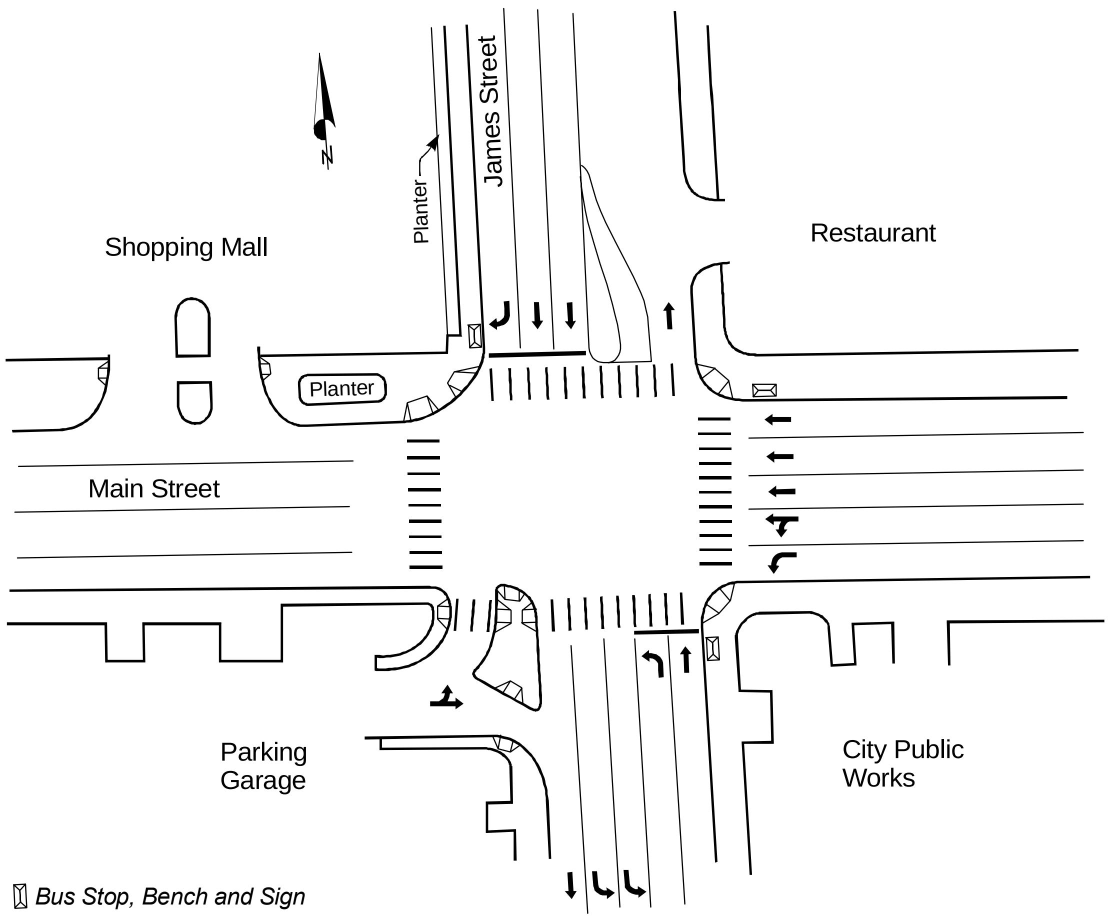


Figure 7-1. Plan Sketch of Intersection.

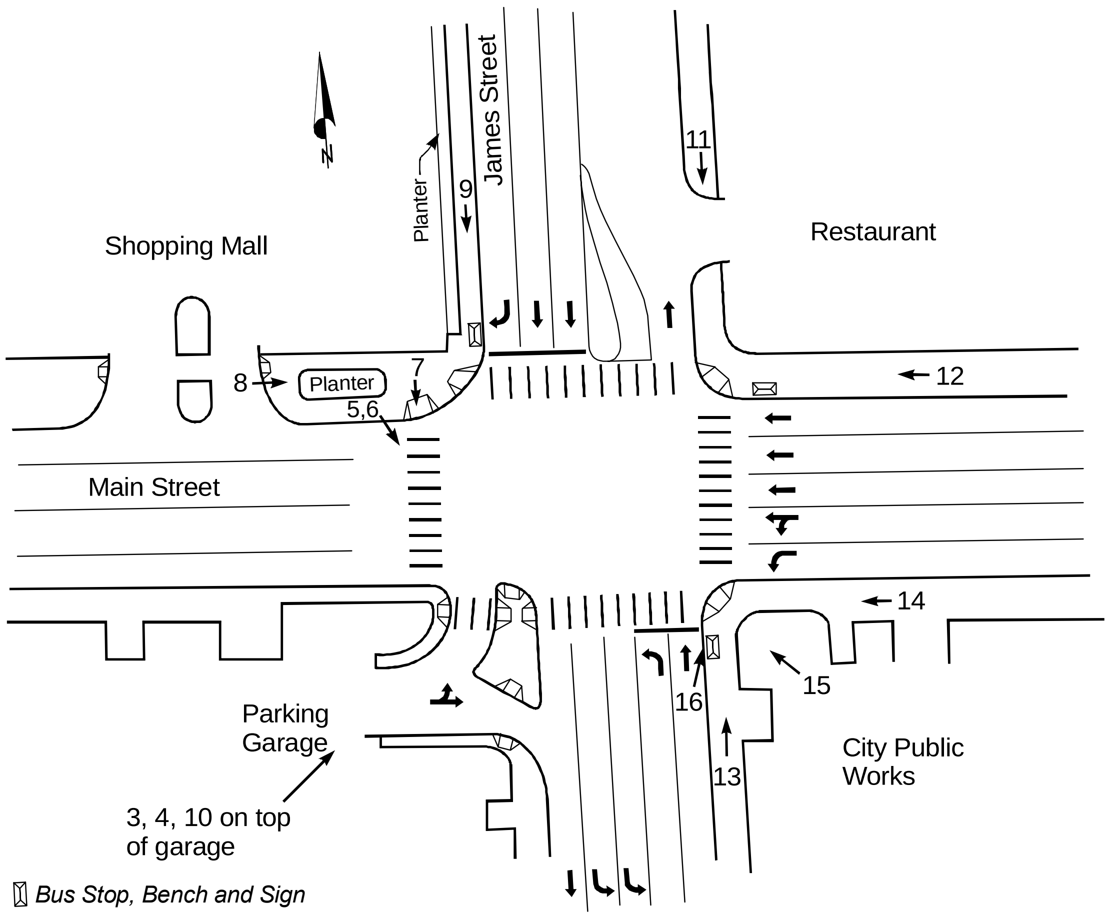


Figure 7-2. Location of Photographs (xx = figure number).

Pedestrian traffic at this intersection, particularly after special events, can be very high. All of the approaches have ADA compliance issues, particularly in the design of curb ramps. Grades and flares are too steep on most curb ramps and none have detectable warnings.

The exits to the parking garage on the southwest corner create two additional "crosswalks" in the approaches to the intersection (see Figure 7-5); these paths across the exits add complexity to negotiating the approach to the intersection on both sides of the garage adjacent to the intersection. During a period of observation, it was noted that a substantial number of pedestrians "created their own path" across that corner, causing increased potential for conflicts with vehicles.

The southwest quadrant has very high curbs, and not all curb ramps are aligned with crosswalk markings. The north-south crosswalk ends at a curb, and a light pole is on the sidewalk where a curb ramp landing should be. The paths of the two garage exits create an island on the corner (see Figure 7-6). This island is steep and not level, with no true landing area, and steep curb ramps. As shown in Figure 7-5, one curb ramp on the island leads out to the southbound right-turn lane.

Figure 7-3. Overhead View of Intersection Looking Northeast.

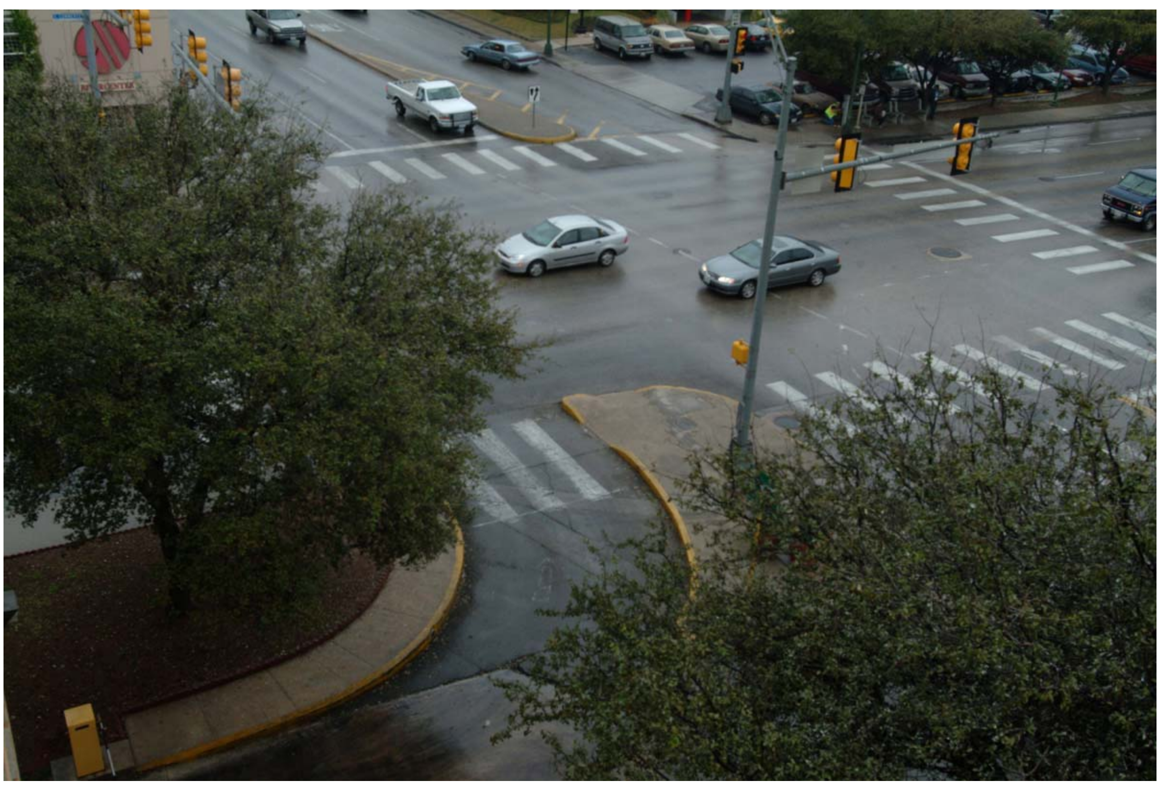


Figure 7-4. Overhead View, Showing Parking Garage Exit.

Figure 7-5. View of Exits from Parking Garage and Corner Island (Southwest Corner of Intersection).

Figure 7-6. Uneven Island and Ramp with No Crosswalk (on Southwest Corner of Intersection).

The design of the northwest corner appears the newest of the four corners (see Figure 7-7). The east-west approach sidewalk has a large planter that effectively divides the sidewalk into two smaller parts, as illustrated by Figure 7-8. Figure 7-9 shows that the north-south approach sidewalk has several street furniture, signs, and other obstructions.

Figure 7-7. View of Crosswalk across West Side of Intersection.

Figure 7-8. Planter Dividing Sidewalk on Northwest Corner of Intersection.

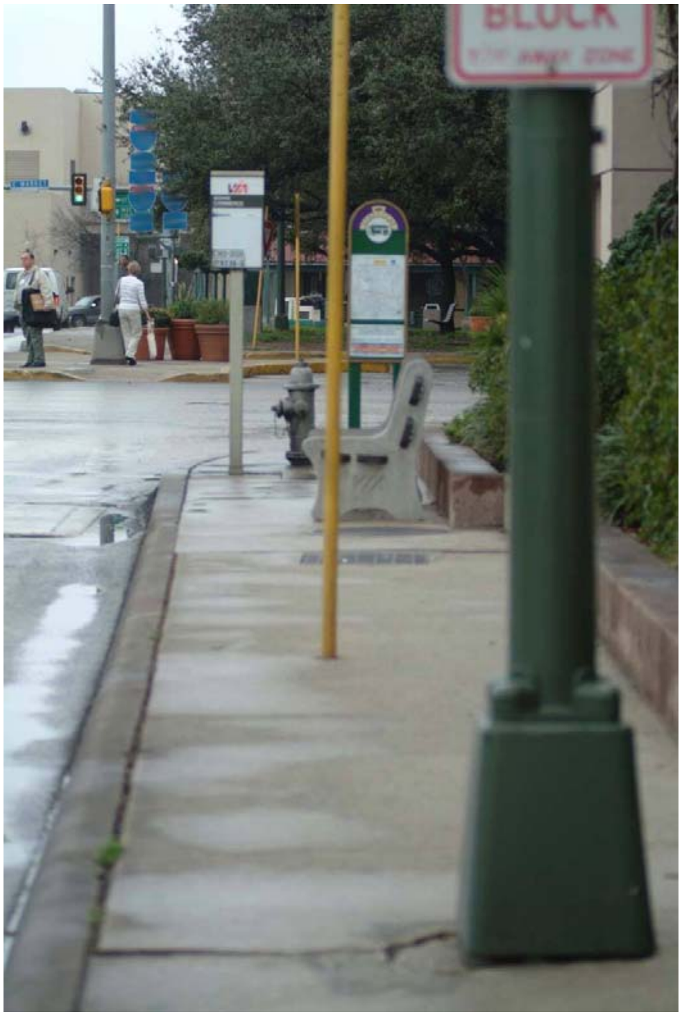


Figure 7-9. Street Furniture in Sidewalk Area Looking South on Northwest Corner of Intersection.

The restaurant in the northeast corner affects pedestrian movement in that area. A driveway is located close to the intersection. The parking area is adjacent to the sidewalk, and inappropriately parked cars can affect walking, especially in the restricted area where the signal pole partially blocks the sidewalk and restricts pedestrian storage (see Figure 7-10). Figure 7-11 illustrates a light pole in the middle of an already narrow approach sidewalk. The other approach sidewalk has good width, but has a cross slope that exceeds the 2 percent maximum allowed (Figure 7-12).

The sidewalks on the southeast quadrant are more open on the approaches, but have obstructions close to the intersection. Figure 7-13 illustrates that the approach sidewalk on James Street has several poles and low-height signs that protrude more than 4 inches [102 mm] between 27 inches [686 mm] and 80 inches [2032 mm] above the surface. The other sidewalk on Main Street has a utility cover in the pedestrian path (Figure 7-14). Figure 7-15 illustrates the multiple decorative paths in the vicinity of the corner. These paths could be disorienting to a visually impaired pedestrian. The substantial change in level and rough pavement at the curb ramp could also cause problems for some pedestrians (see Figure 7-16). However, one positive item is the bus bench, which has been set back from the sidewalk, as shown in Figure 7-13.

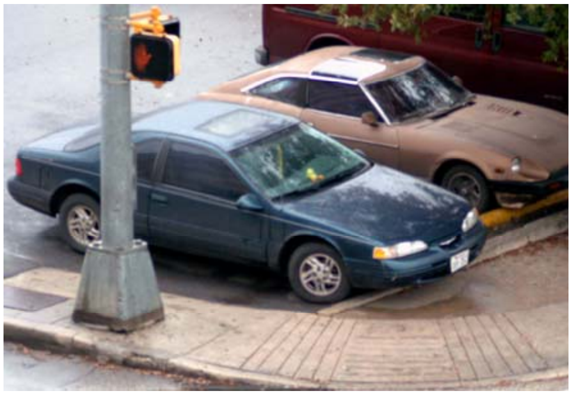


Figure 7-10. Parked Vehicle and Signal Pole Block Pedestrian Travel Near Northeast Corner of Intersection.

Figure 7-11. Light Pole in Narrow Sidewalk on Northeast Corner of Intersection Looking South.

Figure 7-12. Cross-Slope on Approach in Sidewalk on Northeast Corner of Intersection Looking West.

Figure 7-13. Poles and Signs in Sidewalk on Southeast Corner of Intersection Looking North.


Figure 7-14. Utility Cover in the Pedestrian Path at Southeast Corner.

Figure 7-15. Multiple Paths at Southeast Corner of Intersection.

Figure 7-16. Uneven Pavement and Change in Level at Southeast Corner of Intersection.

Issues Considered

Issues to consider during an upgrade to the site include the following:

- ♦ Acquisition of right of way could be costly and difficult to obtain.
- ♦ Redesigning the restaurant driveway or eliminating two parking spaces may require a lengthy negotiation with the restaurant owners to minimize perceived impacts on business.
- ♦ Closing and/or relocating garage exits will also require an agreement with the garage owners, who may be unwilling to alter their points of egress.

- ♦ A number of light poles, signs, and other obstructions would have to be relocated to accommodate compliant ramps, landings, and sidewalk widths.
- ♦ Reconstruction of curb ramps would cause significant disruption to currently existing pedestrian traffic. Coordination and planning would be necessary to minimize those impacts, particularly during times of special events.
- ♦ Improving sidewalk cross slopes also would impact the flow of pedestrian traffic. Again, coordination would be necessary to minimize disruption.

Suggested Designs

A review of this intersection resulted in the following general solutions to address ADA compliance issues:

- ♦ Provide landing areas of at least 5 ft by 5 ft [1.5 m by 1.5 m] at the top of ramps.
- ♦ Reconstruct curb ramps to compliant slopes.
- ♦ Install truncated dome detectable warnings (light and texture contrast).
- ♦ Relocate street furniture and other obstructions.
- ♦ Enforce no parking on sidewalks or add self-enforcing devices such as bollards.
- ♦ Install audible pedestrian signals.
- ♦ Increase pedestrian crossing times.
- ♦ Mill and overlay intersection to improve surface and eliminate lips at the bottom of ramps without increasing roadway crown (and therefore crosswalk grade). Ensure 2 percent maximum cross slope within crosswalk.
- ♦ Relocate signal poles and other supports as needed to eliminate obstructions.
- ♦ Place pedestrian push buttons near ramp landings.
- ♦ Increase width of sidewalks.

In addition, there are suggestions for improvement that are specific to each corner of the intersection.

SW Corner

- ♦ Line up a continuous crossing across James Street and garage exit driveway.
- ♦ Ideally, close existing garage exits and open a new exit at a greater distance from the intersection.
- ♦ Island improvements include the following:
  - On east-west crossing, install cut-through island with a flush 5-ft-wide [1.5 m] crossing. (Island is not wide enough to accommodate compliant ramp grades and a level landing.)
  - Install truncated domes on island cut-through.

- Eliminate northern ramp on island. (A visually impaired person may think this is the crossing location and wander into oncoming southbound traffic.) Block off this curb with the placement of decorative fencing or planters.
- Eliminate a sidewalk wrapping around from the corner toward the garage. Instead, construct a short sidewalk that lines up with the north-south crosswalk with ramps that are accessible to street level and garage surface level.
- Increase available right of way to provide compliant width on the east-west sidewalk, with appropriate landings on the sidewalk and corner island.
- Reduce height of curb along Main Street and install curb ramp at north-south crosswalk.

NW Corner

- ♦ Remove short retaining wall planter from north-south approach to increase available sidewalk width for pedestrians, particularly at bus stop (for wheelchair lift and bus bench).
- ♦ Install audible pedestrian signal to mitigate noise from underground exhaust vent.
- ♦ Reduce turning radius at corner to accommodate two compliant perpendicular ramps.
- ♦ Remove or reduce large planter from east-west sidewalk, as it occupies significant pedestrian space and would be disorienting to a visually impaired pedestrian.
- ♦ Reconstruct ramps with compliant slopes, landings, and truncated domes. If compliant perpendicular ramps cannot be accommodated, install parallel ramps.

NE Corner

- ♦ Acquire additional right of way on corner to provide landing area and storage.
- ♦ Reconstruct restaurant driveway to provide correct cross slope on the sidewalk that crosses the driveway.
- ♦ Relocate newspaper boxes and other street furniture.
- ♦ Improve delineation of parking spaces and eliminate the two stalls closest to the street to prevent cars from parking on the sidewalk.
- ♦ Reconstruct ramps with compliant slopes, landings, and truncated domes. Construct one perpendicular ramp for each crossing.
- ♦ Move crosswalk across Main Street back about 7 ft [2.1 m].

SE Corner

- ♦ Acquire right of way/easement to increase space available for compliant ramps and platoons waiting to cross.
- ♦ Remove corner radius since no northbound traffic can turn right.
- ♦ Reconstruct ramps with compliant slopes, landings, and truncated domes. Construct one perpendicular ramp for each crossing.
- ♦ Reduce height of curb along Main Street.

Figure 7-17 shows some of the suggested improvements for the intersection.

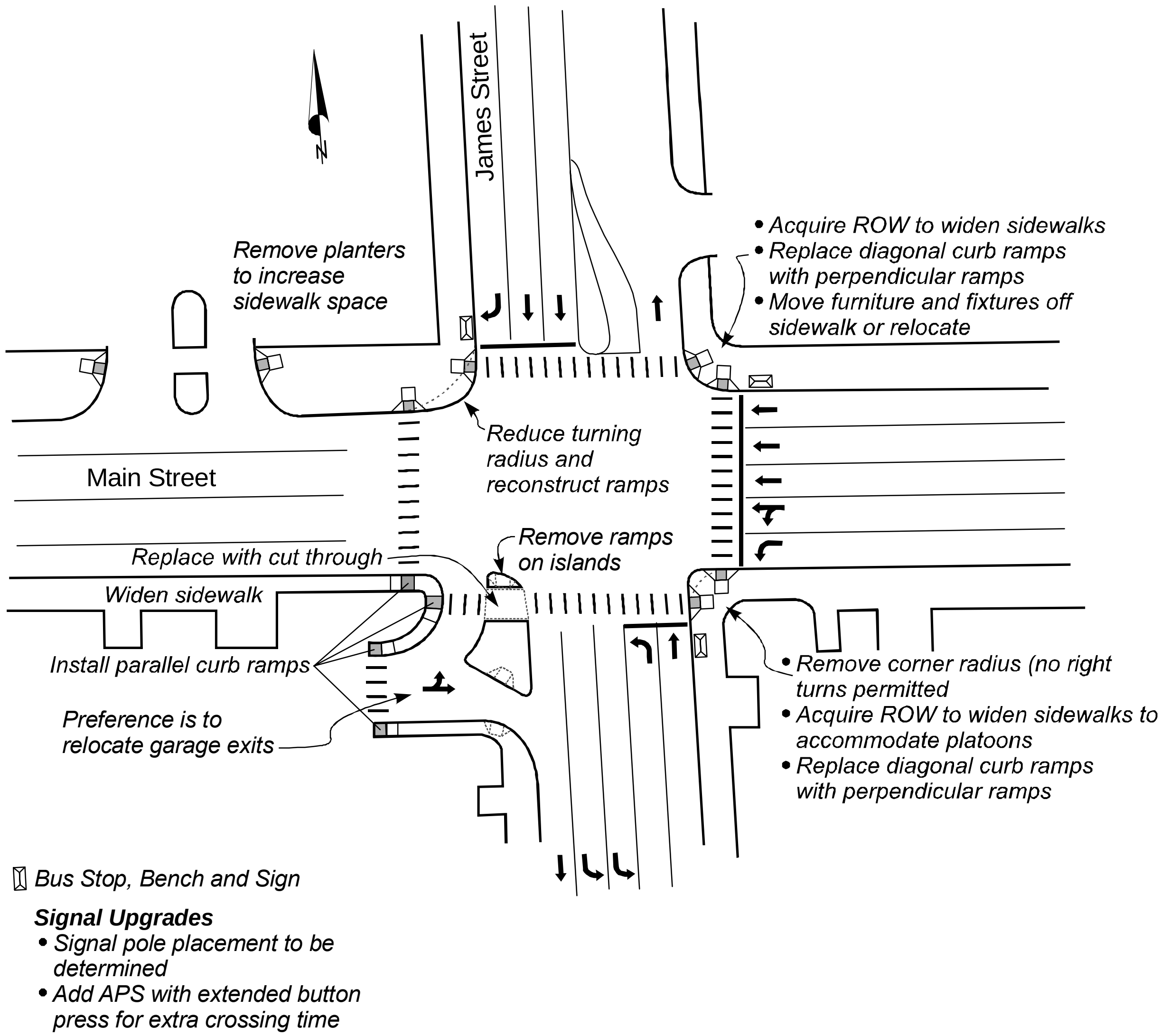


Figure 7-17. Improvement Suggestions for Intersection.

Application 2
Pedestrian and Bicyclist Accommodation

Overview

The following application discusses considerations in accommodating pedestrians at an intersection. The *Urban Intersection Design Guide*, Chapter 7, Section 2 <link> provides additional information on crosswalks.

Background

An unsignalized intersection of an arterial and a major driveway entrance exists between two arterial/arterial intersections within a developed area of a city of approximately 200,000. (See Figure 7-18.) Crockett Parkway is a 58-ft-wide [17.7 m], five-lane arterial with curb and gutter that accommodates approximately 30,000 vehicles per day, with a 45-mph [72.5 km/h] speed limit. Apple Lane is a 40-ft-wide [12.2 m] driveway that provides access to a large office and commercial development located to the south of Crockett Parkway. Apple Lane is not the primary development entrance/exit, but it is the only entrance to the development along Crockett Parkway. Arterial/arterial intersections exist approximately 0.25 mi [0.4 km] to the west and approximately 0.25 mi [0.4 km] to the east of Apple Lane. The city provides good vehicular progression between the two arterial/arterial intersections. Due to traffic flow patterns, there are high volumes of left turns from westbound Crockett Parkway onto Apple Lane and high volumes of right turns from northbound Apple Lane onto Crockett Parkway. The volume of right turns from eastbound Crockett Parkway onto Apple Lane and the volume of left turns from northbound Apple Lane onto Crockett Parkway are minimal.

The city anticipates expansion of the office and commercial development and an increase of traffic volumes on Crockett Parkway. Existing plans are to widen Crockett Parkway to six lanes with a raised median. Anticipating the widening project, the multiple owners of the office and commercial development informed the city that they would be willing to provide land along the south side of Crockett Parkway for the widening project in exchange for two additional project features. First, the owners wish to signalize the intersection of Crockett Parkway and Apple Lane. Second, the owners would like to provide a crossing for pedestrians and bicycles at the intersection. Numerous requests have been submitted to both the city and the owners of the office and commercial development from employees who reside in the area north of Crockett Parkway relatively close to Apple Lane. If the intersection (and a crossing) is made accessible to these residents, many would prefer to either walk or ride bicycles to work. The owners would like to accommodate these employees because fewer parking places would be needed by the employees, the exercise would be good for the employees, and the environment would benefit from the reduction of automobile traffic.

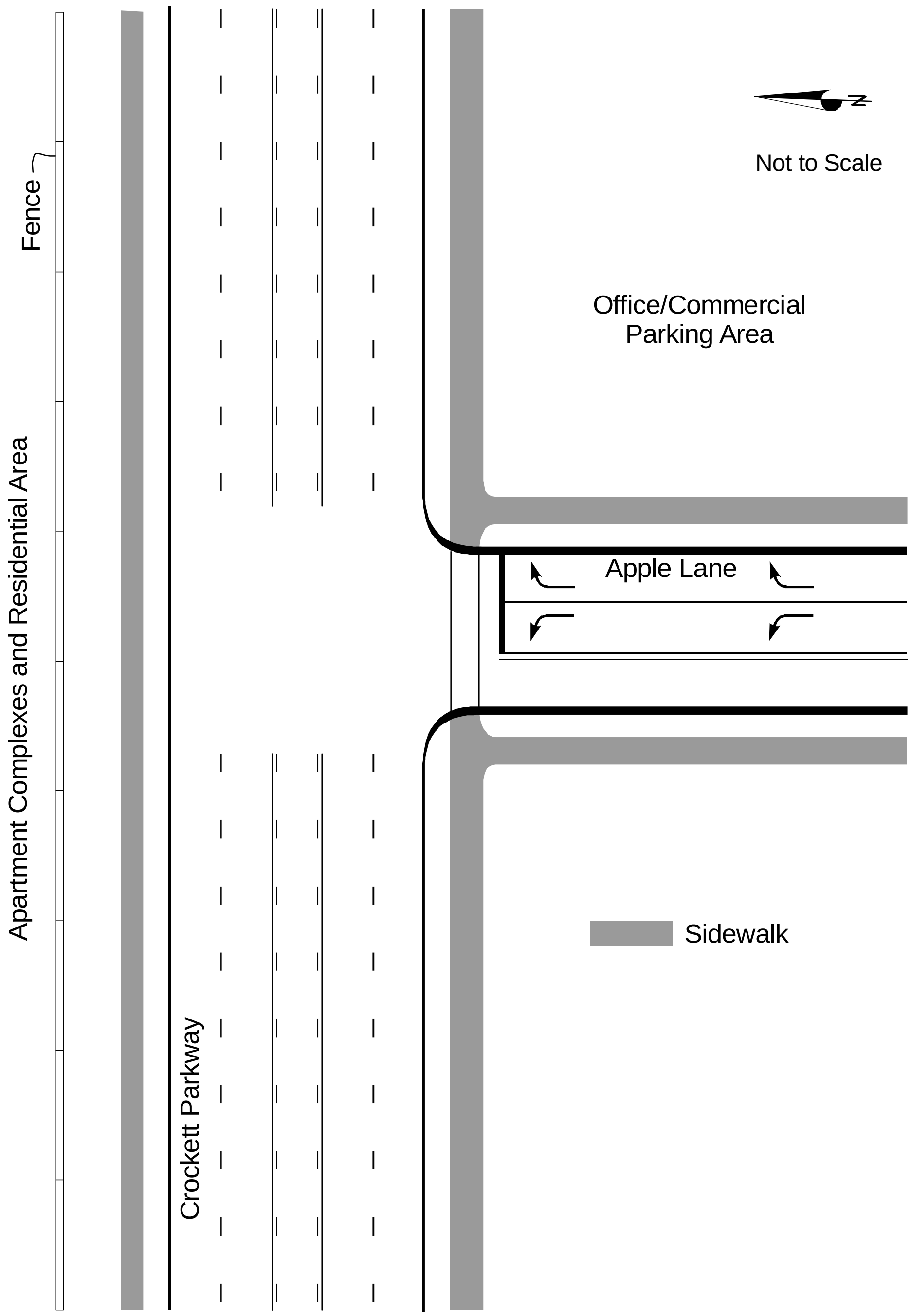


Figure 7-18. Existing Conditions.

Issues Considered

The city has attempted to encourage bicycle traffic by developing bicycle lanes, routes, and paths throughout the city, so city officials were willing to accommodate the owners of the office and commercial development. The city also recognized that the installation of a pedestrian and bicycle crossing of a wide, high-speed arterial (Crockett Parkway) would be difficult (and of questionable safety) without a traffic signal installation. In addition, allowing left turns from westbound Crockett Parkway onto Apple Lane across three high-speed travel lanes also caused some concern. Considering the amount of traffic and operating speeds on Crockett Parkway, the city recognized that the volume of traffic making left turns from northbound Apple Lane and from westbound Crockett Parkway would warrant signal installation. Because of the location of the Apple Lane intersection between two signalized intersections that were about 0.5 mi [0.8 km] apart, it was assumed that signal progression could be maintained between the two arterial/arterial intersections (and through the Apple Lane intersection) as long as the signal operation at the Apple Lane intersection could be designed to minimize disruption of through traffic.

The city planned to widen Crockett Parkway along the south side of the roadway, providing a six-lane arterial with a 17-ft-wide [5.2 m] raised median. As shown in Figure 7-19, the pedestrian/bicycle crossing was incorporated together on the west side of the intersection. The owners of the office/commercial development initiated plans to construct a separate bicycle path to connect the intersection and west-side crossing to existing bicycle lanes and paths within the complex. The crossing was planned to be 14 ft [4.3 m] in width to provide ample space for pedestrians and bicyclists to use the crossing simultaneously. Access northward from the intersection into the apartments and residential area could be provided with minimal problems. The west-side crossing location was preferred because the crossings could be made simultaneously with westbound Crockett Parkway left turns. Also, the crossing would not interfere with high-volume right-turning traffic from northbound Apple Lane. Because of the T-intersection, the median on the west side would not require a left-turn lane and it could remain 17 ft [5.2 m] in width, which provided ample room for storing bicycles and pedestrians and sufficient width to provide curb ramps.

Traffic signals operate with maximum efficiency if “green” time on the major street is maximized. Hence, “green” time should be provided for Crockett Parkway as much as possible. Two specific design features were incorporated into the intersection design to minimize “green” time for Apple Lane traffic and the pedestrian and bicycle crossings. First, the median on the west side of the intersection was equipped with pedestrian signals and pedestrian push buttons. The signals were planned to be programmed to provide crossing Crockett Parkway in two stages. Pedestrians and bicyclists would be required to store in the wide median area and wait for “green” time to cross, which would be provided only when signal progression would allow the disruption. Second, the northbound right-turn lane on Apple Lane was designed to operate as a “free” right-turn lane, and not be controlled by the traffic signal operation. An island was designed to separate the two approach lanes on the northbound Apple Lane approach.

A pedestrian crossing also was designed across Apple Lane on the south side of the intersection. The crossing extended across the free right-turn lane into the island, and then from the island to the southwest corner of the intersection.

Pedestrian signals and push buttons were designed for installation in the island and on the southwest corner of the intersection.

High-visibility, ladder-style crosswalk markings were selected for installation on the pavement to emphasize both the shared pedestrian/bicycle crossing on Crockett Parkway and the pedestrian crossing on Apple Lane.

After finalizing the initial design, the design engineers were informed by the city's legal department that the absence of a marked pedestrian crosswalk on the east side of the intersection did not mean that a "legal" crossing did not exist. Hence, it was determined that a crosswalk should be established on the east side of the intersection as well. The initial design of the intersection was modified, as shown in Figure 7-20, to incorporate the necessary changes.

First, the island on the southeast corner of the intersection was redesigned to incorporate the crosswalk. A curb ramp was designed for the northeast corner of the intersection to connect the crosswalk to the sidewalk that would be located on the north side of Crockett Parkway. Pedestrian signals and push buttons were designed to be installed on the planned traffic signal pole installation to be located on the northeast corner of the intersection.

Pedestrian signals also were designed to be installed on the island to be located in the southeast corner of the intersection. However, in order to separate the two pedestrian signals that will be installed in the island, the traffic signal pole had to be relocated eastward from its originally planned location. An additional pedestal pole was designed to be installed on the island to provide support for one of the pedestrian signal and push button installations.

Providing signal "green" time for crossing Crockett Parkway on the east side of the intersection would likely create some disruption for through-movement traffic on Crockett Parkway. Therefore, it was decided to install pedestrian signals and push buttons in the median island. The operation of the traffic signals at the intersection was planned to be programmed to call for "green" time for crossings at the east-side crosswalk only when "called" by pedestrian push buttons, and provided when it would result in minimal disruption to through traffic on Crockett Parkway.

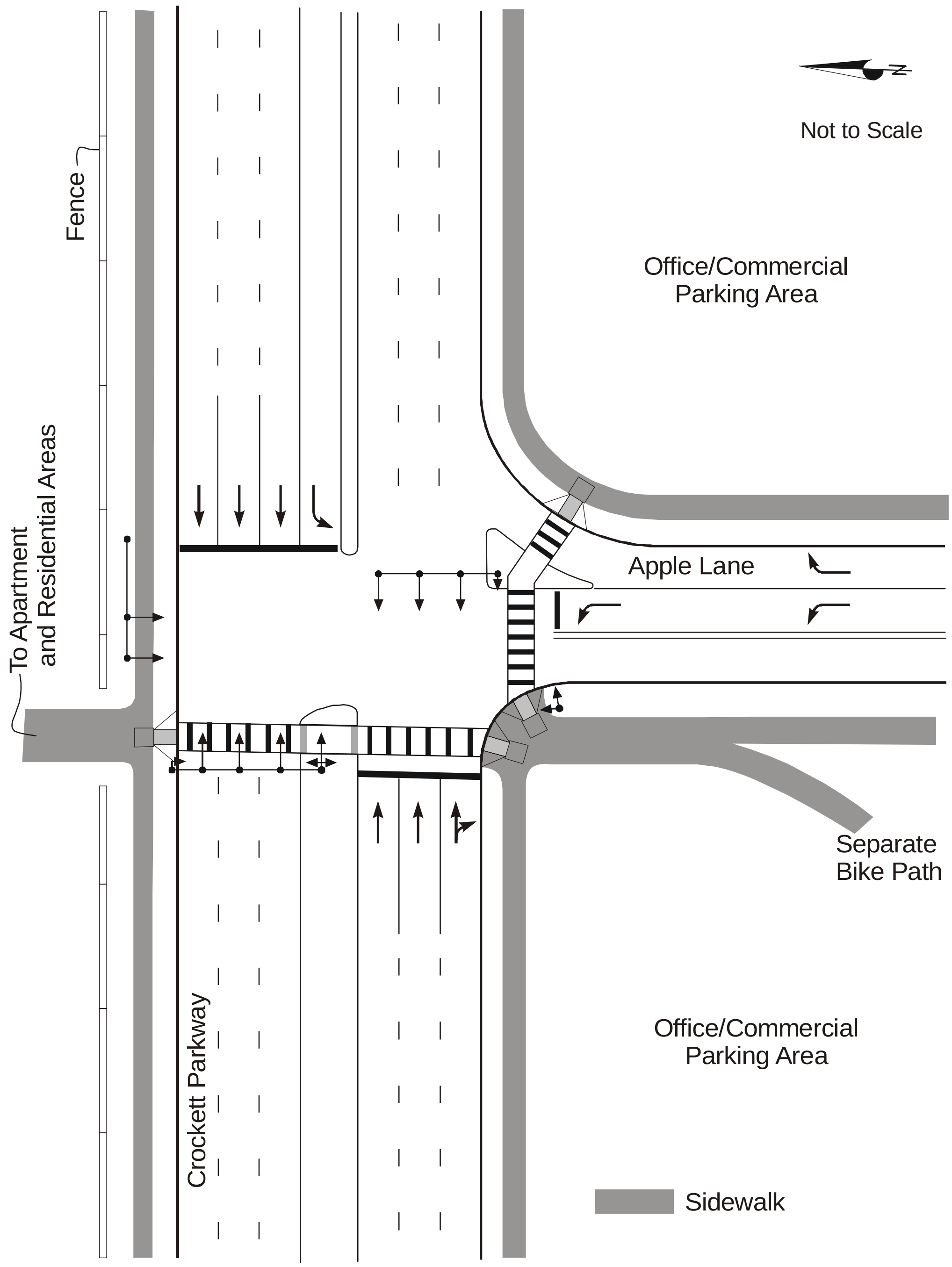


Figure 7-19. Initial Proposed Design.

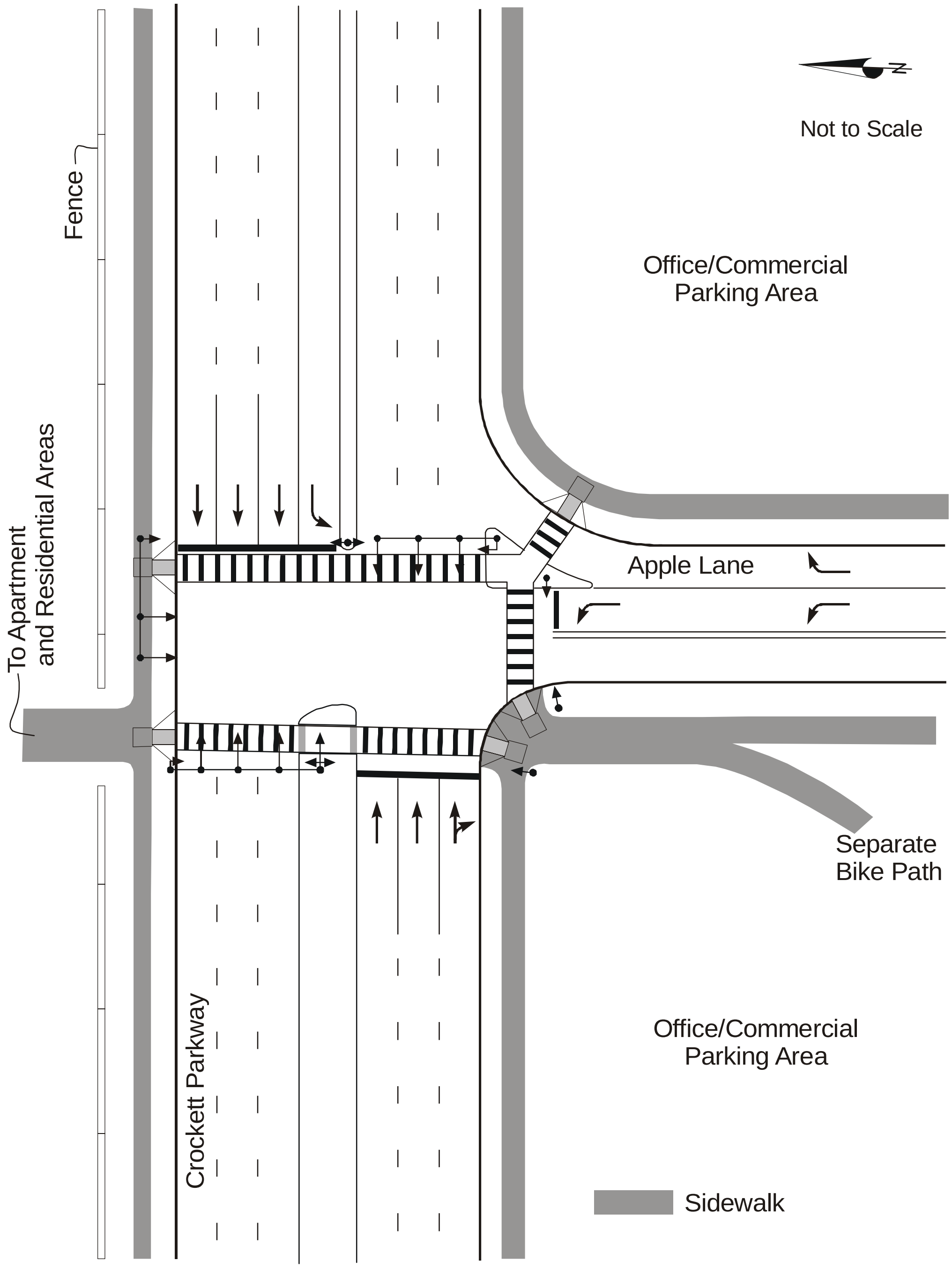


Figure 7-20. Final Proposed Design.

Application 3

Alternative Treatments for Major Street Crossings

Overview

The following are examples of treatments used at major street crossings. These treatments should be judiciously employed because they could lose effectiveness if overused. Chapter 7, Section 2, of the *Urban Intersection Design Guide* <link> presents additional information on crosswalks.

Curb Extension

Curb extensions extend a sidewalk across a parking lane to the edge of the travel lane. They also are called pedestrian bulbs and nubs. Additional information about this type of device is contained in Chapter 5, Section 5 of the *Urban Intersection Design Guide* <link>.

Refuge Medians and Islands

Medians and islands help pedestrians cross streets by providing a refuge area. Additional information is provided in Chapter 4, Section 6 of the *Urban Intersection Design Guide* <link>.

High-Visibility Markings

To heighten driver awareness at uncontrolled crosswalks, high-visibility markings with ladder or “Zebra”-style crosswalk pavement markings have been used. Figure 7-21 is an example of a high-visibility marking. Some agencies use diagonal markings as an alternative treatment. Advantages of the treatment are that it improves the visibility of the crossing from the driver’s perspective and for pedestrians with low vision. Disadvantages include increased cost of installation and maintenance (with paint).

Figure 7-21. Example of High-Visibility Markings.

A study of two experimental and two controlled crosswalk locations was conducted in Clearwater, Florida. The devices installed at the experimental sites included overhead illuminated crosswalk signs, high-visibility crosswalk markings, and standard crossing signs. Significant differences were found in driver daytime yielding behavior between the experimental and control locations. Drivers were 30 to 40 percent more likely to yield at the experimental locations during daylight, while there was a small (8 percent) but insignificant increase in driver nighttime yielding behavior. There was also a large increase (35 percent) in the percentage of pedestrians using the crosswalks at the experimental locations. This suggests that pedestrians may feel that a highly visible crosswalk may provide an additional margin of safety and that they went out of their way to use them. Although pedestrians may feel safer, there is no evidence that they are overconfident or overly aggressive in the high-visibility crosswalk.[1]

Crosswalk Signs and Pavement Markings

Signs and other pavement markings have been used in crosswalk areas. A study of three crosswalks with experimental signs reading "LOOK FOR TURNING VEHICLES" and the painted message "WATCH TURNING VEHICLES" reported positive results. (Note: These are experimental signs and are not included in the current version of the *TMUTCD*. If a district wants to use these types of signs, then a request for experimentation to the TxDOT Traffic Operations Division in accordance with the *TMUTCD* is required in order to install the treatment.) The experiment was conducted at three intersections that had a large number of pedestrians and a high daily traffic volume. At the first site, the signs were installed first, and the pavement markings were added later. At the second site, the pavement markings were installed first and the signs were added later. At the third site, the signs and pavement markings were installed at the same time.

All three methods decreased the average number of conflicts for every 100 pedestrians. The number of pedestrians looking for turning vehicles increased for all vehicle types. In the follow-up studies, both the average number of conflicts and the percentage of pedestrians looking for turning vehicles were as good as or had slightly decreased when compared to the results immediately following installation. In either case, the follow-up study[2] showed a significant safety benefit over the before condition.

Figure 7-22 shows an example of a "LOOK BOTH WAYS" pavement marking used to remind pedestrians to look both ways. Again, this marking would be considered experimental in Texas.

---

[1] Nitzburg, M., and R.L. Knoblauch. "An Evaluation of High-Visibility Crosswalk Treatments-Clearwater, Florida." Report No. FHWA-RD-00-105. August 2001.

[2] Retting, R.A., R. Van Houten, L. Malenfant, J. Van Houten, and C.M. Farmer. "Special Signs and Pavement Markings Improve Pedestrian Safety." *ITE Journal*, Vol. 66, No. 12. December 1996, pp. 28-35.

Figure 7-22. Look Both Ways Pavement Markings.

Advance Placement of Stop and Yield Lines

Advance placement of stop and yield limit lines at uncontrolled crossings is used to encourage drivers to stop a greater distance from the marked crosswalk. Figure 7-23 shows advance yield lines at a midblock crossing. The Yield for Pedestrian sign being used in Shoreline, Washington, is shown in Figure 7-24. Typical applications are locations where drivers are stopping too close to the crossing, especially on multilane approaches. The treatment encourages drivers to stop well in advance of the crosswalk. This helps reduce the potential for pedestrian-related collisions that occur on streets with multiple lanes of traffic when one driver stops to let a pedestrian cross in the crosswalk and the pedestrian is struck by a trailing vehicle in the adjacent lane (see Figure 7-25). With a limit line in advance of the crossing, the trailing vehicle driver is better able to see pedestrians in the crosswalk.

Figure 7-23. Example of Advance Yield Line.

Figure 7-24. Example of Yield for Pedestrian Sign in Washington.

The additional cost for installing and maintaining stop and yield limit lines at a large number of crossings could be significant. If the lines are too far back, visually impaired pedestrians may not hear the sound cues that tell them vehicles have stopped to allow them to cross the street. The lines may reduce availability of on-street parking. Unpublished studies indicate that drivers are less likely to comply with 20-ft [6.1 m] advance stop lines, but compliance is better with 5-ft [1.5 m] advance stop lines. Studies on the effectiveness of stop and yield limit lines in advance of crosswalks on multilane streets found this treatment to be effective; however, the number of sites studied was limited.[3,4]

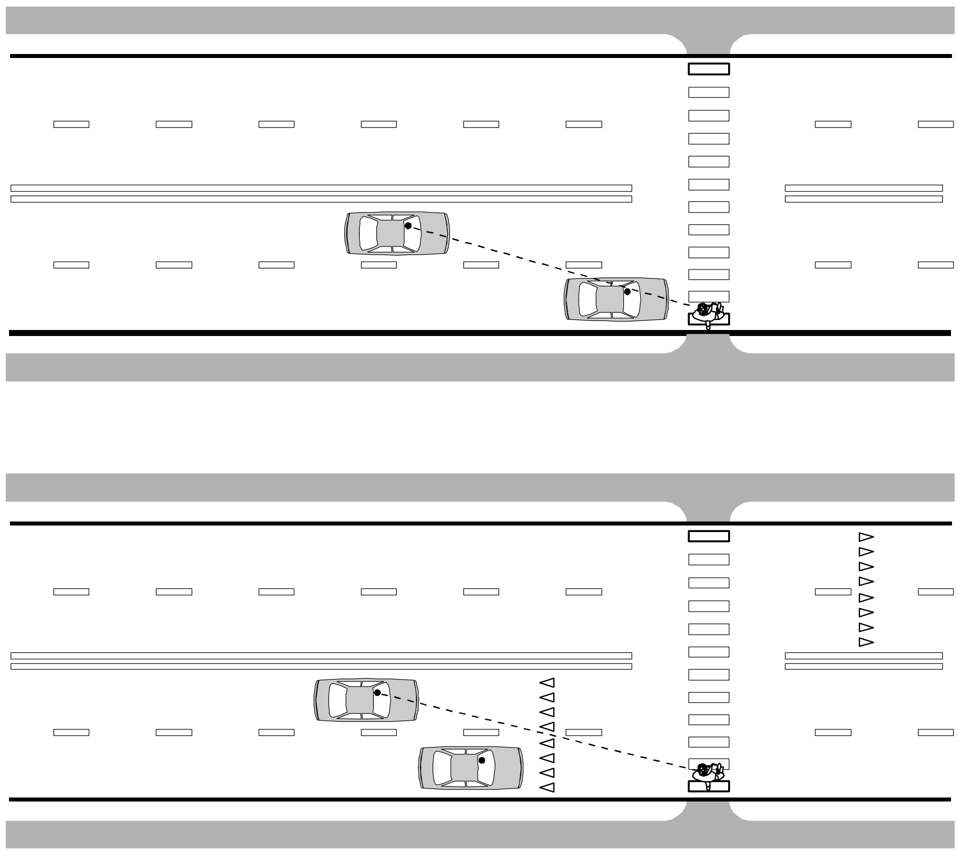


Figure 7-25. Example of Increased Visibility to Pedestrians from Advance Yield Line.

Overhead Signs

Overhead signs at uncontrolled crossings are used to improve visibility of the signs, for example, at locations where the visibility of ground-mounted signs would be limited for drivers in the inner lanes of multilane facilities or where on-street parking might obscure visibility of the signs. The warning signs are installed using span wire or mast arms.

[3] Van Houten, R. "The Effects of Advance STOP Lines and Signs Promote Pedestrian Safety in a Crosswalk on a Multi-lane Highway." *Journal of Applied Behavior Analysis,* 21:245-251, 1988.

[4] Van Houten, R., J.E.L. Malenfant, and D. McCusker. "Advance Yield Markings Reduce Motor Vehicle/Pedestrian Conflicts at Multi-lane Crosswalks with an Uncontrolled Approach." Center for Education and Research in Safety, Halifax Regional Municipality. Presented at the Transportation Research Board Annual Meeting, Washington, D.C., 2000.

Figure 7-26 is an example of an overhead sign.

Figure 7-26. Example of Overhead Pedestrian Sign in Kirkland, Washington.

Pedestrian Railings

Pedestrian railings are used to channelize pedestrians to the safest designated crossing points. Railings typically need to be 4 ft [1.2 m] high to be effective. The cost could be higher if aesthetic enhancements are important. They also are used where there is a need to discourage pedestrians from crossing at locations where complex turning and weaving movements increase the potential for collisions. Figure 7-27 illustrates the use of railings in a median to discourage crossings. Railings need to be highly visible and include a rail that is less than 27 inches [686 mm] above the curb height for detection by pedestrians who are visually impaired and travel with the aid of a white cane.

Disadvantages of railings include:

- may diminish the aesthetic quality of the street environment;
- make pedestrian movement more circuitous, which may encourage pedestrians to walk in the street to circumvent the effectiveness of the railings;
- costs increase if the railing needs to be replaced due to a vehicle striking it;
- considered by some to be anti-pedestrian; and
- can become obstacles to accessing the sidewalk from the street for pedestrians who ignore the railings.

Figure 7-27. Example of a Pedestrian Railing in a Median in Santa Monica, California.

In-Roadway Warning Lights

In-roadway warning lights are used to increase drivers' attentiveness when approaching marked crosswalks occupied by pedestrians at uncontrolled locations. Figure 7-28 shows an installation. Both sides of the crosswalk are lined with durable encased raised pavement markers. Most of the treatments use amber Light Emitting Diode (LED) strobe lighting in the raised pavement markers to alert drivers that they are approaching an occupied crosswalk. However, a few agencies have installed markers without LED strobe lighting. If the markers have lights on both sides, they may be installed on one side of the crosswalk. The LEDs in the raised pavement markers are activated either by push buttons or by automatic detection bollards using infrared sensors that cover the entrance to the crosswalk. Some applications include LED strobe lighting in the pedestrian crossing signs. In-roadway warning lights have been evaluated in numerous studies with varying results. It appears that the effectiveness of this treatment varies widely depending upon the characteristics of the site and existing motorist and pedestrian behavior.

Figure 7-28. Example of In-Roadway Warning Lights.

The ITE Traffic Engineering Council Technical Committee TENC-98-03[5] developed an informational report on in-pavement flashing markers. The report documents the history of how this treatment was developed, the initial test site parameters, signal head illumination and alignment, illumination and flash rate, and various activation methods. The *TMUTCD* provides information on the use of in-roadway warning lights at crosswalks in Section 4L.[6]

An advantage is increased driver awareness of pedestrians in the crossing, especially if the markers and pedestrian warning signs include amber strobe lighting that is activated when a pedestrian is present.

Disadvantages include the following:

- capital cost for installation;
- markers need to be reinstalled when road is resurfaced or undergoes utility repairs;
- may reduce the impact on drivers at crosswalks without this treatment;
- may diminish its effectiveness over time;
- tend to be seen only by the first vehicle in the platoon when there is heavy traffic in the other direction that restricts drivers' views of the entire crossing;
- tend to become shiny with use;
- low sun angles cause markers to be not as apparent to drivers;
- very directional, depending on the manufacturers' specifications;

[5] Traffic Engineering Council Technical Committee TENC-98-03. *In-Pavement Flashing Lights at Crosswalks*. Washington, D.C., ITE. February 2001.
[6] *Texas Manual on Uniform Traffic Control Devices for Streets and Highways*. Texas Department of Transportation. 2003. http://www.dot.state.tx.us/TRF/mutcd.htm. Accessed February 4, 2003.

- rapid degradation of the raised markers, including fogging, caused by harsh on-street conditions;
- lack of long-range visibility;
- could create slipping hazard for bicyclists when wet; and
- some brands of markers more susceptible to snowplow damage than others.

Flashing Beacons

Flashing beacons are used to increase driver attentiveness when approaching marked crosswalks at uncontrolled locations. Figure 7-29 shows a pedestrian crossing at a location with overhead flashing beacons. Flashing amber lights are installed on overhead signs, signs in advance of the crosswalk, or signs located at the entrance to the crosswalk on pedestal poles. Where pedestrian detection is used to activate beacons, it is necessary to install accessible pedestrian signals (APSs) so that visually impaired pedestrians can identify the crossing interval.

Figure 7-29. Example of Overhead Flashing Beacon.

The City of Los Angeles[7] studied two crosswalks across multilane major streets where overhead flashing beacons activated by microwave sensors had been installed. The results of the study indicated that the number of drivers yielding to pedestrians in the crosswalks increased by 10 to 14 percent after installation of the overhead beacons.

Automated Detection

Automated detection devices are used at some locations to activate flashing beacons, in-roadway warning lights, or other active warnings to alert drivers when pedestrians are present. Only activating the device when a pedestrian is present alerts drivers when a pedestrian is crossing the street rather than being a constant warning of a crossing location, thereby improving the effectiveness of the activated beacons. An advantage is that

[7] "Microwave Sensors Show Some Success in Detecting Pedestrians at Crosswalks in L.A." Urban Transportation Monitor, July 9, 1999.

pedestrians do not have to press the button to activate the warning devices. A disadvantage is that false calls have been reported by a number of agencies as a serious problem.

This type of treatment is based on the need to improve the credibility of warning signs and crosswalks. A recent study[8] recommended the following guidelines when using an automated detection system with in-roadway warning lights:

- If a bollard detection system is used, the bollards should be placed along the same line as each row of the in-roadway warning lights to avoid the possibility of a pedestrian entering a crosswalk between the row of lights but outside the bollards. Figure 7-30 shows a bollard detection system.
- Video detection was found to be superior to ultrasonic-based systems but still had false and missed activations. Infrared and microwave detection systems need further testing in conjunction with flashing crosswalks.
- A sign such as Yield for Pedestrians, preferably over the roadway, reminds drivers of their responsibilities. This sign could be retrofitted with lights that flash only in conjunction with the in-roadway warning lights. Alternatively, a beacon that flashes only with the in-roadway warning lights could be mounted below the standard pedestrian crosswalk sign.
- To improve pedestrian understanding of how the in-roadway warning lights work, custom-made signs directed at pedestrians could be placed on or near the bollards. (Note that if the selected treatment is not included in the *Texas Manual for Uniform Traffic Control Devices* or is not part of TxDOT standards, then a request for experimentation to the TxDOT Traffic Operations Division in accordance with the *TMUTCD* is required in order to install the treatment.) The suggested wording might include FLASHING CROSSWALK – WALK BETWEEN POSTS TO ACTIVATE – WATCH FOR CARS – CROSS ONLY WHEN IT IS SAFE TO DO SO. These messages would need to be audible to be of benefit to an unfamiliar pedestrian who is visually impaired.

[8] Huang, H., R. Hughes, C. Zegeer, and M. Nitzburg. "An Evaluation of the LightGuard™ Pedestrian Crosswalk Warning System." Florida Department of Transportation, Safety Office, June 1999.

Figure 7-30. Example of Bollard Detection System.

Application 4
Alternative Treatments for Residential Street Crossings

Overview

Example treatments used at residential street crossings follow. Chapter 7, Section 2 of the *Urban Intersection Design Guide* <link> presents additional information on crosswalks.

Raised Crosswalk

A raised crosswalk is typically raised 6 inches [152 mm] above the roadway pavement to an elevation that matches the adjacent sidewalk. This treatment includes a flat area on the top that constitutes the crosswalk. This flat area may be made of asphalt, patterned concrete, or brick pavers. Where raised crosswalks meet the sidewalk, provision of a detectable warning surface with truncated domes is required to mark the street interface for pedestrians with visual impairments. Figure 7-31 shows an example of a raised crosswalk.

Figure 7-31. Example of Raised Crosswalk in Portland, Oregon.[9]

The objective of this treatment is to control traffic speeds approaching and then traversing the crosswalk to improve the safety of

pedestrians using the crosswalk. Advantages for this treatment include reducing traffic speeds at the crosswalk and providing an easier crossing for pedestrians. It also focuses the pedestrian crossing activity in the desired location. A disadvantage is the cost of

[9] Pedestrian and Bicycle Information Center. Image Library. http://www.pedbikeimages.org/index.cfm. Accessed November 25, 2003.

installation.[10] How the raised crosswalk affects drainage needs to be examined in the design phase to avoid undesirable ponding or flooding.

Drivers and passengers with disabilities have expressed concerns about the level of pain experienced by persons with spinal injuries when crossing vertical deflections in the roadway.

A recent study showed that the percentage of drivers yielding to pedestrians increased from an average of 15 percent before installation to 55 percent after the raised crosswalk was installed.[11] The 85th percentile speed declined from 31 mph [50 km/h] in the before period to 25 mph [40 km/h] in the after period. A report by ITE also evaluated the benefits of raised crosswalks and found speeds decreased from 37 to 35 mph [60 to 56 km/h] at one site and from 30 to 21 mph [48 to 34 km/h] at another site.[12]

Entry Treatments

Entrance treatments are used to create a sense of community or neighborhood identity. Entrance features may consist of textured and colored pavements, curb extensions, raised crosswalks or speed tables, landscaping, and entry signage at key entryways into neighborhoods or small towns. Entrance treatments create visual and/or audible cues to tell drivers that they are entering a local residential area or that the surrounding land uses are changing.

The advantage of entry treatments is that they reduce traffic speeds as vehicles enter the residential street. A disadvantage is the cost of installation. However, there are minimal cost implications if this design is incorporated as streets are being constructed.

Raised Intersections

Raised intersections are constructed as raised platforms 6 inches [152 mm] above the approaches to the intersection (see Figure 7-32). They frequently use asphalt and patterned concrete or brick pavers. The height matches the elevation of the adjacent sidewalk. Where raised intersections meet the sidewalk, provision of a detectable warning surface with truncated domes is required to mark the street interface for pedestrians with visual impairments. Accommodating the flow of stormwater near the raised intersection, especially when retrofitting a raised intersection, is needed to avoid ponding or flooding.

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[10] *Alternative Treatments for At-Grade Pedestrian Crossings*. An ITE Informational Report by Nazir Lalani and the ITE Pedestrian and Bicycle Task Force, Institute of Transportation Engineers, 2001.

[11] Watkins, K. "Cambridge's Traffic Calming Program – Pedestrians Are the Focus." Compendium of Papers, ITE Annual Meeting in Nashville, TN, 2000.

[12] Ewing, R. *Traffic Calming, State of the Practice.* Report No. FHWD-RD-135. Washington, D.C.: ITE under contract with US DOT, FHWA, 1999.

Figure 7-32. Raised Intersection in Portland.[9]

The objective is to slow vehicles as they approach the intersection and traverse the raised intersection, thereby improving the safety of pedestrians crossing at the intersection. Disadvantages include:

- ♦ cost of installation (however, it is minimal if the design is incorporated as streets are being constructed),
- ♦ vehicles can mount the sidewalk more easily, and
- ♦ pain experienced by those with spinal injuries (drivers and passengers with disabilities have expressed concerns about the level of pain experienced by persons with spinal injuries when crossing vertical deflections in the roadway).

Traffic Calming

Several documents are available with information on traffic calming measures used in residential areas including the following:

- ♦ ITE, Traffic Calming, State of the Practice.[12]
- ♦ ITE Web site (http://www.ite.org) in the section on traffic calming.
- ♦ TxDOT, Handbook of Speed Management Techniques.[13]

[13] Parham, A.H., and Fitzpatrick, K. *Handbook of Speed Management Techniques.* FHWA/TX-99/1770-2. Texas Transportation Institute. College Station, TX, 1998.

- ITE, Alternative Treatments for At-Grade Pedestrian Crossings.[10]

Application 5

Alternative Signal Control at Crossings

Overview

This section presents information on alternative signals that have been installed for pedestrian crossings. The discussions focus on types of signals generally not located at intersections or whose appearance or operations are significantly different from typical pedestrian crossings at signalized intersections. Chapter 7, Section 2 of the *Urban Intersection Design Guide* <link> presents additional information on crosswalks. Chapter 8 <link> provides general information on signals including pedestrian signals.

Midblock Signal

Examples of a midblock signal are shown in Figure 7-33 from University Way, Washington, and Figure 7-34 from Los Angeles, California. The city of Los Angeles has used midblock signals at 105 locations in the downtown and other retail areas. The treatment provides pedestrians an opportunity to cross midblock at a controlled crosswalk. The city used the pedestrian warrant contained in the California *Traffic Manual* to determine treatment locations, along with consideration of intense retail activity, high pedestrian volumes, midblock crossing demand, the presence of existing signals at the end of the subject block, and block length greater than 600 ft [183 m].[10]

Figure 7-33. Example of a Midblock Signal in Washington.

Figure 7-34. Example of a Midblock Signal in Los Angeles.

During the WALK interval, a steady red signal indication is displayed to drivers approaching the crosswalk. During the flashing DON'T WALK interval, drivers see a flashing red indication and, after stopping, they may proceed through the crosswalk area in front of them if it is not occupied by pedestrians. After the pedestrian clearance interval ends, the signal turns green to allow drivers to proceed. The flashing red minimizes the interruption to traffic progression. Vehicles remain stopped during the 4- to 7-second WALK interval. However, they are not required to wait the full 12 to 20 seconds that would be necessary if a steady red indication were displayed during the completion of the DON'T WALK clearance interval. A variation is to have drivers see a steady red indication during the DON'T WALK interval. Drivers may not proceed through the crosswalk area in front of them until the signal turns green. Signals remain green for drivers until a pedestrian reactivates the push button.

Split Midblock Signal

Tucson, Arizona, also uses midblock signals. They have an example where the pedestrian would cross the street in two stages:

- first to a median island and proceed along the median to a second signalized crossing point a short distance away, and
- then the pedestrian activates a second crossing button, and another crossing signal changes to red for the traffic, giving the pedestrian a WALK signal.

Figure 7-35 shows a close-up of the railing at a split midblock signal in Tucson. Figure 7-36 shows the split midblock signal treatment being used in Bellevue, Washington.

Figure 7-35. Example of a Split Midblock Signal in Tucson.

Figure 7-36. Split Midblock Signal Treatment in Bellevue.

The two crossings operate independently of each other, which allows signal operation to better fit into the major street traffic progression for each direction. This reduces the potential for:

- ♦ stops,

- delays,
- crashes, and
- environmental air-quality issues.

Intersection Pedestrian Signals (Half Signals)

Intersection pedestrian signals (also know as half signals) are used to provide signal control for a pedestrian crossing the major street while minimizing delay for major street traffic by retaining Stop sign control on the minor street. This treatment has been used at locations where there is heavy pedestrian demand to cross the major street, but the side street traffic on the minor approach is light. The lack of signal control on the side street does not attract more traffic to the street as conventional intersection signals would.

The cost of installation is significant. Drivers on side streets may be confused about right-of way assignment: the right of way relies on gaps in main street traffic to enter or cross the main street.

This treatment has been tested in several cities including Tucson, Arizona; Portland, Oregon; and Fairfax, Virginia. This device is not included in the current version of the *TMUTCD*. If a district wants to use this device, then a request for experimentation to the TxDOT Traffic Operations Division in accordance with the *TMUTCD* is required in order to install the treatment. Figure 7-37 shows an example of a half signal in Seattle.

Figure 7-37. Example of a Half Signal in Seattle, Washington.

Hawk Crossings

The objective of a Hawk (high-intensity activated crosswalk) crossing is to stop vehicles to allow pedestrians to cross while also allowing vehicles to proceed as soon as the pedestrians have passed. It is a combination of a beacon flasher and a traffic control signaling technique for marked crossings. The unit is normally off until activated by a pedestrian. The signal begins with a flashing yellow indication to warn approaching drivers, just like a school bus signal. The flashing yellow is then followed by a solid yellow indication advising the drivers of the requirement to prepare to stop. The signal is then changed to a solid red indication during the pedestrian interval, when drivers must stop at the crosswalk. The beacon signal then converts to an alternating flashing red, allowing drivers to proceed when safe.

This application provides a pedestrian crossing without signal control for the side street. This treatment is currently used in Tucson, Arizona, and their guidelines are summarized elsewhere.[14] An evaluation at one site found that motorists yielding to pedestrians increased from 31 to 93 percent. Figure 7-38 shows a Hawk signal. This device is not included in the current version of the *TMUTCD*. If a district wants to use this device, then a request for experimentation to the TxDOT Traffic Operations Division in accordance with the *TMUTCD* is required in order to install the treatment.

The advantages include:

- drivers are likely to stop for a form of traffic control resembling a traffic signal,
- minimized delay for major street traffic, and
- additional vehicular traffic is not attracted to the side street, which may be residential.

Disadvantages include:

- it may require driver education,
- drivers have a tendency to remain stopped when it is safe to proceed, and
- it may be confusing to have a dark signal display, which may convey a power outage to some drivers.

The Hawk is currently not included in the *MUTCD* or *TMUTCD* as a pedestrian crossing treatment. The device has similarities to an emergency-vehicle traffic control signal.

[14] Glock, J.W., R.B. Nassi, R.E. Hunt, and B.W. Fairfax. "Implementation of a Program to Reduce Pedestrian-Related Accidents and Facilitate Pedestrian Crossings." Paper submitted for the Pedestrian Project Award, Partnership for a Walkable America and ITE, August 2000.

Figure 7-38. Example of a Hawk Signal in Tucson, Arizona.

Application 6

Alternative Treatments for Signalized Intersections

Overview

Following are signalized intersection treatments that have the intention of making street crossings more pedestrian friendly. Some treatments, such as high-visibility markings, curb ramps, signs, refuge islands, and pavement legends, are also used at uncontrolled crossings and are discussed in Chapter 7, Application 3 <link>. Chapter 7 of the *Urban Intersection Design Guide* <link> presents additional information on crosswalks. Information on traffic signals for pedestrians is in the *Urban Intersection Design Guide,* Chapter 8, Section 5 <link>. As with all treatments, the *TMUTCD* should be consulted for guidance on selecting appropriate devices.

Treatments

The following treatments have been implemented to improve the pedestrian crossing at a signalized intersection.[10]

Leading Pedestrian Signal Intervals permit pedestrians to begin crossing several seconds before the release of potentially conflicting motor vehicles at signalized intersections. Equipment or new timing is installed at signalized intersections to release pedestrian traffic 3 seconds in advance of turning vehicles for signals with protected left-turn movements. The WALK indication or walking person symbol is displayed 3 seconds in advance of the green signal indication for vehicles. Accessible Pedestrian Signal would be needed to inform visually impaired pedestrians that the walk signal is shown.

Lagging Pedestrian Signal Intervals delay pedestrian crossing several seconds until after the release of potentially conflicting motor vehicles at signalized intersections.

Educational Signs for Pedestrian Signal Indications are used to improve the understanding of pedestrian signal indications at signalized intersections (see Figure 7-39). They are installed above pedestrian push buttons or integrated into the push button housing.

Figure 7-39. Examples of Educational Signs.

Advance Stop Lines at Signalized Intersections encourage drivers to stop a greater distance from the marked crosswalk. They reduce the potential for pedestrian-related collisions on four-lane streets that are caused when a driver stops to let a pedestrian cross who is then struck by a trailing vehicle in the adjacent lane (see Figure 7-25). Standard white stop lines are placed preferably 5 ft [1.5 m] to 20 ft [6 m] in advance of marked crosswalks at signalized intersections. The signal head visibility needs to be checked when moving the stop line upstream from the crosswalk.

Pedestrian Railings at Signalized Intersections channelize pedestrians to the safest designated crossing points. A typical description of the treatment is to use 4-ft-high [1.2 m] railings. The split midblock signal uses pedestrian railings as part of the treatment. Figure 7-35 and Figure 7-36 are photographs of installations.

Scramble Patterns at Signalized Intersections enable pedestrians to cross in all directions at an intersection, including diagonally rather than having to cross two legs of intersection. This reduces the distance pedestrians have to walk and reduces delays for pedestrians. There are three pedestrian indications at each corner, one each for the typical crosswalks and one for the diagonal crosswalk. During the time period when the diagonal crosswalk pedestrian indication permits pedestrians to cross, the vehicle indications display red on all approaches of the intersection.

Push Button Treatments at Signalized Intersections provide additional information to pedestrians. One example of this treatment incorporates a pedestrian acknowledgement device using a high-intensity LED indicator.

Automated Detection at Signalized Intersections detects pedestrians and/or eliminates unnecessary calls if the pedestrian leaves the area. This treatment is used also to extend pedestrian intervals if pedestrians are detected in the crosswalk. Pedestrians are detected at the curbside of and/or in a pedestrian crossing by means other than those requiring a physical response by pedestrians. Most applications use either infrared or microwave technology.

Wheelchair Detection at Signalized Intersections activates treatments specifically needed to assist pedestrians in wheelchairs to cross at a pedestrian crossing. In-pavement loop detectors are used to detect wheelchairs and to activate pedestrian crossing indications.

Accessible Pedestrian Signals at Signalized Intersections provide information to pedestrians who are visually impaired that is comparable to the visual information that is available. Under the *Draft Guidelines for Accessible Public Rights-of-Way*,[15] APS installation would be required at:

- new signalized intersections that have actuated pedestrian signals,
- intersections that lack the cues needed by people with visual disabilities, and
- intersections that are undergoing signal upgrades.

[15] U.S. Access Board. Draft Guidelines for Accessible Public Rights-of-Way. June 17, 2002. http://www.access-board.gov/rowdraft.htm. Accessed September 2003.

Additional information on accessible pedestrian signals is in Chapter 8, Section 5 of the *Guide* <link>.

Countdown Pedestrian Signal Indications at Signalized Intersections provide information to enable pedestrians to make better decisions about when to enter the crosswalk. Countdown signals are used in conjunction with conventional pedestrian signals to provide information to pedestrians regarding the amount of time remaining to safely cross the intersection. The countdown timer starts either at the beginning of the pedestrian phase or at the onset of the pedestrian clearance interval. At the end of the pedestrian clearance interval, the countdown device displays a zero and the DON'T WALK indication appears. Figure 7-40 shows examples of countdown devices in Florida.

Figure 7-40. Examples of a Countdown Indication.

Animated Eye Pedestrian Signal Displays at Signalized Intersections encourage pedestrians to look for turning vehicles traveling on an intersecting path by including a prompt as part of the pedestrian signal display. An animated eye display uses an LED pedestrian signal head and adds animated eyes that scan from side to side. The device uses a narrow (8-deg) field of view LED on a black background. The display is highly visible to pedestrians while limiting pedestrian signal displays to drivers. The blue LEDs display two blue eyes with blue eyeballs that appear to scan from left to right at the rate of one cycle per second.

Curb Extensions at Signalized Intersections reduce pedestrian exposure to vehicular traffic and the potential of being struck. The sidewalk extends across the parking lanes to the edge of the travel lanes to narrow the distance of the road that pedestrians cross. Curb extensions also improve the visibility of pedestrians waiting to cross by:

- bringing them closer to the center of the driver's cone of vision, and

- minimizing the impact of parked vehicles on driver's ability to see pedestrians waiting to cross.

Overhead Signs at Signalized Intersections make drivers more aware of the presence of pedestrians at specific locations. Overhead signs on mast arms alert drivers to the presence of pedestrians at signalized crossings. Figure 7-41 shows one style of a pedestrian crossing sign on a mast arm.

Figure 7-41. Example of Pedestrian Crossing Sign on Mast Arm in Tucson, Arizona.

Warnings of Turning Vehicles at Signalized Intersections encourage pedestrians to watch for through traffic and turning vehicles. Word legends, signs, and auditory devices are placed at each end of the crosswalk so that they are legible to pedestrians waiting to cross.

Turn Prohibitions at Signalized Intersections improve the pedestrian environment by reducing conflicts between turning vehicles and pedestrians crossing the street in the crosswalk at signalized intersections. Signs are placed prohibiting right turns on red at signalized intersections. (On one-way streets, this could involve prohibiting left turns on red.)

Perpendicular Crossings at Skewed Intersections shorten pedestrian crossing distances and reduce pedestrian clearance signal timing. Transverse pedestrian crossing markings are placed perpendicular to the road to be crossed instead of parallel to the skewed intersecting road. This treatment can be accompanied by textured or decorative pavements to further delineate the crossing location.

Application 7

Alternative Treatments for School-Related Crossings

Overview

The majority of motorists do not reduce vehicular speed in school zones unless they perceive a potential risk such as the presence of police or crossing guards, or they observe that children are present. Chapter 7, Section 2, of the *Urban Intersection Design Guide* <link> presents additional information on crosswalks.

Recommended Guidelines for School Trips and Operations

The Institute of Transportation Engineers developed a recommended practice on the selection of safe walking trip routes to school and traffic control measures called *School Trip Safety Program Guidelines*.[16] TxDOT developed materials that can assist with developing designs and selecting treatments at and near schools.[17]

Treatments

Following are example treatments used near schools identified in *Alternative Treatments for At-Grade Pedestrian Crossings*.[10] If a district wants to use experimental signs or pavement markings, then a request for experimentation to the TxDOT Traffic Operations Division in accordance with the *TMUTCD* is required in order to install the treatment.

Portable Signs are placed in the school crosswalk during school hours (see Figure 7-42). Some require drivers to stop when children are in the crosswalk. They also are used in advance of the crosswalk to notify drivers to slow to a specific speed (e.g., 15 mph [24 km/h]).

[16] *School Trip Safety Program Guidelines*. Recommended Practice, ITE Technical Committee 4A-1. Institute of Transportation Engineers. 1984.

[17] Cooner, S.A., K. Fitzpatrick, M.D. Wooldridge, and G.L. Ford. Traffic Operations and Safety at Schools: Recommended Guidelines. FHWA/TX-03/4286-2. Texas Transportation Institute. College Station, Texas, October 2003.

Figure 7-42. Portable Sign.

Overhead School Signs are installed on signal mast arms to warn drivers of the presence of school-age pedestrians crossing at the signal (see Figure 7-43). Overhead placement of the signs increases their visibility, but the overhead treatment is more difficult and costly to install and maintain. Wind loading on the span wire or mast arm is increased, which may necessitate a stronger and, therefore, more expensive design.

Figure 7-43. Example of Overhead School Signs.

Fluorescent Yellow-Green Signs with Flashing Beacons are installed at crosswalks used by school-age pedestrians to warn drivers of the presence of school-age pedestrians. Some applications use flashers that are active for a fixed, predetermined period of time. Other applications use sensors to activate flashers when pedestrians are detected or use pagers to activate the flashers from a remote location. The exact costs depend on whether sensors are included in the treatment. An advantage is that the combination of flashing beacon and fluorescent yellow-green signs has the potential to attract drivers' attention to the pedestrian crossing and the presence of school-age pedestrians. Disadvantages include that overuse of these types of devices may erode their effectiveness, and energy and ongoing maintenance costs can be significant.

Part-Time Street Closures can be used to create a pedestrian-only environment for part of the day. Gates can be used to close streets to traffic for part of the day during school hours, e.g., from 6:00 AM to 6:00 PM (see Figure 7-44). Several agencies have used part-time closures to deal with high levels of pedestrian activity near schools, to promote safety, and to deter gang violence. The treatment creates a unified school campus by creating a pedestrian mall on the section of the street that is closed to traffic. During closure hours, this may cause major detouring of traffic onto parallel streets, some of which could be residential. A study of a part-time closure of a street bisecting a high school campus in Ventura, California, showed that 6000 of the 8000 vehicles using the street on weekdays during the closure hours diverted to a parallel major street.[10] Volumes rose from 14,000 vehicles per day to over 20,000 on the parallel major street, two blocks away. The remaining 2000 vehicles used residential streets to bypass the closure, causing these streets to be closed part-time for several years until the residents felt that drivers had become used to using the parallel major street.

Figure 7-44. Example of Sign Used to Close Road During School Hours.

Portable Orange Barrels or large cones with reflector strips are placed in the school crosswalk during school hours to encourage drivers to slow down. Portable barrels in the school crosswalk attract drivers' attention to the crossing when children are crossing. Deploying the barrels each day takes time. Barrels are also prone to being hit or suffering weather damage, thereby requiring periodic replacement.

Chapter 8
Signals

Contents:

Application 1
Signal Visibility

Overview

The *Texas Manual on Uniform Traffic Control Devices* (*TMUTCD*) contains numerous standards and guidelines relative to the installation of traffic signals. The *Urban Intersection Design Guide,* Chapter 8 <link> includes discussions on intersection design considerations for signals. One of the design-related issues is adequate sight distance. A driver approaching a signalized intersection must be able to see the traffic signals at a specific distance from the appropriate stop position (or stop line if provided) so that the driver has adequate time and distance available to bring the vehicle to a stop prior to reaching the appropriate stop position. These sight distances vary according to operating speed. As operating speeds increase, the required sight distances increase.

Sight distance restrictions are caused by topographic conditions, vegetation (large trees), or man-made structures, like buildings or highway overpasses/underpasses. Most often, sight distance restrictions result from installing traffic signals at intersections that are located "on the other side of the hill" or "around the curve."

Treatments

The *TMUTCD* suggests that a warning sign (SIGNAL AHEAD sign, W3-3) may be installed in advance of a signalized intersection when the recommended sight distance is not available. A warning beacon may be used as a supplement to draw attention to this sign. Also, a BE PREPARED TO STOP sign or a "Be Prepared to Stop When Flashing" sign may be installed as a supplement to the SIGNAL AHEAD sign if desired.

TxDOT has recently installed "Be Prepared to Stop When Flashing" signs at two locations; Waco and Brenham in Texas. Information about design, installation, and operation of these signs is available in the following documents.

- ♦ Messer, C.J., S.R. Sunkari, H.A. Charara, and R.T. Parker. *Design and Installation Guidelines for Advance Warning Systems for End-of-Green Phase at High Speed Traffic Signals*. Texas Transportation Research Report 4260-2, September 2003.
- ♦ Sunkari, S.R., C.J. Messer, H.A. Charara, and R.T. Parker. *Signal Technician's Installation and Maintenance Manual for Advance Warning for End-of-Green Phase at High Speed Traffic Signals*. Texas Transportation Research Report 4260-3, September 2003.
- ♦ Messer, C.J., S.R. Sunkari, H.A. Charara, and R.T. Parker. *Development of Advance Warning Systems for End-of-Green Phase at High Speed Traffic Signals*. Texas Transportation Research Report 4260-4, September 2003.

Depending on the conditions that exist at and in advance of the signalized intersection that has the sight restriction, a supplemental traffic signal(s) may be installed to provide the motorist with an advance indication of the signals that control the approach. Such supplemental signals cannot be installed at all locations where sight restrictions exist.

The *TMUTCD* identifies specific requirements for traffic signal installations, including a minimum number of signal faces and positioning those signal faces within an appropriate cone of vision from the appropriate stopping location. Hence, most traffic signals are installed on the far side of the intersection and essentially “in line” with the approach lanes. When the far-side signals cannot be seen by motorists until they are close to the intersection, supplemental signals may be installed on the near side of the intersection to provide an advance notice of the signal indications that exist at the intersection. There is a limitation to where these signals should be installed. It would not be appropriate to install supplemental traffic signals a significant distance upstream of the intersectional approach. The most appropriate location for supplemental signals would be on one of the traffic signal poles installed at the intersection, on span wires supporting other signals at the intersection, or on other poles (utility or luminaire poles, for example) that exist at the intersection.

Because these supplemental signals are installed at locations that are not considered “typical,” caution must be exercised. Supplemental signals should not be installed if they may create possible confusion to motorists or pedestrians. Depending on where the supplemental signals are installed and “aimed,” motorists on conflicting approaches or pedestrians at the intersection may misinterpret the signal’s function and believe the signal indication is applicable to their desired movement. Hence, it is possible that a conflict may be created if the supplemental signals are not installed properly. This issue could be addressed by installing signals with louvered or programmable lenses so that the supplemental signal faces can be seen only by motorists approaching the intersection who are controlled by that signal’s indications.

It is not possible to provide any additional guidelines for the selection and installation of supplemental traffic signals. Obviously, supplemental signals should be considered at any intersection where sight distances to traffic signals are less than what is suggested by the *TMUTCD*. However, each potential location for supplemental signals is site specific and must be analyzed individually to determine if these signals can be installed without creating undesirable confusion.

Example Locations

Two signalized intersections having supplemental traffic signals were identified as example locations. The first example is located along U.S. Highway 290 east of Austin. The signalized intersection is located near the bottom of a crest vertical curve so approaching motorists on the high-speed U.S. Highway 290 approach had difficulty seeing the traffic signals installed at the intersection (located on span wires). An additional traffic signal was installed at a high elevation on the nearside, median steel strain pole supporting the signal span wires. This installation, shown in Figure 8-1, can be seen further upstream as needed in advance of the intersection.

The second example is located on Villa Maria Drive, an arterial street in Bryan, Texas. A horizontal curve is located in advance of the intersection, and an approaching driver cannot see the signals installed at the intersection, located around the curve to the right. The installation of a supplemental traffic signal, installed on the span wire located on the near side of the intersection and illustrated in Figure 8-2, provides the advance signal indication for the approaching motorist.

(A) Approach to Traffic Signal at Intersection of U.S. 290 and FM 3177 (Decker Lane).

(B) Traffic Signal More Visible Beyond Crest.
Figure 8-1. Traffic Signal Just Visible Beyond Crest of Hill.

Figure 8-2. Supplemental Signal Due to Horizontal Curve at Villa Maria and Cavitt Ave.

Application 2
Traffic Signal Design

Overview

The *Urban Intersection Design Guide,* Chapter 8, Section 3 <link> includes information on signal support systems.

Background

A city of about 150,000 planned the widening of a major arterial street, Lafayette Boulevard, from its four-lane, divided cross section to a six-lane, divided cross section. Several intersections along the arterial were signalized and would remain signalized. Each of these intersections required signal design modifications. The city engineering staff reviewed the various potential signal layouts that were available for consideration.

Basically, there were five possible signal layouts that were considered:

- span wire configuration with wooden poles and guy wires or with steel strain poles,
- steel poles with signals mounted overhead on cantilever arms,
- steel poles with signals pole-mounted,
- combination of steel poles with signals placed overhead on cantilever arms and side-mounted on poles, and
- signals placed overhead on an ornamental structure that spans over the travel lanes and has supports on both sides.

The city council had already established desired design features for signal hardware, which immediately eliminated any consideration for span wire configurations. While this type of design would be considered the most efficient from a construction cost viewpoint, the span wire layout was not considered aesthetically pleasing. The remaining four layouts were considered for the final traffic signal design.

The cross-sectional design of the six-lane, divided arterial street also was established. The arterial would have raised curbs and gutters, and a raised median. The travel lanes would be 14 ft [4.3 m] in width for the outside travel lanes, and 12 ft [3.7 m] in width for the center and left travel lanes. The median would be 18 ft [5.5 m] in width (face-of-curb to face-of-curb). Separated left-turn lanes, 12 ft [3.7 m] in width, would be provided within the median as necessary. City engineers determined that pedestrian volumes along and across Lafayette Boulevard were minimal. Therefore, it was decided that intersections along Lafayette Boulevard would be designed primarily for vehicular traffic, but pedestrians would be accommodated in the design features. To accommodate right turns at intersections, a minimum return radius of 35 ft [10.7 m] was established, although 50-ft [15.2 m] radii were preferred. A longer radius accommodates large trucks making right turns and provides space for larger islands that provide storage area for pedestrians.

The typical signal design used in the city consisted of signal poles with cantilever arms. In the downtown area of the city, some of the existing traffic signal installations have pole-mounted signals. The city staff decided that the signal design for the widened arterial ideally should remain consistent with existing installations, if possible. Also, pedestrians were to be accommodated in the design, although large pedestrian volumes were not expected at any of the arterial intersections.

Issues Considered

The geometric design requirements for the widened arterial street created very large intersections, which, in turn, created some difficulty with selecting the preferred design for the traffic signal installation. The wide and multiple travel lanes made the pole-mounted signal option inadequate because driver cone of vision requirements could not be provided unless the signal heads were mounted in the median. The city had removed older fixed signal pole locations in median areas years before as a safety benefit, and the city staff did not want to re-install signal poles in medians (except for breakaway pedestal poles for pedestrian signals). Therefore, pole-mounted signals alone would not be considered as an appropriate signal design layout.

The decision to place signals overhead in an ornamental structure spanning over the travel lanes was given special consideration. Such a design was selected for the downtown area signal installations in the city's master plan for a renovated downtown area. However, spanning over the proposed new Lafayette Boulevard was not considered applicable. Such a structure would be difficult to design considering the long span length, and its presence would make it difficult to accommodate the occasional oversized, high load. Spanning over half the roadway and having a support structure in the median would be feasible; however, the city did not want to have a rigid fixed object in the median area. Therefore, installing signals on an ornamental overhead structure was eliminated from consideration.

The only possible signal layout design remaining was steel poles with cantilever arms, with or without pole-mounted signals. The city staff had experience with cantilever arm lengths designs in the past and knew that keeping mast arm lengths at or less than 45 ft [13.7 m] was desirable. If longer mast arms were required, then signal poles needed to support those longer mast arms had to be larger (and more expensive) than normal, and the foundations for poles supporting longer mast arms were considerably larger, deeper, and more expensive. Hence, a preferred design was to keep mast arm lengths as short as possible.

Accommodating pedestrians at these signalized intersections also created some operational and design concerns. The wide, multiple travel lanes and long return radii (50 ft [15.3]) created lengthy walk distances for pedestrians. The initial signal pole layout at a proposed intersection (with Laddie Lane) to accommodate both signals for vehicular traffic and pedestrian signals and push buttons resulted in the need for very long mast arms, about 10 ft [3.0 m] longer than the desired 45-ft [13.7 m] minimum mast arm length. (See Figure 8-3.) Signal phase lengths would require relatively short clearance times for pedestrian clearances with this design, assuming that pedestrians would cross Lafayette Boulevard and store in the median.

The length of signal mast arms could be reduced by moving the signal poles further from the intersection so that they could be placed closer to the outside travel line. Pedestrian crossing times could be lessened by reducing the length of the crossings by moving the crosswalks further from the intersection. Providing these two changes, plus constructing two pedestrian ramps on each corner in line with the crosswalks, was another design option considered. However, these changes would have required motorists to stop their vehicles much further from the intersection, affected right-turn-on-red movements (because motorists would have to actually travel across the crosswalk to reach the intersection), and required additional time for signal clearances. In addition, the traffic signal heads would have been located beyond the 180-ft maximum distance from the stop line (on the Laddie Lane approaches) permitted by the *Texas Manual on Uniform Traffic Control Devices*. Hence, this alternative design was not selected.

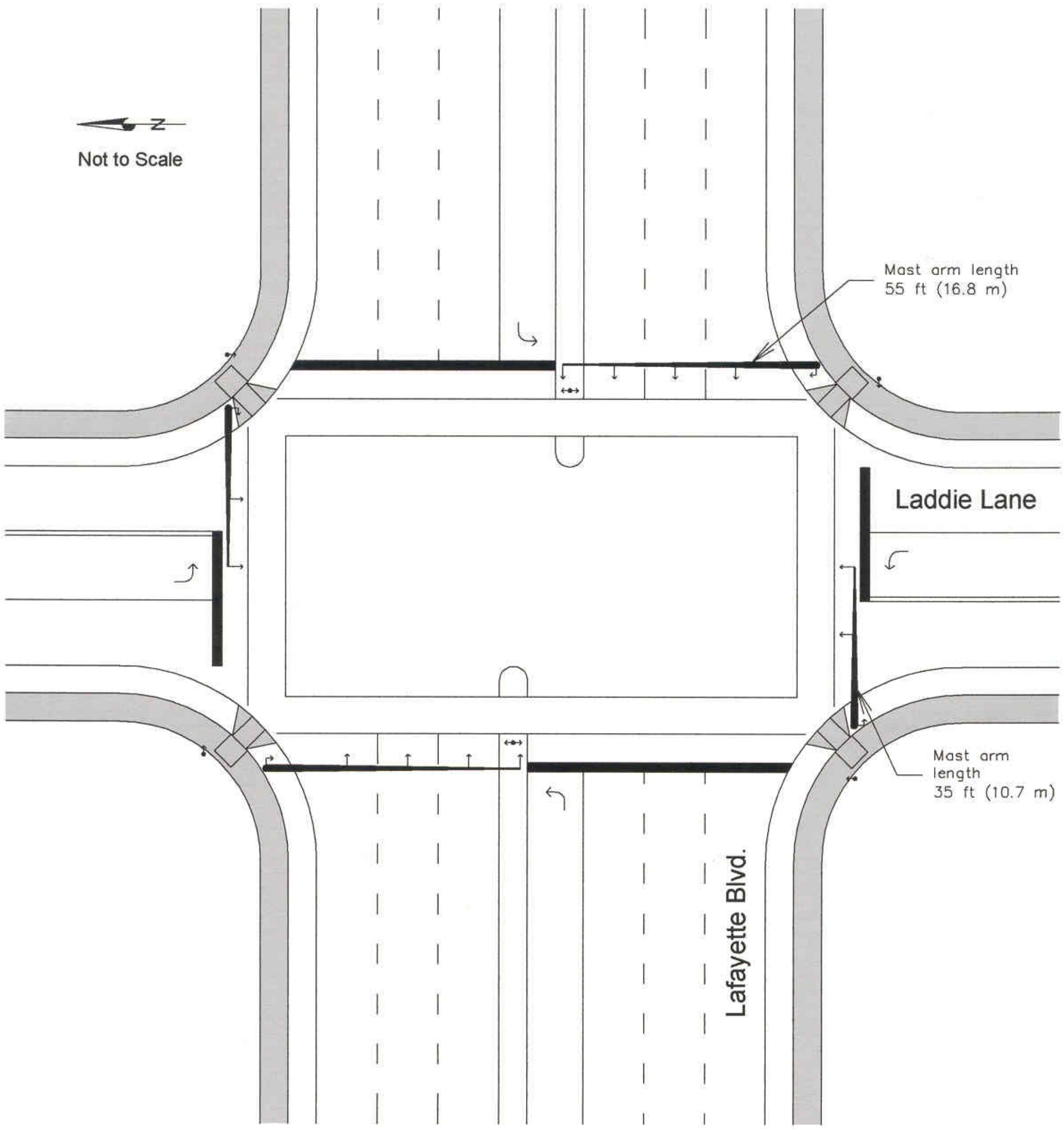

Figure 8-3. Initial Proposed Design.

A recommendation was made to alter the initial intersection design to include islands at the corners of the intersections. The addition of the islands, as shown in Figure 8-4, provides the opportunity to keep mast arm lengths below the 45-ft [13.7 m] maximum, and reduce pedestrian walk and clearance times. At the same time, the proposed design incorporated the desired lane widths and 50-ft [15.3] return radii. Channelizing islands had to be designed with a cut-through because there was insufficient space for curb ramps. Pedestrian push buttons had to be accessible from the cut-through islands, so additional pedestal poles were necessary for push-button installations. This design did not provide for pedestrian storage in the median. Hence, pedestrian phase walk times would need to be relatively long. However, because pedestrian volumes were expected to be low and pedestrian phases (with lengthy crossing times) would be provided only when pedestrians activated the phase, the decision to keep the design was considered appropriate.

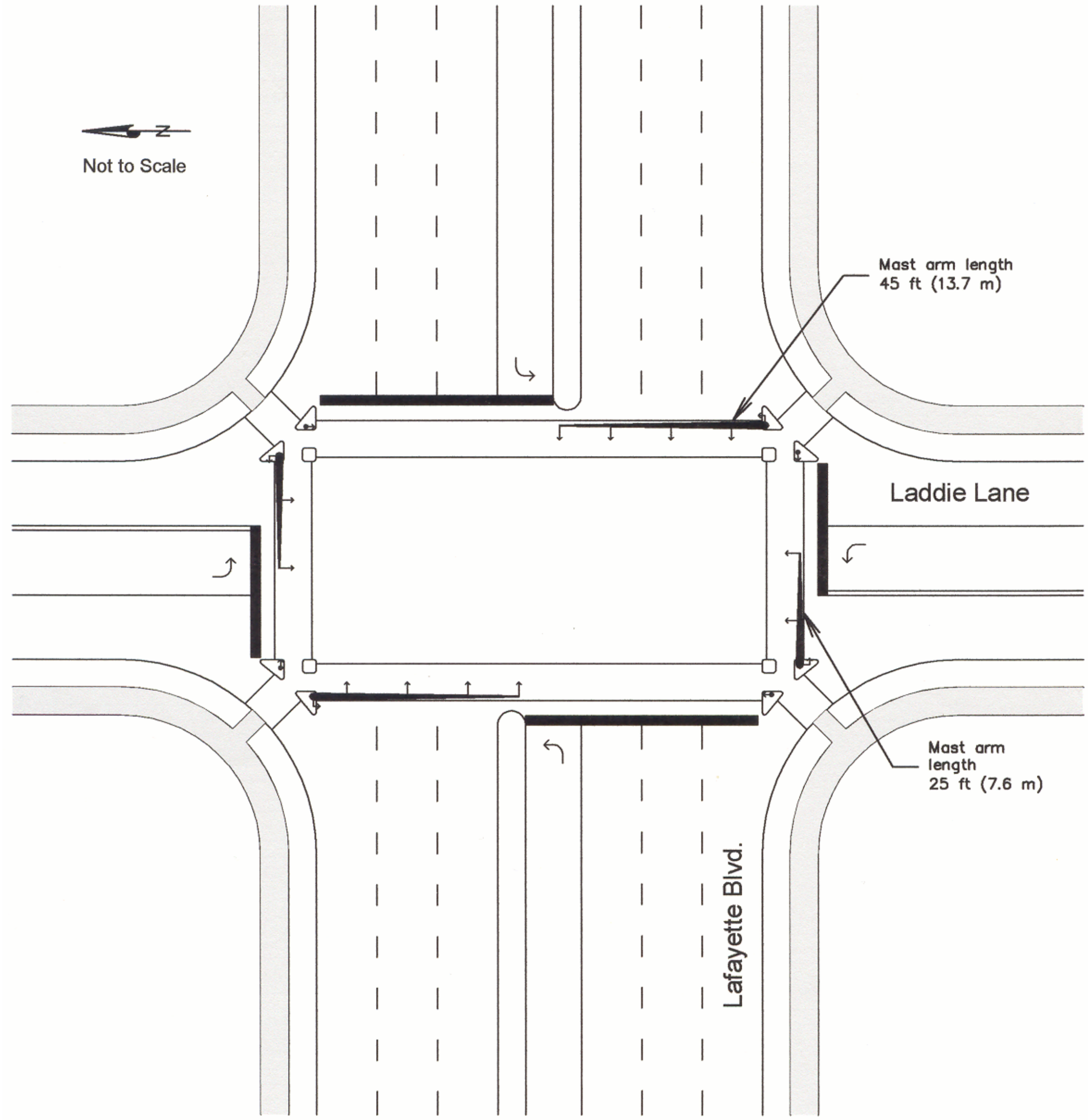

Figure 8-4. Final Proposed Design.

Design Selected

The intersection design incorporating the corner islands became the preferred geometric design for the signalized intersections along Lafayette Boulevard. It also was selected as the city's preferred intersection design along future six-lane, divided arterial streets. This design development process was unique. Typically, the geometric design of a roadway is determined initially and then traffic signals are designed to fit into the geometry of the roadway. In this example, the geometric design of the intersection was designed concurrently with the traffic signal design to provide an overall optimum, cost-effective design.

Application 3
Signal Support Considerations

Overview

The *Urban Intersection Design Guide,* Chapter 8, Section 3 <link> includes information on signal support systems.

Background

An intersection of two arterials is being designed and constructed near a major urban area. The initial design is shown in Figure 8-5. Traffic signals will not be warranted at the intersection initially because development in the area has not occurred and will not occur for several years. Because the intersection designer desires to prepare the intersection for eventual signalization, the designer has assumed that the city eventually will provide the following traffic signal features at the intersection:

- Signal heads will be installed on poles and mast arms.
- Pedestrian signals will be installed for all crossings with push button detectors.
- Vehicle detection will be provided by video imaging.
- Ground-mounted controllers will be used.
- The intersection will be illuminated when signalized.
- The city separates wiring for signals from wiring for luminaires.
- The city uses underground polyvinyl chloride (PVC) conduits to house wiring.

Issues Considered

Recognizing the need to accommodate these future traffic signal design features, the designer of the intersection incorporates the following geometric design features in the initial intersection design.

- The signal poles will be located on the corners of the intersection; therefore, long mast arms will be needed. Long mast arms require a large underground support structure (48 inches [1219 mm] in diameter), which requires much space. Hence, additional right of way is desired. Also, to minimize mast arm lengths, the poles should be located as close to the travel lanes as possible. This would require moving the sidewalk further from the roadway. Moving the sidewalk further from the roadway also makes it easier to accommodate the pedestrian landings and curb ramps. Therefore, the intersection was designed with sidewalks positioned 7 ft [2.1 m] from the curb.
- Pole locations could be located between the curb and the sidewalk at a sufficient distance from the travel way to satisfy clear zone requirements. The poles also could be placed where they may be accessible to pedestrians and used to house pedestrian push buttons.

- The separation between the sidewalk and the curb also provides sufficient space for the ground-mounted controller, and the sidewalk can be used by the signal technician, saving the cost of an additional concrete pad.
- The intersection was designed with very long curb return radii. Placement of pedestrian crosswalks away from the intersection and closer to the beginning of the curb returns, with curb ramps at the end of each crosswalk, was considered in the initial design. However, positioning sidewalks (and curb ramps) further from the intersection would have required placement of stop lines a considerable distance from the intersection, at locations close to or beyond the 180-ft [55 m] maximum permitted distance between stop lines and traffic signal heads. Motorists desire to stop relatively close to the intersecting street, especially when right turns on red are being made. Hence, in order to provide stop lines relatively close to intersecting streets and at appropriate distances from signal heads, pedestrian crosswalks were installed closer to the center of the intersection, and single curb ramps were installed at each corner of the intersection.
- To minimize disruption to the intersection when signals are to be installed, underground conduits were installed beneath all four approaches to the intersection as part of the original intersection construction. A 4-inch-diameter [102 mm] PVC conduit (for traffic and pedestrian signal wiring), a 2-inch-diameter [51 mm] PVC conduit (for luminaire wiring), and a 2+-inch-diameter [51 mm] PVC conduit (for coaxial cable used for video imaging) were designed for installation. These conduits were to be sealed and terminated in a small pull box on each corner of the intersection.

Design Selected

These design features, illustrated in Figure 8-5, will save the city money when it eventually constructs the signal installation, but more importantly, they will provide the space and geometry to incorporate an effective and efficient signal installation that will not require reconstruction of the intersection.

As shown in Figure 8-6, if separate right-turn lanes are provided on all approaches to the intersection, the pole locations could be moved to the islands. The resulting design does not help to shorten mast arm lengths, but it does locate signal faces closer to the stop lines. The signal poles can be used for pedestrian push button locations, but the buttons must be accessible. Otherwise, additional poles will be needed for pedestrian push buttons.

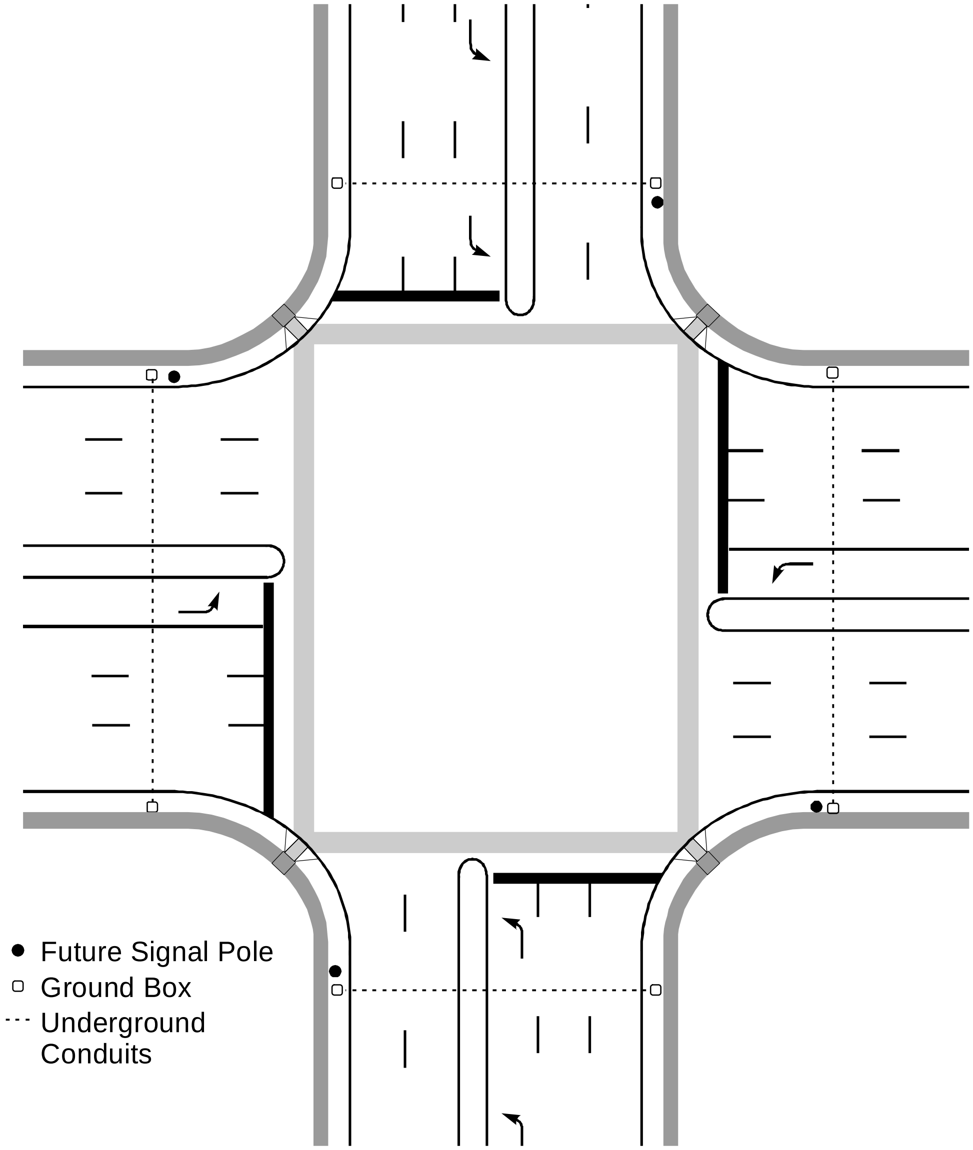

Figure 8-5. Intersection Design to Accommodate Traffic Signal Installation.

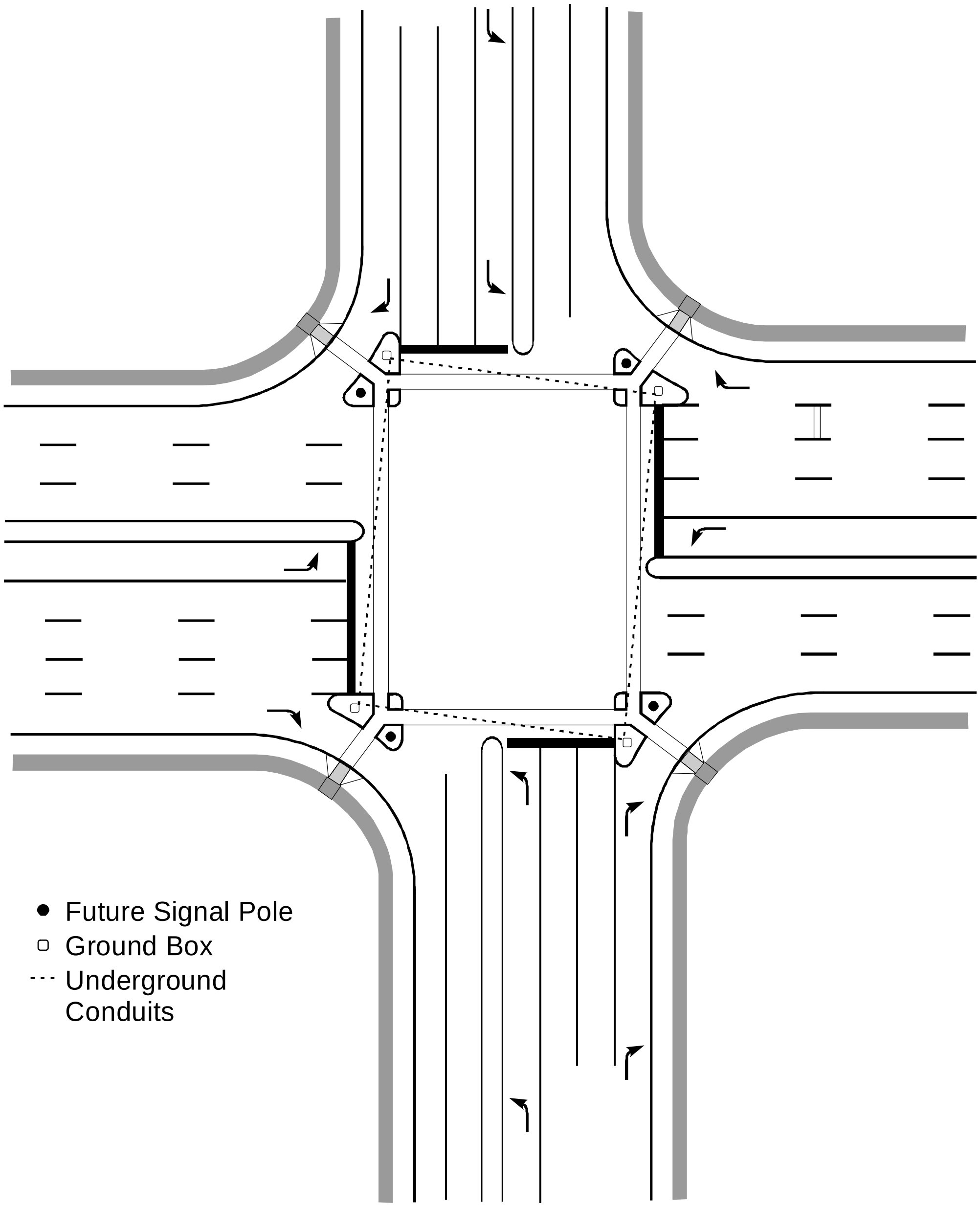

Figure 8-6. Alternate Intersection Design to Accommodate Future Traffic Signal Installation.

Chapter 9
Markings

Contents:

Application 1
Markings Checklist

Overview

The following presents a checklist on pavement markings. The *Urban Intersection Design Guide*, Chapter 9 <link> presents additional information on pavement markings.

Background

During an intersection design, several elements are competing for attention. Following is a checklist that can be used to review a design to assist in identifying whether markings were adequately considered within the design. The objective of the checklist is to assist with consideration of various pavement marking elements. It is not meant to be a comprehensive, point-by-point inspection on all pavement marking requirements at an intersection. Rather it is to serve as a reminder to check various elements of the intersection design.

Checklist

Checklist For Markings At An Urban Intersection

***Checklist scale**

Y = Yes or Acceptable N = No or Needs Improvement I = Irrelevant to Site

*Y	N	I	**MARKINGS**
			Are the required markings present at the intersection?
			Is an end of a school zone present? If so, are markings appropriate?
			Is a bus stop present? If so, are markings appropriate?
			Is a high occupancy vehicle (HOV) lane present? If so, are markings appropriate?
			Is a bicycle lane present? If so, are markings appropriate?
			Is a railroad crossing nearby? If so, are markings appropriate?
			Do parking spaces need to be delineated?
			Are markings needed for parking restrictions?
			Is retroreflective yellow needed on nose of median?
			Is retroreflective yellow or white needed on island?

Checklist For Markings At An Urban Intersection

Checklist scale

*Y = Yes or Acceptable N = No or Needs Improvement I = Irrelevant to Site

*Y	N	I	**MARKINGS (Continued)**
			Are old pavement markings adequately removed?
			Do markings conflict with signs?

*Y	N	I	**TREATMENTS**
			Is (are) left-turn lane(s) present? If so, are additional markings through the intersection needed?
			Are pavement arrows or the word ONLY needed on the pavement?
			Is advance information on lane assignments needed?
			Are crosswalk markings needed?
			Are high-visibility markings needed for the crosswalk?
			Can the crosswalk marking material (e.g., ladder) be spaced to avoid the wheel path?
			Is an advance yield or stop line needed?
			Are contrast markings needed?
			Are double white or yellow lines needed?
			Is hatching needed at the intersection?
			Are the markings for an offset left turn optimal?
			Do the markings need to be supplemented with raised pavement markers?

Checklist For Markings At An Urban Intersection

Checklist scale

*Y = Yes or Acceptable N = No or Needs Improvement I = Irrelevant to Site

*Y	N	I	MATERIAL
			Is the better material selected for the situation (raised markers versus paint versus combination)?
			Were aesthetics considered?
			Are bricks or other aesthetic treatments planned for the crossing location? If so, was the appropriate material selected?
			If a brick crosswalk or other aesthetic treatments are present are supplemental pavement markings needed to increase visibility?
			Will markings be adequately visible during snow, ice, or rain conditions?

*Y	N	I	STOP BAR LOCATION
			Is adequate sight distance present at the stop bar?
			Do the signals meet visibility requirements with selected stop bar location?
			Is the stop bar in the optimal location considering all users of the intersection?

Application 2

Traffic Control Devices for a Bicycle Lane

Overview

This application provides an example of traffic control devices for a bicycle lane. Information on bicycle lanes is included in *Urban Intersection Design Guide,* Chapter 9, Section 4 <link> and Chapter 4, Section 6 <link>.

Background

Bicycle lanes are useful for encouraging bicycle travel and separating bicycles from vehicles and pedestrians. However, problems can arise at intersections with conflicts between through-bicycles and right-turning vehicles.

An intersection that is being redesigned has two bicycle lanes as part of its new configuration. The bicycle lanes will interact with right-turn lanes that are also part of the new design. Minimizing conflicts between bicycle traffic and right-turning vehicles is important, as is allowing bicycles to travel safely through the intersection.

This signalized intersection is in a suburban fringe area, and contains a major four-lane arterial (First Street) and a minor four-lane arterial (Mara Street). First Street has a very wide raised approach median and double left-turn bays at the intersection, in addition to the right-turn lane. Mara Street is also four lanes with no median and a single left-turn bay at the intersection (see Figure 9-1). The two northern quadrants are vacant; the southwest corner contains a large professional building, while a free-standing pharmacy/variety store is on the southeast corner. The intersection is in somewhat of a valley, as each leg of the intersection rises as it departs. The west side of the intersection is substantially higher than the east side.

In the redesign of the intersection, right-turn lanes with a corner island will be included on First Street. In addition, a bicycle lane in each direction of First Street must be carried through the intersection in a manner that minimizes conflicts with right-turning vehicles prior to the intersection and crossing vehicles at the intersection.

Issues Considered

Issues to consider during an upgrade to the site include the following:

- acquisition of right of way,
- adequate signing and markings with a clear message of the expectations regarding the priority of bicycles over right-turning vehicles,
- adequate marking to carry the bicycle lane through a driveway near the transition taper for the right-turn lane, and
- retention of bicycle lane between through lanes and right-turn lanes.

Suggested Designs

- Construct the approach to the intersection such that right-turning vehicles must cross the bicycle lane to enter the right-turn lane, yielding the right of way to bicycles. The bicycle lane would then be located between the right-turn lane and the right-hand through lane on the intersection approach.
- Align the bicycle lane such that it is to the left of the island separating through traffic from right-turning traffic. This aligns their travel path with the bicycle lane on the other side of the intersection and keeps bicycles separated from pedestrians waiting on the island to cross the street.

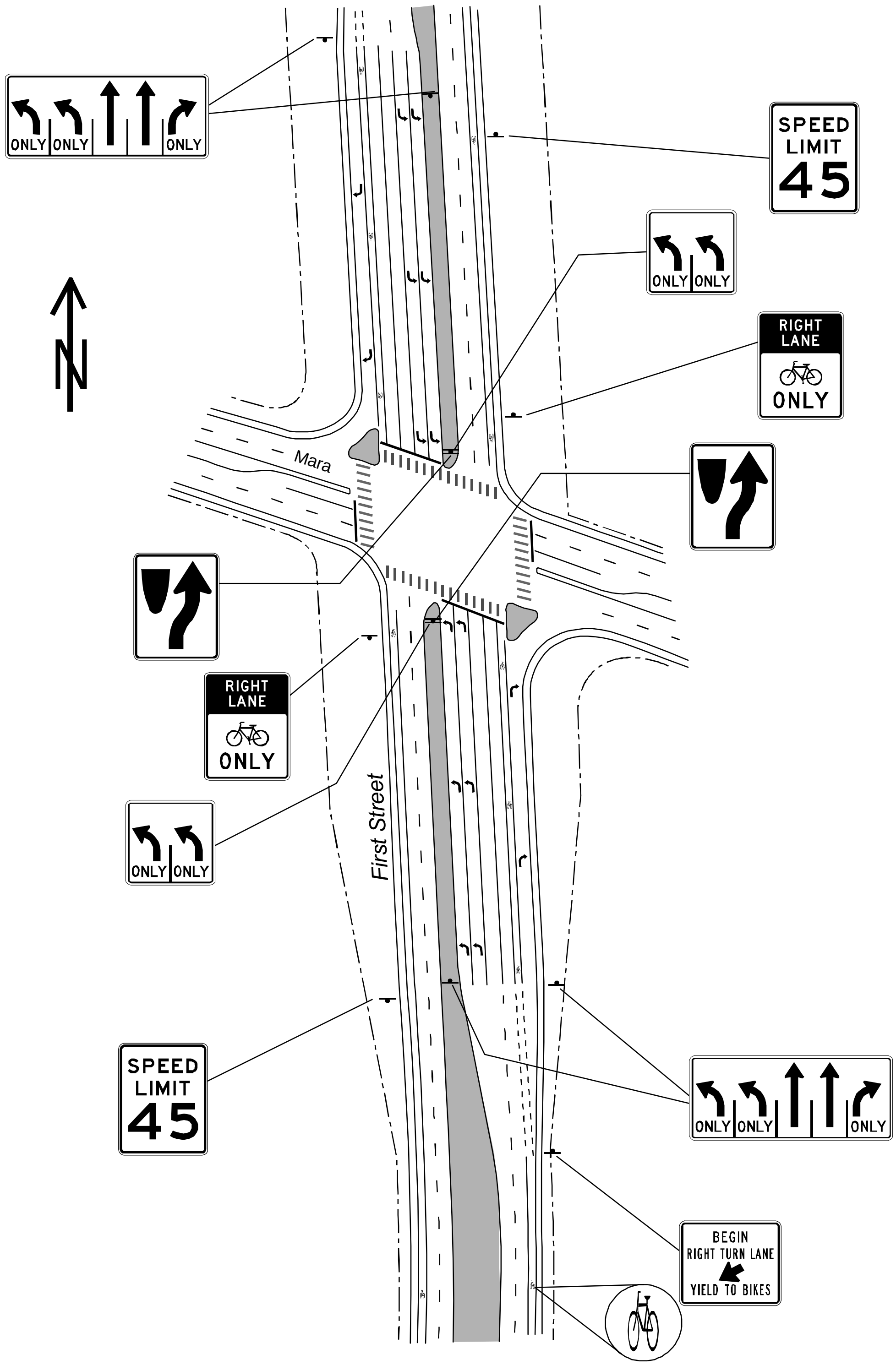

Figure 9-1. Sketch of Intersection with Bicycle Lane Carried through Right-Turn Lane (Note: Signals not shown on sketch).

Chapter 10
Checklist

Contents:

Application 1
Signs Checklist

Overview

The following presents a checklist on signs. The *Urban Intersection Design Guide*, Chapter 10 <link> presents additional information on signs.

Background

During an intersection design, several elements are competing for attention. Following is a checklist that can be used to review a design to assist in identifying whether signs were adequately considered within the design. The objective of the checklist is to assist with consideration of various sign elements. It is not meant to be a comprehensive, point-by-point inspection on all sign requirements at an intersection. Rather it is to serve as a reminder to check various elements of the intersection design.

Checklist

Checklist For Signs At An Urban Intersection

*__Checklist scale__

Y = Yes or Acceptable N = No or Needs Improvement I = Irrelevant to Site

*Y	N	I	**SIGNS**
			Is there adequate space on the roadside or median to place signs?
			Were overhead guide or warning signs considered?
			Are required signs included (e.g., intersection control, regulatory, warning, guidance – including advance street name supplement)?
			Are/will signs be obstructed by vegetation?
			Do any city ordinances require additional/special signs?
			Are signs properly spaced from the intersection?
			Do signs obstruct visibility for traffic exiting adjacent property?
			Can any – existing or proposed – signs be eliminated? Consolidated?
			For existing signs and supports to be retained, is the sign condition adequate? Is the support adequate?

Checklist For Signs At An Urban Intersection

*Checklist scale

Y = Yes or Acceptable N = No or Needs Improvement I = Irrelevant to Site

*Y	N	I	**SIGNS (Continued)**
			Do signs obstruct each other?
			Are signs clear of pedestrian path (both width and height)?
			Are signs adequate for bicyclists? Are signs adequate for transit users (including signs for disabled users)?
			Are special purpose signs needed?
			Would the location benefit from using larger letters on the street-name signs (e.g., to accommodate the reduction in visual acuity associated with increasing age)?
			Do unusual geometrics create the need for special signs? Are advance signs necessary?
			Are any non-standard (non-*TMUTCD*) signs needed? If so, these signs will require approval.
			Are block numbers included on the street name signs?
			Do back-to-back signs have compatible shapes?
			Are median signs needed to improve visibility?
			Does median width require treatment as two intersections?
			Are lane assignment signs at correct location for drivers to make decision?
			Do signs agree with pavement markings?
			Should internally illuminated signs be considered?

Application 2

Traffic Control Devices for Dual Left-Turn Lanes

Overview

The inclusion of signs and markings at dual left-turn lanes provides drivers with additional guidance on how to maneuver through the intersection. Information on traffic control devices is included in the *Urban Intersection Design Guide*, Chapter 9 for Markings <link> and Chapter 10 for Signs <link>.

Example

Figure 10-1 illustrates typical signs and pavement markings for an intersection of two arterial streets with dual left-turn lanes and single right-turn lanes.

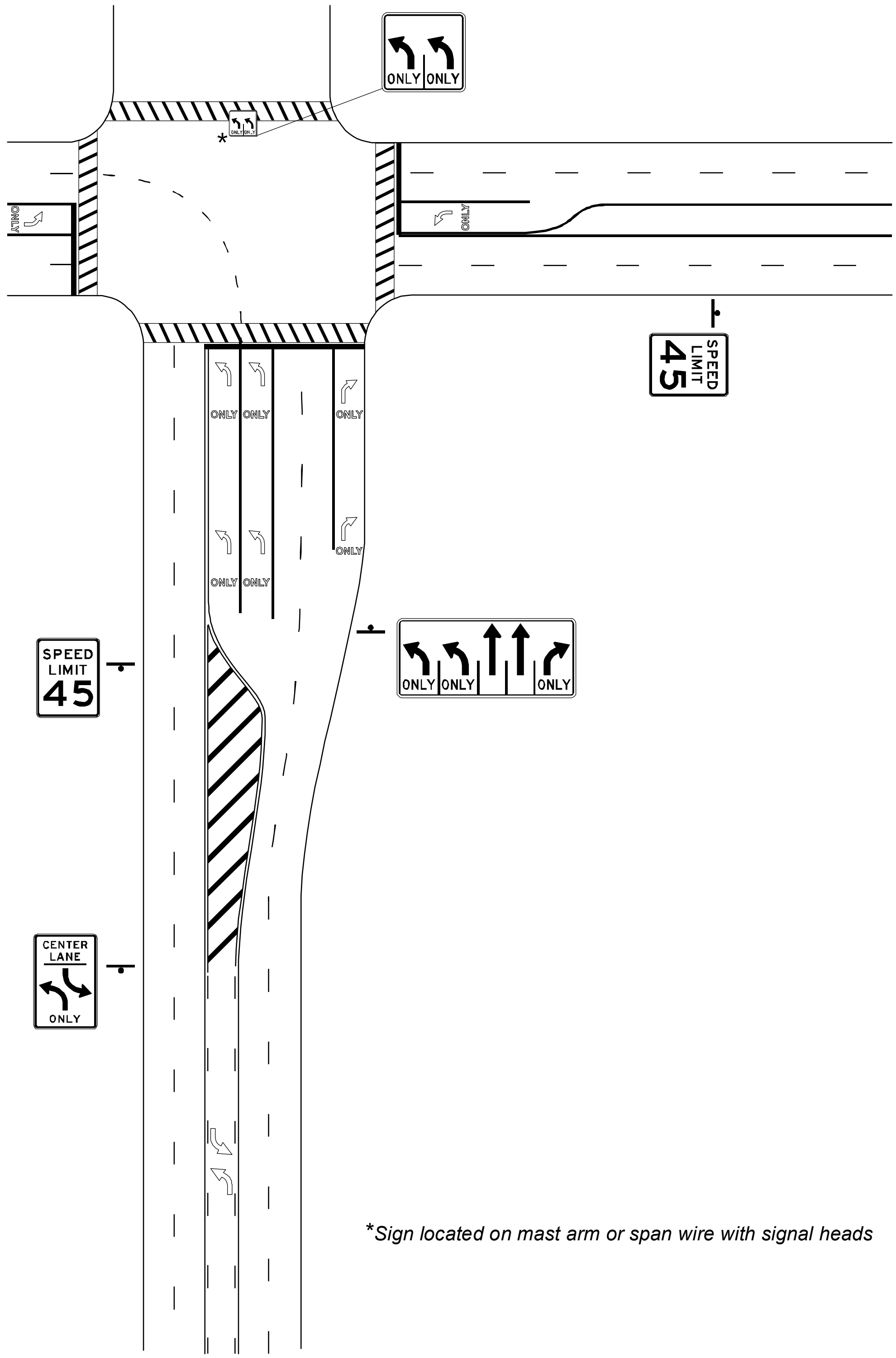

Figure 10-1. Example of Signs and Pavement Markings for Intersection with Dual Left-Turn Lanes and Single Right-Turn Lanes.

Chapter 11
Influences from Other Intersections

Contents:

Application 1
Realignment of Intersection

Overview

Two closely spaced T-intersections can present challenges because of a lack of space for left- or right-turn queuing. The close spacing of the two intersections presents a complex design problem that may not always be solvable without modifying the geometry of the intersection. The *Urban Intersection Design Guide,* Chapter 11, Section 1 <link> provides further information regarding closely spaced intersections.

Background

Problem. Two intersections on a major roadway, Austin Road, are very closely spaced. The intersections are not functioning well because inadequate space between the intersections is available for queuing. An additional challenge at the intersection is the small curb radii that are present. Transit buses occasionally use the intersection but have trouble negotiating the right turns at the intersection without encroaching on adjacent lanes.

Austin Road is an arterial with high volumes in a commercial area. Austin Road's intersections with Lilac Street and Oregon Street (collectors) are approximately 100 ft [30 m] apart. Combined with the large number of driveways in the area, there are several access points and turning maneuvers on this arterial. Lilac Street leads north into a residential subdivision, while Oregon Street leads south into more commercial development. The intersections are surrounded by fast-food restaurants on all sides except the southeast corner, which houses a grocery store. The lanes on Austin Road are narrow, and there are many commercial signs and other visual distractions. The curb radii at the intersections are very small (15 ft [5 m]), making right turns more difficult for larger vehicles.

It has been difficult to provide a satisfactory signal timing strategy for the intersections because of their close proximity. A potential solution for this issue could be to use one controller and treat the two intersections as a single intersection for signalization purposes. Inadequate storage is available between the signals for left-turning vehicles, however, and their close proximity prevents the efficient coordination of the traffic signals.

Known Information. The information known for this intersection includes:

- The intersections are controlled by traffic signals.
- Lilac St. and Oregon St. have stop control.
- The design speed on Austin Rd. is 45 mph [72 km/h].
- The design speed on Lilac St. and Oregon St. is 30 mph [48 km/h].

Issues Considered

Issues to consider during an upgrade to the site include the following:

- acquisition of right of way (the preferred realignment will require purchasing the corner of the grocery store parking lot, eliminating some of the parking spaces for the grocery store);
- relocation of utilities;
- accommodation of traffic during construction;
- accommodation of pedestrians during and after construction (provision of marked crosswalks added because of high likelihood of pedestrians in an area having a grocery store, fast food, and other retail outlets); and
- adequate signing and markings to guide motorists.

Proposed Design

An alignment based on minimum horizontal radius without superelevation is shown in Figure 11-1. Using a horizontal curve radius of 300 ft [91 m] based on the design speed of 30 mph [48 km/h] (see Table 2-5 of the *Roadway Design Manual* <link>), the design will eliminate approximately 32 parking spaces from the grocery store parking lot and require modifying its circulation pattern.

Further details of the design are shown in Figure 11-2. The intersection curb radii are designed at 50 ft [15 m], accommodating occasional large vehicles. The southwest corner curb radius is designed at 40 ft [12 m] because the deflection present in the realigned roadway allows a bus to negotiate the turn without encroachment. The increased curb radii used in the realigned intersection will improve the efficiency of right-turn maneuvers.

The realigned intersection will also reduce the complexity of the original two intersections and provide a single intersection that allows a better signal timing strategy.

The selected design has several trade-offs. The appropriateness of the choices made should be evaluated according to the characteristics of the site:

- The increased curb radii will:
  - provide better accommodation for large vehicles;
  - improve turning efficiencies;
  - increase pedestrian crossing time;
  - decrease signal timing efficiency somewhat because of the increased pedestrian crossing time for the larger intersection (increased from 11 to 13 sec to cross minor roadway, increased from 16.5 to 18.5 sec to cross major roadway);
  - require the use of longer traffic signal mast arms; and
  - decrease signal timing efficiency because of increased lost time due to the increased size of the intersection.
- The radii used for the reverse curves on Oregon St. will:

- minimize the amount of right of way (ROW) obtained for the project without requiring a design exception; and
- require the elimination of approximately 32 parking spaces from the grocery store parking lot.

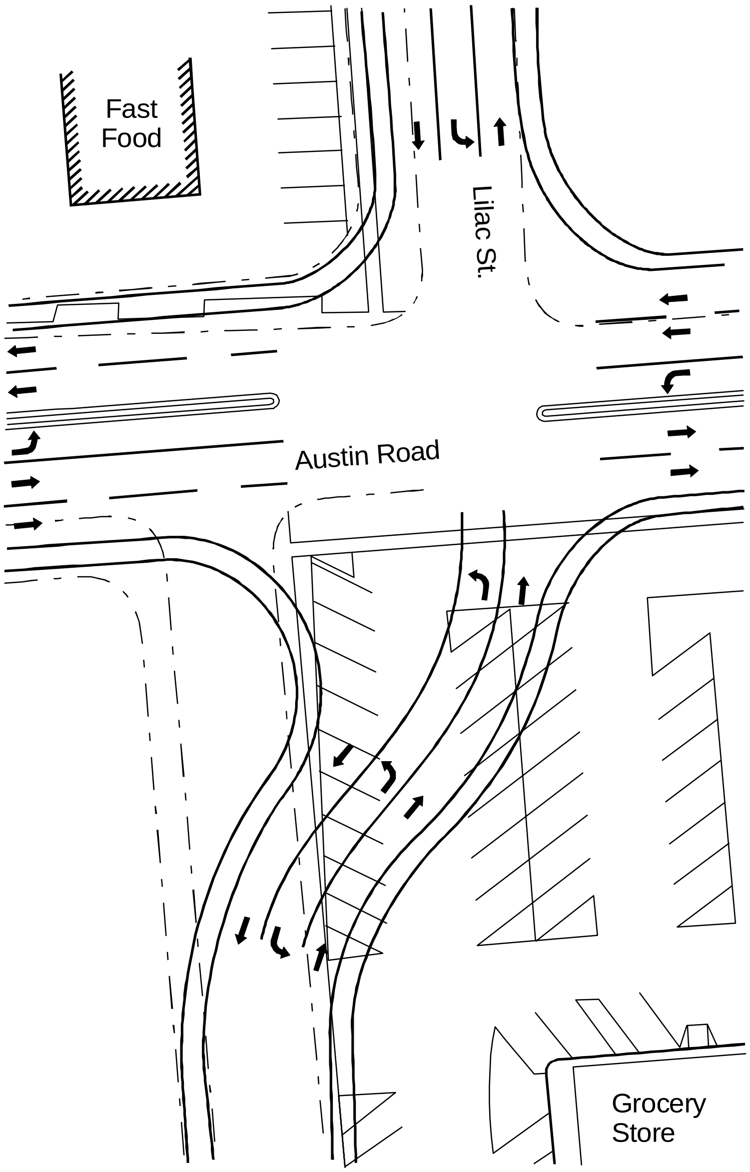

Figure 11-1. Sketch of Proposed Realignment Based on 30 mph [48 km/h] Design Speed.

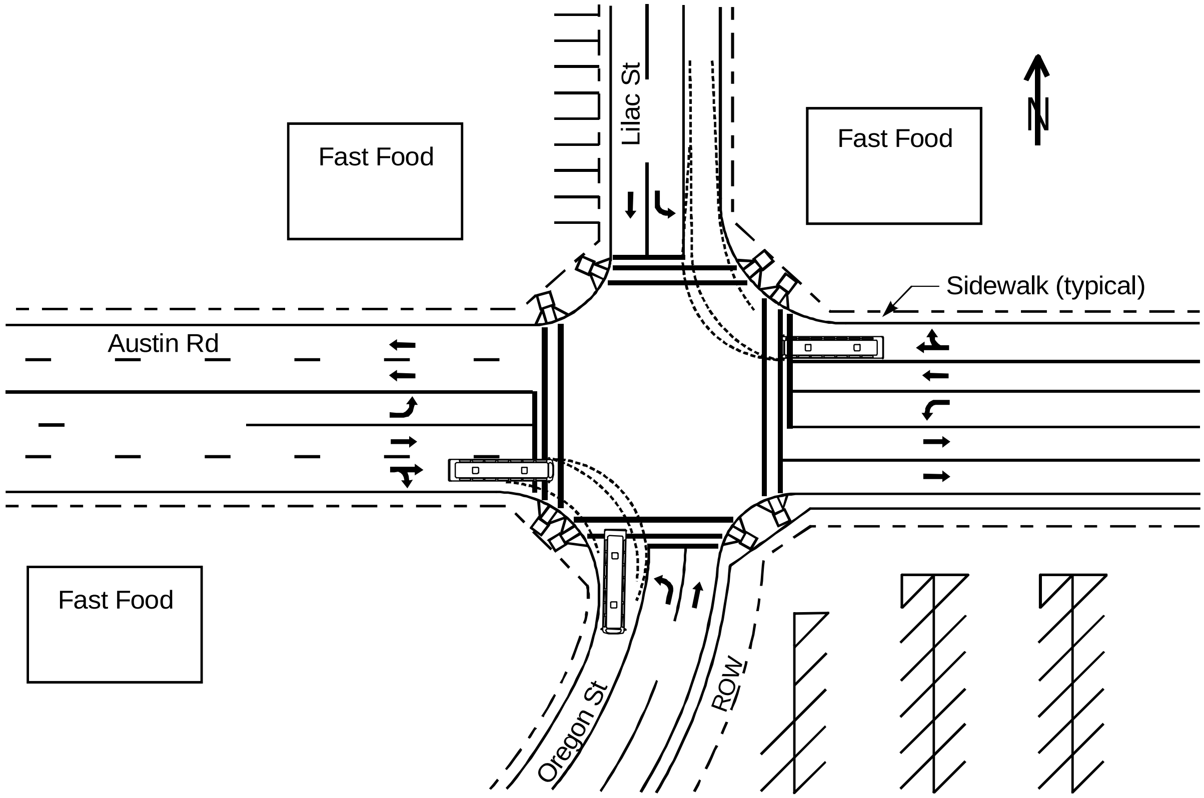

Figure 11-2. Intersection Details for Proposed Realignment.

Application 2

Control of Access to Driveways

Overview

The presence of driveways can adversely impact the operations of roadways. The introduction of additional conflict points near an intersection can overload drivers and result in an increased crash risk. Capacity can also be affected if drivers slow to enter driveways or avoid other drivers exiting driveways. The *Urban Intersection Design Guide,* Chapter 11, Section 3 <link> provides further information regarding driveways and their influence on intersections.

Background

A suburban intersection is in an area of heavy commercial development. The large numbers of driveways in close proximity to the intersection approaches creates traffic flow problems and increased potential for crashes with turning vehicles.

A signalized suburban intersection of two four-lane major arterials, White Parkway and Compass Boulevard, has a high level of commercial development on the approach streets. White Parkway and the northbound approach of Compass Blvd. have a continuous two-way left-turn lane up to the storage area for the intersection, where the TWLTL is converted to a left-turn bay. A large number of driveways open onto Compass Boulevard. Traffic volumes are high on both streets, and flow into and out of the commercial establishments is steady. A sketch of the unimproved intersection is shown in Figure 11-3.

Issues Considered

Issues to consider during an upgrade to the site include the following:

- accommodation of traffic flow during construction,
- negotiation with business owners to allay fears of decreased business because of change in access,
- adequate signing and markings to inform drivers of changes to cross section, and
- acquisition of right of way,

Proposed Design

- Construct a raised median on the approaches of Compass Boulevard. Extend the median approximately 300 ft [91 m] from the intersection, to discourage left-turning movements onto or off of Compass in the vicinity of the intersection. (See Figure 11-4 for a sketch of improvements.)

- Improve delineation with raised marker buttons on the centerline approach to the median.
- Improve radii on free-flow right-turn lanes on each approach to facilitate turning movements from street to street.

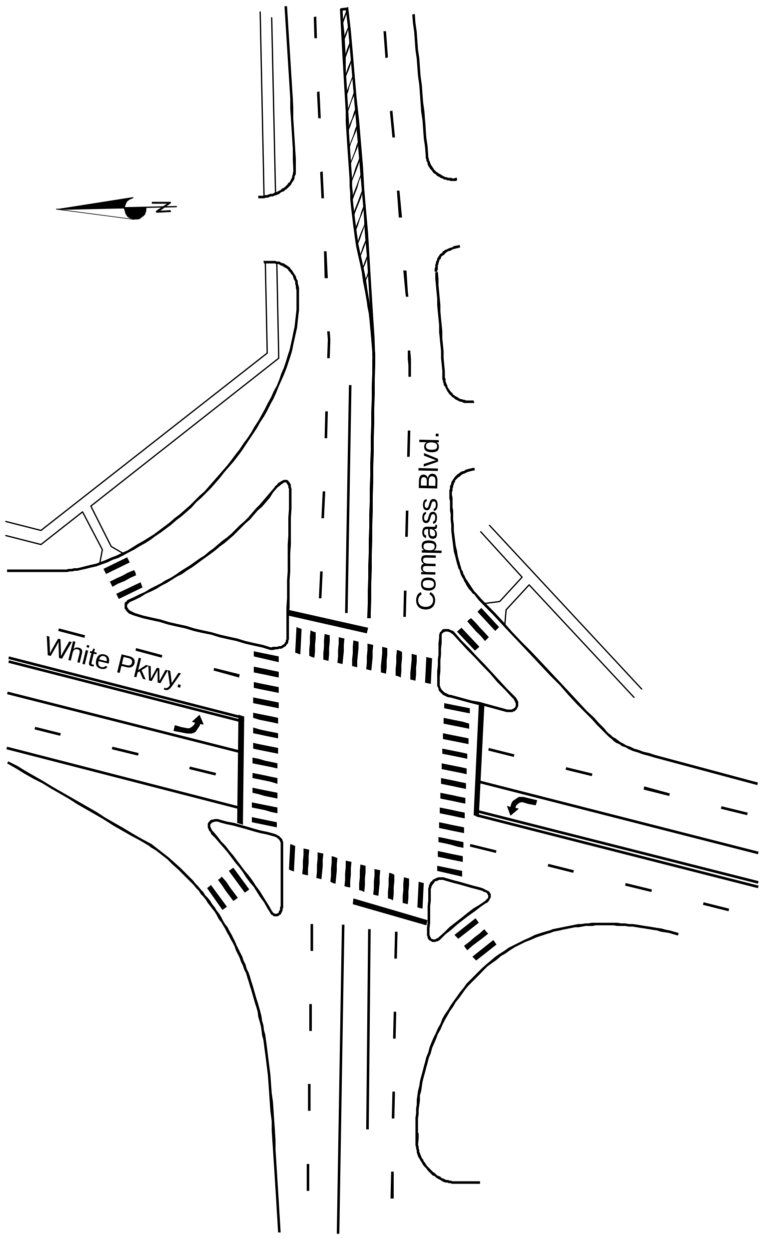

Figure 11-3. Sketch of Intersection Before Improvements.

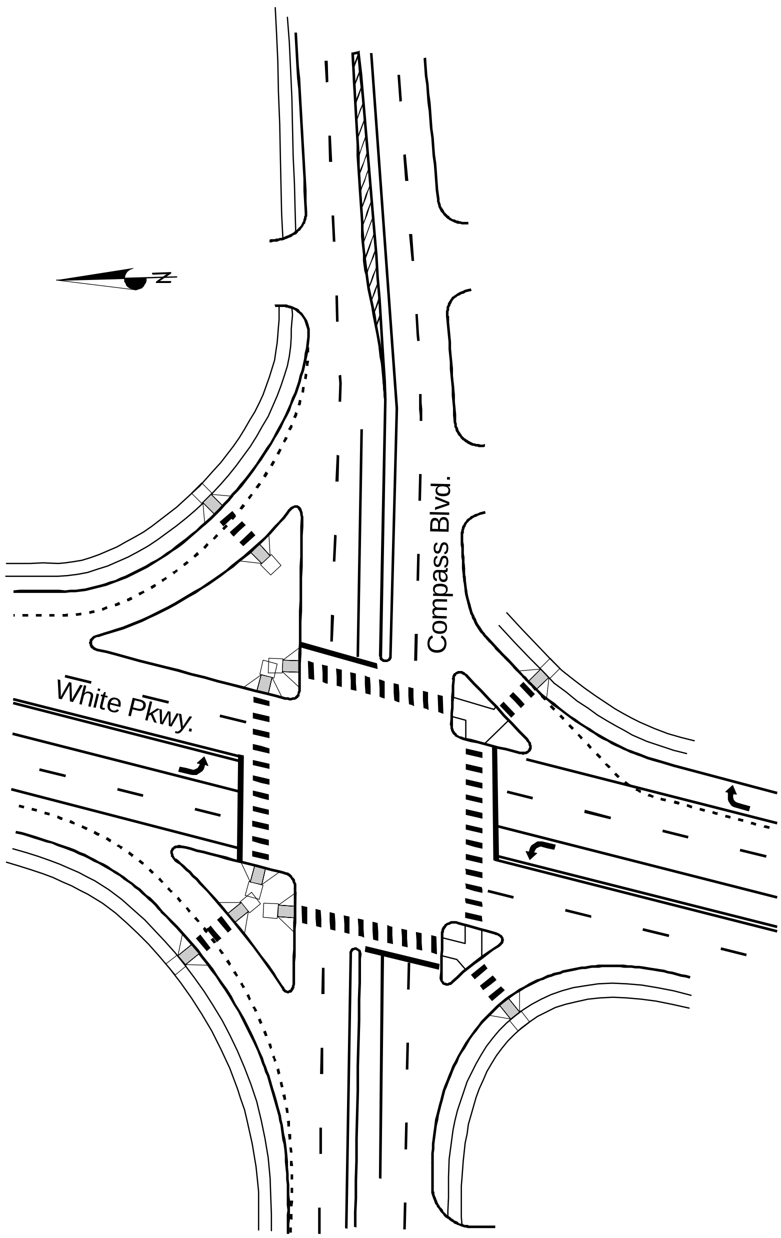

Figure 11-4. Sketch of Intersection with Improved Medians and Right-Turn Lanes.

Application 3
Turning Restrictions

Overview

The presence of an intersection near the end of a ramp can adversely impact operations due to drivers attempting to quickly cross other traffic in order to turn. The introduction of additional conflict points near an intersection can overload drivers and result in an increased crash risk. The *Urban Intersection Design Guide,* Chapter 11, Sections 1 <link> and 3 <link> provide further information regarding driveways and nearby intersections and their influence on intersections.

Background

Highway ramps near street intersections can experience extensive weaving and conflicts due to the many different movements in a small area. Restriction of some of the movements can improve safety and efficiency of operations.

The exit ramp from a major highway in a suburban area connects with the local street network in close proximity to a downstream intersection. A large number of drivers desire to turn left at that intersection and must cross other lanes of traffic to use the left-turn lane.

A stop-controlled exit ramp from Highway 713 intersects a major arterial (Concert Boulevard) approximately 400 ft [122 m] upstream of a signalized intersection with a minor arterial (Sam Houston Street) and shopping center entrance. (See Figure 11-5 for illustration.) A raised median on Concert Boulevard permits only right-turning traffic from the exit ramp. Many of the drivers on the exit ramp seek to enter the shopping center, which requires a left turn from eastbound Concert at the Sam Houston intersection. Drivers attempting this maneuver must immediately turn right from the ramp (as in Figure 11-6), cross two lanes of through traffic on Concert Boulevard, and enter the left-turn bay. All of these lane changes occur within 400 ft [122 m]. In addition to the increased potential for crashes, drivers who wish to make this maneuver must wait for an adequate gap to turn, which creates large queues and long delays on the ramp. Eliminating this movement would improve safety and efficiency at this location.

Issues Considered

Issues to consider during an upgrade to the site include the following:

- There is limited space for expansion at this intersection. The bridge columns limit the amount of median area available west of the intersection. Widening Concert Boulevard will also be difficult because of a stormwater viaduct on the south side of the street, and other entrance and exit ramps for Highway 713 on the north side of the street.
- Proper signing and markings are needed to acclimate drivers to the change in configuration. Signs will be necessary on the ramp to inform drivers that left turns to Sam Houston Street are not permitted from the ramp. Supplemental signing is needed

to show alternate entrances to the shopping area so as to provide guidance on when to exit from Highway 713.

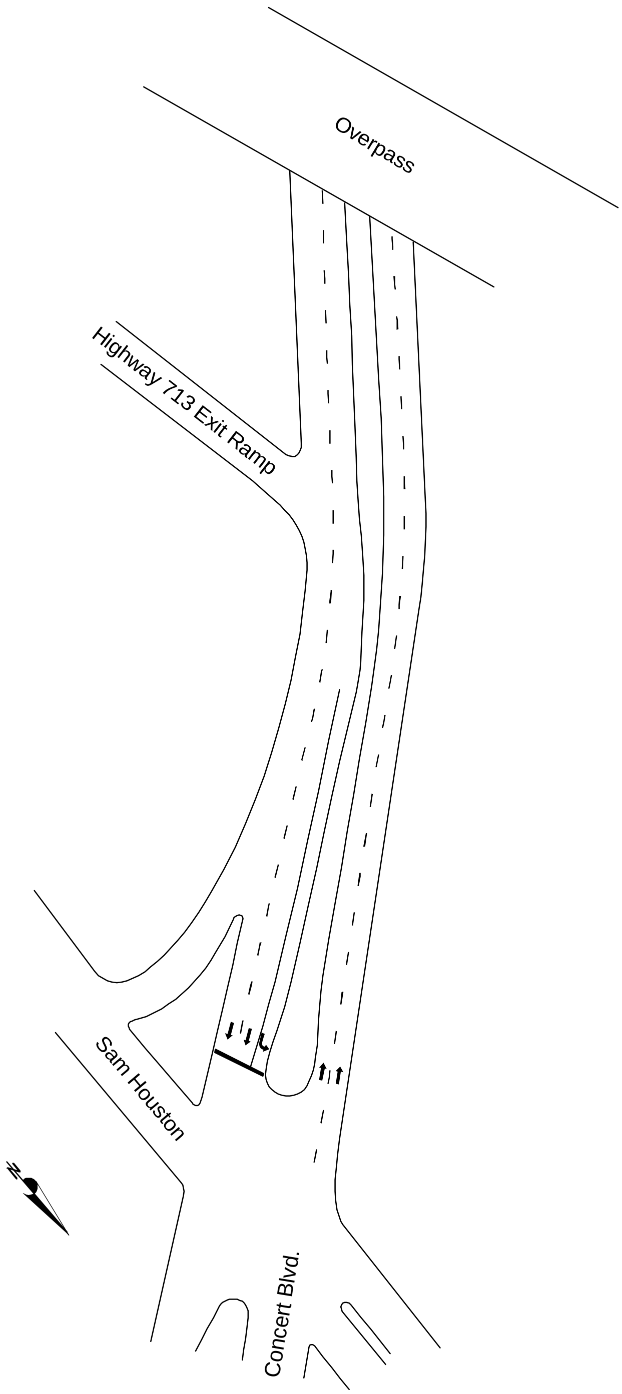

Figure 11-5. Current Conditions, Prior to Improvements.

Figure 11-6. Ramp Traffic Crossing Arterial to Make Left Turn.

Proposed Design

The suggested design is to separate the eastbound left-turn lane on Concert Boulevard with a modified median that prevents ramp traffic from entering the left-turn lane. A sketch of this new design is shown in Figure 11-7 and Figure 11-8. The design uses a raised median and turning restrictions to prevent vehicles exiting on the Highway 713 exit ramp from turning left into the shopping center on Concert Boulevard. Openings were necessary in the raised median to allow for adequate drainage.

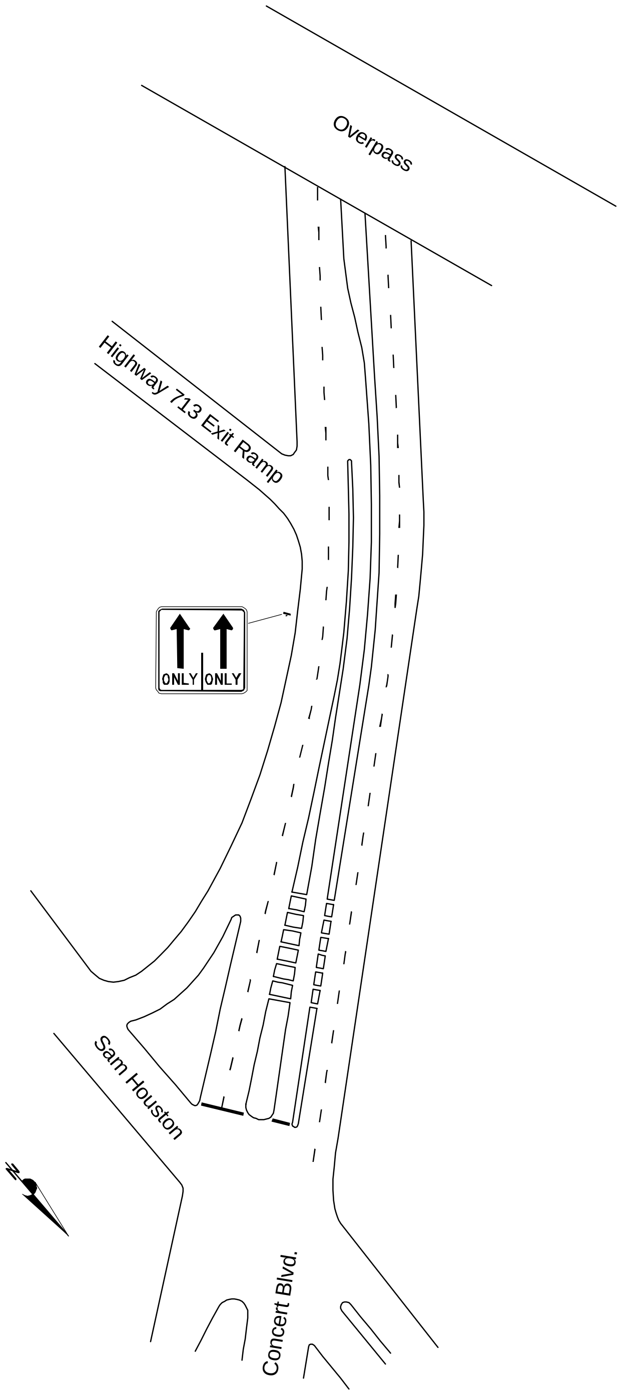

Figure 11-7. Suggested Improvement to Median.

Figure 11-8. Median Added to Limit Left Turns by Traffic from Ramp.