Toolbox on Intersection Safety and Design

Chapter 1 – Geometric Design

Project Deliverable No. 2 – Draft Chapter

Prepared for:

The Institute of Transportation Engineers
and
The Federal Highway Administration

By:

By: Brian Wolshon, Ph.D., P.E., P.T.O.E.
Louisiana State University
Baton Rouge, Louisiana

February 2, 2004

Table of Contents

Introduction and Background 1
Functional and Safety Considerations 1
Intersection Elements 2
Area 2
Approaches 4
Control 4
Spacing 4
Intersection Types 5
Users 5
Vehicles 5
Pedestrians 6
Bicycles 8
Conflicts and Crash Patterns 8
Intersections Conflicts 8
Intersection Crashes and Countermeasures 10
Elements of Intersection Design 10
Horizontal Alignment 11
Sight distance 13
Channelization 16
Design of Channelizing Islands 20
Turning Lanes 21
Vertical Alignment 24
Profile Grades 24
Intersecting Grades 24
Cross-Section 26
Unconventional Design Configurations 27
Median U-Turn Intersection 28
Superstreet Median Intersection 29
Single Quadrant Roadway Intersection 30
Jughandle Intersection 32
Bowtie Intersection 34
Paired Intersection 35
Continuous Flow Intersection 36
Split Intersection 38
Continuous Green T-Intersection 39
Roundabouts 40
Access Control and Management 41
Intersection Corner Clearance 42
Access Location and Design 42
Intersection Traffic Calming 45
References 46
Bibliogrpahy 48

List of Figures

Figure 1. Intersection Physical Area 3
Figure 2. Intersection Functional Area 3
Figure 3. Intersection Conflict Points 9
Figure 4. Intersection Realignment Alternatives 12
Figure 5. Signal Installation at a Skewed Intersection 13
Figure 6. Intersection Turning Analysis 16
Figure 7. Right in-Right Out Island 17
Figure 8. Channelization to Delineate an Exclusive Right Turn Lane 18
Figure 9. Left Turn Lane Separation Island 19
Figure 10. Island Used to Create a Right Angle Intersection 19
Figure 11. Design Dimensions for Large Corner Islands in Urban Conditions 21
Figure 12. Left Turn Lane at a Rural Unsignalized Intersection 23
Figure 13. Offset Opposing Left Turn Lanes on a Divided Highway 23
Figure 14. Intersection with steep approach grades 25
Figure 15. California Street, San Francisco, CA 25
Figure 16. Cross-section Enhancement at a High Pedestrian Intersection 27
Figure 17. Median U-Turn Intersection Diagram 28
Figure 18. Superstreet Median Intersection Diagram 30
Figure 19. Single Quadrant Roadway Intersection Diagram 31
Figure 20. Jughandle Intersection Diagram 32
Figure 21. Left Turn Loop Intersection Diagram 33
Figure 22. Bowtie Intersection Diagram 34
Figure 23. Paired Intersection Diagram 36
Figure 24. Continuous Flow Intersection Diagram 37
Figure 25. Split Intersection Diagram 39
Figure 26. Continuous Green T-Intersection 40
Figure 27. Intersection Corner Clearance Dimensions 44

List of Tables

Table 1. AASHTO Design Vehicle Dimensions 7
Table 2. Functional Intersection Distances 43

INTRODUCTION AND BACKGROUND

The American Association of State Highway and Transportation Officials (AASHTO) defines intersections as "the general area where two or more highways join or cross, including the roadway and roadside facilities for traffic movements within the area," with the main objective of their design to "facilitate the convenience, ease, and comfort of people traversing the intersection while enhancing the efficient movement of motor vehicles, buses, trucks, bicycles, and pedestrians" (1). Within these broad descriptions, specific designs of individual intersections can vary greatly from location to location based on the alignment and functional classification of the intersecting roadways, the type and amount of traffic each is expected to carry, and the land use characteristics in the vicinity of the intersection, among many others. Despite the number of factors that can influence intersection designs, the design goal is always the same; maximize both the efficiency and safety of traffic operations within the intersection.

Highway intersections are categorized in several different ways. Some of the most common are based on the grade and division of movements (at-grade, grade-separated without ramps, and interchanges), the functional classification of the intersecting roadways (arterial-arterial, arterial-collector/local, local-local, etc.), and based on the amount of development within the intersection vicinity (central business district, urban, suburban, rural, neighborhood, etc.). These various categories often overlap in different combinations. As a result, the design features of one set of intersections may not necessarily be the best for another.

The focus of this chapter is on primarily on at-grade intersections in urban and suburban areas, summarizing the general principles of intersection design and highlighting the application of techniques and practices that increase the safety and efficiency of intersection operations. The first section discusses the fundamentals of intersection operation and safety, the components of intersections, and how these elements contribute to the design process. The second section presents the standards for intersection design, including the considerations for horizontal and vertical alignments and cross-sections. It also includes a discussion of the various intersection sight distance conditions and the design of channelization elements. The third section focuses on application of specific design treatments and innovative intersection configurations that can improve the operational efficiency and safety of intersections within high volume arterial corridors. The final two sections of this chapter highlight the application of access control and management techniques and traffic calming principles to enhance the safety and efficiency of intersections, including the design and placement of driveways near intersections and the use of geometric features to reduce speed, decrease flow rates, and enhance pedestrian safety at neighborhood intersections.

Functional and Safety Considerations

Intersections are among the most important elements of highway networks because of their impact on both the safety and mobility of road system. Intersections are often the controlling factor in determining the capacity of urban roadway corridors (2). Thus, it is necessary to design intersections that present as few impediments to efficient travel as possible. However, intersections are also areas of concentrated conflicting crossing, merging, and diverging traffic streams that can impact travel delay and the number and severity of roadway crashes. As a result, the goal of intersection design is to achieve a balance between safety and mobility. Like

most highway features safe and efficient traffic flow cannot be achieved by design alone. It requires a coordinated effort between, design, traffic control, traffic and land use planning as well as driver education and traffic enforcement.

Various references have suggested the objectives, principles, and guidelines that should be considered when designing intersections. Generally, these sources agree that five topic areas need to be considered during the design process. These include:

- *Human Factors*, such as driver and pedestrian habits, reaction time, and driver expectancy;
- *Traffic*, including the volumes, speeds, sizes, and characteristics of the vehicles that will use the intersection;
- *Physical Elements*, to account for the topography and development in the vicinity of the intersection, the angle of intersection between the roadways, and various other environmental factors;
- *Economic Factors*, including the cost of construction, the effect on adjacent residential and commercial properties, and energy consumption; and
- *Functional Intersection Area* (defined later).

Most design sources also agree that intersection designs should manage conflicting maneuvers to facilitate safe and efficient crossings and changes in direction intersection while reducing the potential for crashes as well as their severity. This can be accomplished by:

- Minimizing the number of points of conflict;
- Simplifying conflict areas;
- Limiting the frequency of conflicts; and
- Limiting the severity of conflicts.

Intersection Elements

Rarely do intersections allow a "one-size-fits-all" design. Every intersection is unique in terms of the number and type of intersecting roadways, volume and composition of traffic, horizontal and vertical angles of the intersecting roadways, adjacent land-use development, the available sight distances at the approaches, and so on. The most critical elements and the manner in which they guide the design of the intersection are summarized below.

<u>Area</u>

Intersections are defined in terms of their physical and functional areas. The *physical area* of an intersection, shown in Figure 1, is defined as the area where the interesting roadways overlap, bounded on all sides by the edge of pavement radius return, also commonly referred to as the *intersection threshold*. The *functional area* of an intersection extends for some distance in advance of the approach thresholds as shown in Figure 1. The size of the influence area is different for each intersection and is difficult to define with exactness. However, it includes the area to the point at which drivers perceive and react to stimuli within the intersection vicinity. This includes the maneuvering areas in which drivers slow or accelerate to change lanes or merge as well as area used for queue storage.

Figure 1. Intersection Physical Area

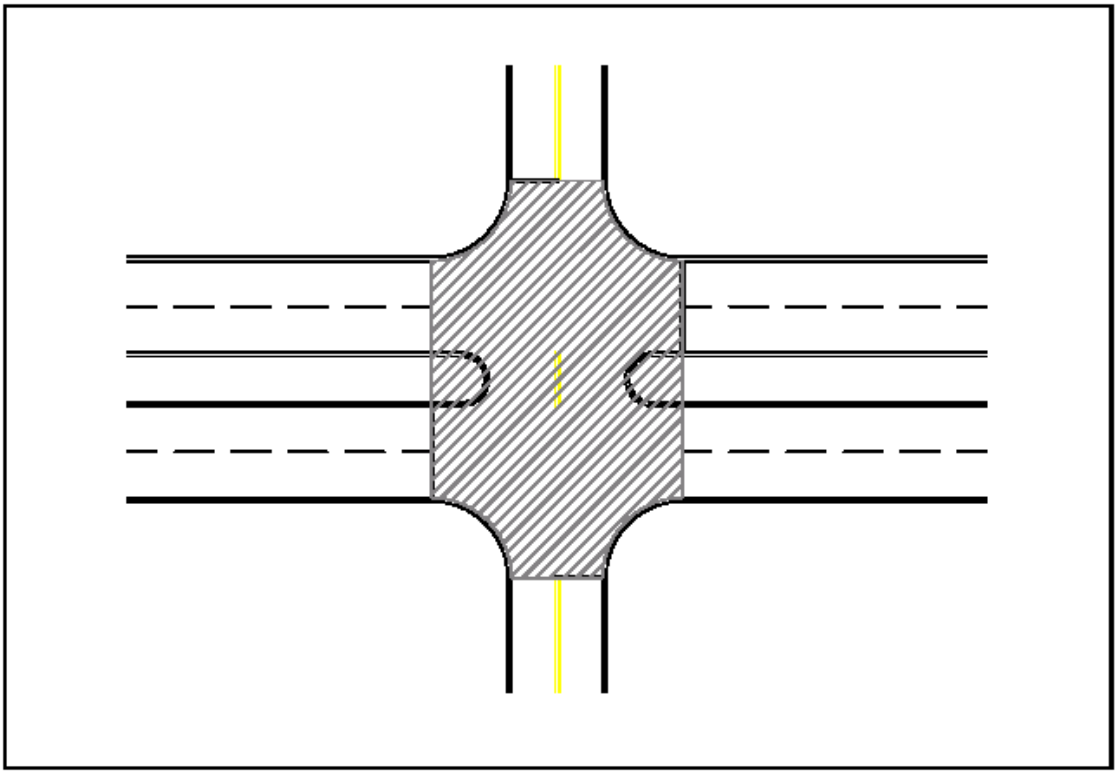
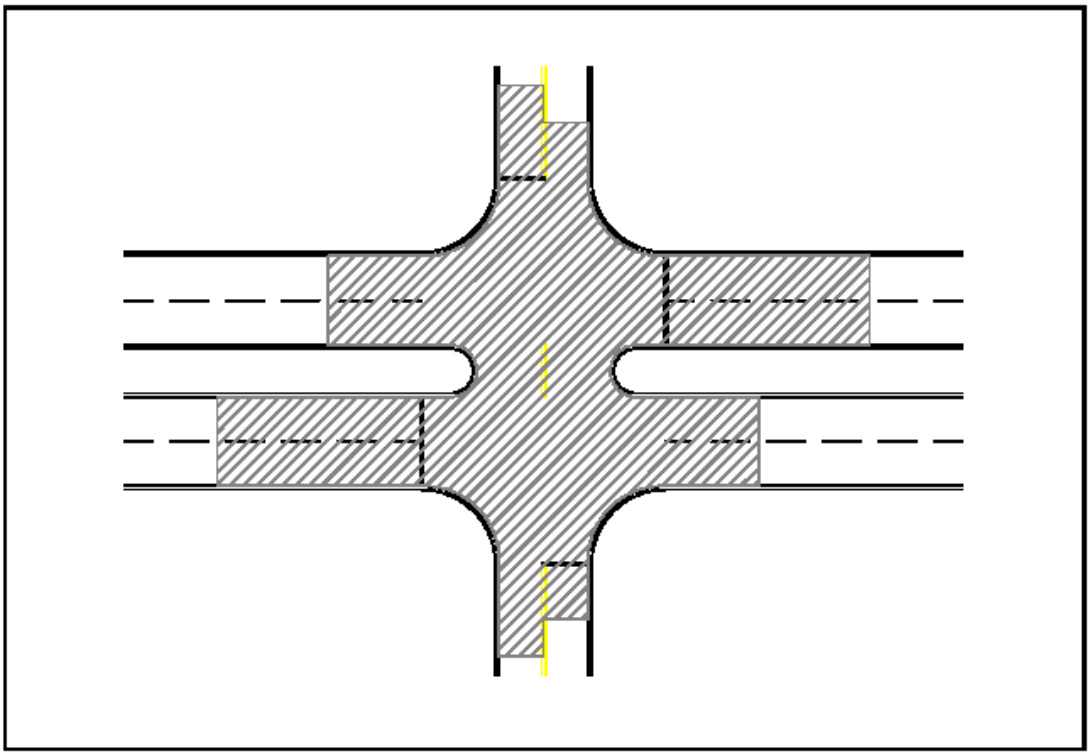


Figure 2. Intersection Functional Area



The recognition of these areas is important because they must be taken into account when analyzing sight distances, locating areas of on street parking, bus stops, and access/egress points to adjacent developments.

Approaches

Each roadway that enters n intersection forms an *approach*. Since intersections occur at the junction of two highways, most of them incorporate four approach legs. In cases where one of the road ends dead-ends into the other, a three-leg, or "T" – intersection is formed. Occasionally, more than two roads will intersect at a single point to form complex multileg intersections. Although AASHTO recommends avoiding the creation of multileg intersections whenever possible, they are common in urban centers like Washington D.C. where diagonal avenues traverse a base grid pattern of perpendicular streets.

Often, intersections occur between roadways of varying functional classifications, for instance at the intersection of arterial and collector-distributor roadways. When this occurs, the higher classification, or *major roadway* receives preferential treatment in design and control. This is logical given that the major road also usually has higher volume and operating speeds than the minor road. The differentiation between major roadways and *minor roadways* is important in design because it can determine the need for and placement of channelization devices and the design of the intersecting cross-slopes.

Control

The design of an intersection must be undertaken with full consideration to the type of control that will be present once it is operational. Most intersections, particularly those incorporating moderate to high traffic volumes, are controlled by either stop signs or traffic signals. These devices have the simple purpose of assigning right-of-way to the preferred movement. A yield sign may also assign right-of-way at intersections. In certain very low volume conditions, such as those associated with local neighborhood street or in lightly traveled rural roads, no form of traffic control may also be used. The geometric design considerations for each of these control conditions vary, impacting the sight distance requirements in each of the quadrants adjacent to the intersection. Specific information on these requirements is offered later in this chapter and a more detailed treatment of intersection signalizations and traffic control is included in Chapters 2 and 4 of this book.

Spacing

Another consideration that can effect the safe and efficient movement of traffic is the spacing of intersections. Proper intersection spacing, particularly for signalized intersections, is critical for providing coordinated signal timing. Generally, optimal timing progression for two-way movements requires that travel time between intersections to be about half of the cycle length. Given the operating speeds and cycle lengths used in most suburban areas, the most effective progression would occur with signalized spacing of about one-half mile.

The need to provide access to adjacent properties and access to cross-streets may in some case suggest the need for more closely spaced signalized intersections. This can be the case for large traffic generators and attractors located along high volume corridors. However, frequent

stopping for red lights and traffic congestion from downstream intersections can result in travel delay and driver frustration. Generally speaking, intersection spacing of not less than 500 feet for vehicular traffic and 300 feet for pedestrians is desirable (3).

Intersection Types

Intersection designs also vary based on the volume and mix of the traffic at the junction. At the intersection of two high volume or high-speed roadways, a *grade separated intersection* may be warranted. Grade separated intersections may be as simple as bridges and tunnels that separate through traffic stream or as complex as *interchanges* that incorporate separate dedicated roadways for turning traffic. Simple grade separated intersections are highly effective for the movement of high through traffic volumes. However, they are also limited by the fact that they do not permit direct turning movements to the intersecting roadway. The major drawback to interchanges is their obvious construction expense as well as the need to acquire substantial right-of-way.

Intersections are also created by driveways. Although their purpose is to provide access and egress to properties adjacent to the highway, driveway intersections may still carry significant volumes of traffic and must be designed with same geometric and control features used on highway-to-highway intersections. Another family of intersections are those created at *highway-railroad grade crossings*. Because of the obvious hazards created by vehicle-train conflicts, these intersections receive special design consideration. Among these considerations are special provisions for sight distance, traffic control, and vertical and horizontal alignments. The requirements for the design of highway-rail grade crossings are outside of the scope of this chapter, however they can be found in both the Green Book (1) and the *Railroad-Highway Grade Crossing Handbook* (4).

Users

Intersections are also important locations because of interaction of motorized and non-motorized modes of transport at them. Although the design of highway facilities concentrates exclusively on motor vehicles, intersections in particular must accommodate the needs of different user groups so that they may interact safely with one another. The following sections briefly highlight some of the predominant categories of intersection users and how their needs impact the design of intersections. A more detailed discussion intersection users is included in Chapter 6.

Vehicles

AASHTO defines 19 different design vehicles within four general classifications, including passenger cares, buses, tracks, and recreational vehicles (1). These vehicles each have different lengths, widths, heights, and articulation points that impact their abilities to accelerate, decelerate, and turn at intersections. Since it is not practical to design for all of these vehicles at every intersection, designers must select a design vehicle(s) for which the intersection will accommodate.

The selection of a particular design vehicle is based on the type of vehicles that would be expected to use the intersection. It is not uncommon, however, to require more than one design vehicle at an intersection since they will likely need to account for the operating envelops of both

small and large vehicles. For most high volume urban roadways, a tractor semitrailer with a 50-foot wheelbase (WB-50) is used for designing turning areas. In areas where trucks are prohibited, the use of a passenger car (PC) may be used, although it is suggested that a single unit truck configuration (SU) or a 40-foot tractor semitrailer combination (WB-40) be usedto permit adequate maneuvering area for emergency, fire, garbage, and delivery vehicles to operate in the area. The dimensions of the AASHTO design vehicles are included in Table 1.

Pedestrians

The presence of pedestrians, particularly in urbanized areas, can play a significant role in the design of highway intersections. Pedestrians are defined as any person on foot, include a variety of different pedestrian types and physical capabilities that affect certain features of intersections. Design elements for the safe and efficient movement of pedestrians around intersections include (5):

- *Sidewalks and clearly marked crosswalk areas* - Crosswalks at intersections should also include curb cut ramps for wheelchairs and pedestrians with baby carriages;
- *Traffic control features* such as crossing signals properly timed to accommodate pedestrians moving at slower walking speeds;
- *Grade separations* such as overpasses and tunnels, although these features can be viewed as cost prohibitive if not adequately designed and properly located such as cases where they are viewed as an inconvenient or dangerous crossing option;
- *Raised islands* can be used by pedestrians as areas of refuge within high volumes roads, particularly where crossings can be accomplished in two stages;
- *Auto-free shopping streets* provide a conflict free environment and can create attractive and profitable commercial areas where pedestrians can move comfortably and conveniently;
- Traffic calming measures to reduce speeds an limit volume through neighborhoods
- *Paved and widened shoulders* in areas where cost or right-of-way limits sidewalk availability wide shoulders can, under the right conditions, be used to accommodate various forms of pedestrian traffic;
- *Lighting* can also enhance pedestrian safety around intersections. Recent highway safety statistics revealed that over 60 percent of pedestrian fatalities from vehicle crashes occurred at night.

One of the key parameters when designing for pedestrians is walking speed. Although walking speeds can vary based on grade steepness, temperature, and time of day, pedestrians generally maintain rates of between 2.5 and 6.0 feet per second (fps). Thus, walking speeds for design 4.0 fps can normally be assumed. When designing in areas where there is a significant presence of older persons, a walking design speed of 3 fps should be considered. Safety conditions for elderly pedestrians around intersections can also be enhanced by:

- *Simple designs* that minimize crossing widths and complex elements like channelization and turning lanes;
- *Refuge islands* at wide intersections;
- *Oversized, reflectorized signs* with larger letter sizes for enhanced legibility and properly located signals with large signal indications;
- Use of *repetition and redundancy* in all design features.

Table 1. AASHTO Design Vehicle Dimensions

US Customary

Design Vehicle Type	Symbol	Dimensions (ft)											
		Overall			Overhang								Typical Kingpin to Center of Rear Axle
		Height	Width	Length	Front	Rear	WB_1	WB_2	S	T	WB_3	WB_4	
Passenger Car	P	4.25	7	19	3	5	11	–	–	–	–	–	–
Single Unit Truck	SU	11-13.5	8.0	30	4	6	20	–	–	–	–	–	–
Buses													
Inter-city Bus (Motor Coaches)	BUS-40	12.0	8.5	40	6	6.3[a]	24	3.7	–	–	–	–	–
	BUS-45	12.0	8.5	45	6	8.5[a]	26.5	4.0	–	–	–	–	–
City Transit Bus	CITY-BUS	10.5	8.5	40	7	8	25	–	–	–	–	–	–
Conventional School Bus (65 pass.)	S-BUS 36	10.5	8.0	35.8	2.5	12	21.3	–	–	–	–	–	–
Large School Bus (84 pass.)	S-BUS 40	10.5	8.0	40	7	13	20	–	–	–	–	–	–
Articulated Bus	A-BUS	11.0	8.5	60	8.6	10	22.0	19.4	6.2[a]	13.2[a]	–	–	–
Trucks													
Intermediate Semitrailer	WB-40	13.5	8.0	45.5	3	2.5[a]	12.5	27.5	–	–	–	–	27.5
Intermediate Semitrailer	WB-50	13.5	8.5	55	3	2[a]	14.6	35.4	–	–	–	–	37.5
Interstate Semitrailer	WB-62*	13.5	8.5	68.5	4	2.5[a]	21.6	40.4	–	–	–	–	42.5
Interstate Semitrailer	WB-65** or WB-67	13.5	8.5	73.5	4	4.5-2.5[a]	21.6	43.4-45.4	–	–	–	–	45.5-47.5
"Double-Bottom"-Semitrailer/Trailer	WB-67D	13.5	8.5	73.3	2.33	3	11.0	23.0	3.0[b]	7.0[b]	23.0	–	23.0
Triple-Semitrailer/ Trailers	WB-100T	13.5	8.5	104.8	2.33	3	11.0	22.5	3.0[c]	7.0[c]	23.0	23.0	23.0
Turnpike Double-Semitrailer/Trailer	WB-109D*	13.5	8.5	114	2.33	2.5[e]	14.3	39.9	2.5[d]	10.0[d]	44.5	–	42.5
Recreational Vehicles													
Motor Home	MH	12	8	30	4	6	20	–	–	–	–	–	–
Car and Camper Trailer	P/T	10	8	48.7	3	10	11	–	5	19	–	–	–
Car and Boat Trailer	P/B	–	8	42	3	8	11	–	5	15	–	–	–
Motor Home and Boat Trailer	MH/B	12	8	53	4	8	20	–	6	15	–	–	–
Farm Tractor[f]	TR	10	8-10	16[g]	–	–	10	9	3	6.5	–	–	–

* = Design vehicle with 48 ft trailer as adopted in 1982 Surface Transportation Assistance Act (STAA).
** = Design vehicle with 53 ft trailer as grandfathered in with 1982 Surface Transportation Assistance Act (STAA).
a = Combined dimension is 19.4 ft and articulating section is 4 ft wide.
b = Combined dimension is typically 10.0 ft.
c = Combined dimension is typically 10.0 ft.
d = Combined dimension is typically 12.5 ft.
e = This is overhang from the back axle of the tandem axle assembly.
f = Dimensions are for a 150-200 hp tractor excluding any wagon length.
g = To obtain the total length of tractor and one wagon, add 18.5 ft to tractor length. Wagon length is measured from front of drawbar to rear of wagon, and drawbar is 6.5 ft long.

- WB_1, WB_2, and WB_4 are the effective vehicle wheelbases, or distances between axle groups, starting at the front and working towards the back of each unit.
- S is the distance from the rear effective axle to the hitch point or point of articulation.
- T is the distance from the hitch point or point of articulation measured back to the center of the next axle or center of tandem axle assembly.

(source: 1)

Additional details on the use of design to enhancing the mobility and safety of pedestrian facilities can be found in the FHWA publication *Pedestrian Facilities Users Guide — Providing Safety and Mobility* (6).

Bicycles

Intersections can be challenging locations for the design of safe and efficient movement of bicycle traffic. While one of the fundamental bicycle safety principles is to separate bicycles from vehicles whenever possible, intersections by their nature put these two modes in conflict. Fortunately, the hazardous nature of these interactions at intersections can in most cases be lessened through effective combinations of design geometrics and traffic control.

Bicycle traffic on highways can be accommodated by standard lanes, or better by using increased lane widths and on paved shoulders. The treatment of bicycle traffic at intersections depends largely on the type of travel lane. For shared lane and shoulder bicycle facilities, relatively few special accommodations are made aside from the placement of bicycle route designation and guidance signs. On facilities with exclusive bicycle lanes, design treatments are more formalized and specific. Among the most critical is the accommodation of bicycle turning movements at the intersection. In general, bicyclists are encouraged to stay to the right side of the road. At intersections right-turning vehicles must cross paths with through bicyclists. Signing and pavement markings help to control and guide these conflicting movements. Although, left turning bicyclists need to position themselves on the right side of left turn lanes, these areas are not typically explicitly designated by pavement markings.

Other simple and cost-effective features for enhancing bicycle safety and mobility include paved shoulders, wide outside traffic lanes, bicycle-safe drainage grates, flush manhole covers, and the maintenance of a smooth, clean riding surface. Detailed and specific guidance for the design of bicycle lanes at intersections is can also be found in Chapter 2 and in AASHTO's *Guide for the Development of Bicycle Facilities* (7)

Conflicts and Crash Patterns

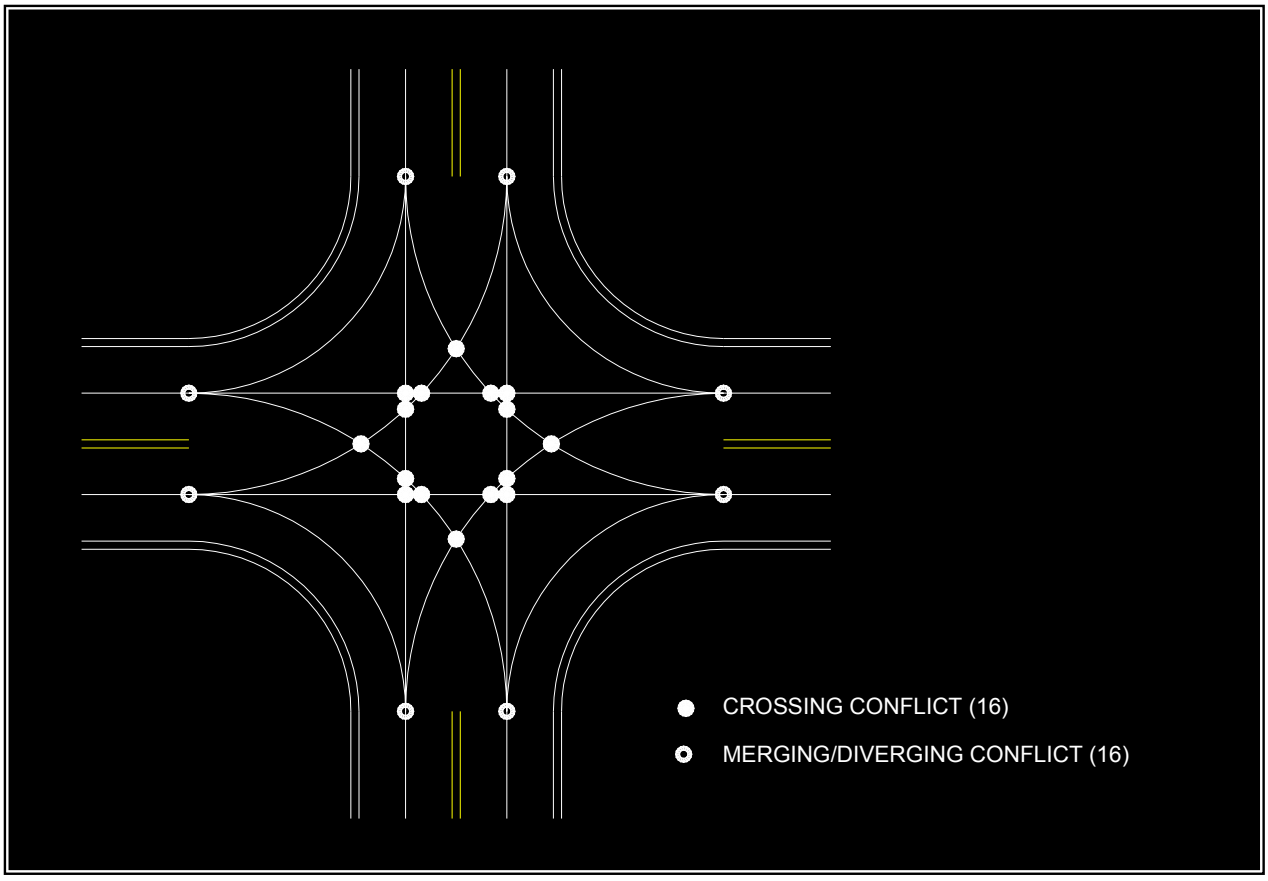
Traffic entering most intersection is allowed to cross, enter on to, or exit from one direction into any other. The combination of these maneuvers creates areas of conflict. Although, they can often be eliminated or relocated using various geometric and control means, conflicts are a fact of life at intersections. With an understanding of how and where they occur, designers can better apply design and control measures reduce both the number and severity of crashes at intersections.

Intersections Conflicts

A conventional four-leg intersection creates a total of 32 points of conflict between the various through and turning movements. These conflict points can be classified into one of three different types: crossing, merging, and diverging. Shown diagrammatically in Figure 3, crossing maneuvers occur at locations where vehicle travel paths cross one another, merging maneuvers occur where vehicles from one traffic stream enter into another, and diverging are located at points in which vehicles depart a traffic stream. Generally speaking, crossing maneuvers are the most hazardous because the crashes associated with them often occur at angles more severe than merging and diverging related crashes and the speed differential of the

conflicting vehicles (such as left turn angel crashes) is can be more pronounced than the other conflicts. These impact angels also mean that many of these crashes involve areas of vehicles, such as side doors, that leave the occupants more vulnerable to the effects of these collisions. As a result, the crashes typically associated with the crossing conflict are the most severe to vehicle occupants.

Figure 3. Intersection Conflict Points



The number and location of crossing conflicts can, and usually is, significantly diminished or moved with the application of certain simple design treatments and/or the installation of traffic control devices. For example, exclusive turn lanes and channelizing islands (discussed later) can be used to separate turning vehicles from the through traffic stream and move conflict points away from one another to ease the driving task. Traffic control is also a very effective method of dealing with conflicts. A two-phase traffic signal with directional protected left-turn phasing eliminates all crossing conflicts from an intersection. The installation of stop sign to assign right-of-way at an intersection, although not eliminating crossing conflicts, would diminish the frequency of directly conflicting crossing streams.

Intersection Crashes and Countermeasures

Intersections are the locations with the highest number of motor vehicle crashes in the US. In 2000, over 2.8 million intersection-related crashes occurred. This accounts for 44 percent of all reported crashes. These crashes also resulted in the loss of about 8,500 lives and over one million injuries resulting in a societal cost of about $40 billion per year (8). Pedestrian crashes are also a significant concern at intersections. Nearly 50 percent of all pedestrian fatalities and non-fatal injuries occur at or near intersections.

The frequency, type, and severity of collisions that occur at intersections can vary between locations. The most common types of accidents are crossing collisions when one vehicle strikes the side of another, rear-end collisions, sideswipe accidents resulting from improper lane changes, and pedestrian bicycle accidents. Factors such as traffic volume and speed, the percentage of turning vehicles, the geometric design, pedestrian volume, weather and lighting conditions, and traffic control all play significant roles in the safety conditions at an intersection. The four factors most often cited of the cause of intersection accidents include, poor design, inadequate traffic engineering, driver licensing and education, and driver disregard for intersection traffic control.

There are a number of countermeasures that can be implemented to lessen the adverse effects of intersection hazards. The type of countermeasure depends on the nature of the intersection and the safety concerns apparent at a particular location. Some of the most effective design treatments include (9):

- *Addition of turn lanes at intersections* – Exclusive-use left turn lanes have been shown to decrease intersection accidents by about 32 percent and injuries by as much as 50 percent
- *Unconventional intersection designs* – These include roundabouts and median u-turn configurations, both of which are discussed later in this chapter
- *Pavement improvements* – Improve pavement skid resistance and ability to drain effectively
- *Improve sight distance* – Sight distance at intersections can be improved by clearing obstruction from the required clear zone envelop and more simply by prohibiting on-street parking near intersections and by moving stop lines further back from the intersection threshold.

ELEMENTS OF INTERSECTION DESIGN

Experience has shown that the horizontal and vertical alignment conditions of roads at and near intersections are more restrictive than those of open roadway conditions. The alignments of highway intersections should be designed to allow the safe traversal of the intersection area and to minimize the interference between vehicles, pedestrians, and other users. They should also permit drivers to clearly see and be seen by drivers in all other lanes on the intersection, facilitate a clear understanding of directions of travel, be clear of unexpected hazards, and be consistent with the segments of highway previously traveled. The challenge to designer is to meet these needs in as cost-effective a manner as possible, balancing the overlapping and, often, competing needs of safety, efficiency, and economy. The following sections summarize the basic elements

of intersection design, while describing how certain designs can improve intersection safety and mobility.

Horizontal Alignment

The horizontal alignment of an intersection is a direct reflection of the alignment of the approaching roads. Since roads that intersect at acute angles can make it difficult for divers to see traffic approaching on some of the crossing legs, create problems for large vehicle turning movements, and extend both the time and distance required to cross the intersecting highway, it is strongly recommended that intersecting roadways should cross at or very near right angles.

Unfortunately, the alignment of the approaching roadways, topographic features, and adjacent development can occasionally make the creation of 90˚ intersections difficult to achieve. When this condition occurs a number of design treatments can be applied to reduce the effects of these severe angles.

At locations in which angles of 60˚ or less are present, a redesign of the intersection is encouraged. Redesign treatments generally fall into two categories, those that increase the intersection angle through a redesign of the road alignments and those that maintain the oblique angle but attempt to lessen the hazardous effects of the geometry. Like all design treatments, however, there are trade-offs between their specific benefits and costs. Several of these treatments, along with their characteristics are discussed below.

Generally, realignment options are substantially more expensive since they usually require the acquisition of right-of-way and the reconstruction of the road approaches. Figure 4 shows three common methods of addressing skewed intersections. Diagrams (A) and (B) involve a full realignment of one of the intersecting roadways, usually the lower classification of the two, to create a perpendicular crossing. A drawback to this treatment is that the addition of four curves to the minor road alignment near the intersection can be as significant a hazard as the skewed intersection. For this reason it is suggested that these types of realignments also incorporate speed reductions and advanced warning signs.

Diagrams (C) and (D) split the intersection into two separate three leg perpendicular intersections. Although these configurations eliminate the problem of skew, they can have significant consequences on the operational efficiency of the minor road. In these designs all through traffic on the minor road is required to make two turns, one right and one left. Left turning traffic in Diagram (C) can be accommodated with a center two way left turn (TWLT) lane between the intersections. Another important consideration is the spacing between the intersections. This separation needs to be long enough to permit minor street through traffic to first complete a weaving maneuver across the through lane and into the turn lane and provide an adequate turning bay length to store queued left turners in both directions. The required storage length is a function of the turning volume and the number of turning opportunities at signalized or unsignalized locations. The weaving distance is based on operating speeds in the area. The recommended *minimum* length is 750 feet for off-peak speeds of 45mph, 600 feet for off-peak speeds of 40mph, and 500 feet for off-peak speeds of 35mph. Thus, high speed and high volume intersections can require an unworkably long separation of the two intersections.

Figure 4. Intersection Realignment Alternatives

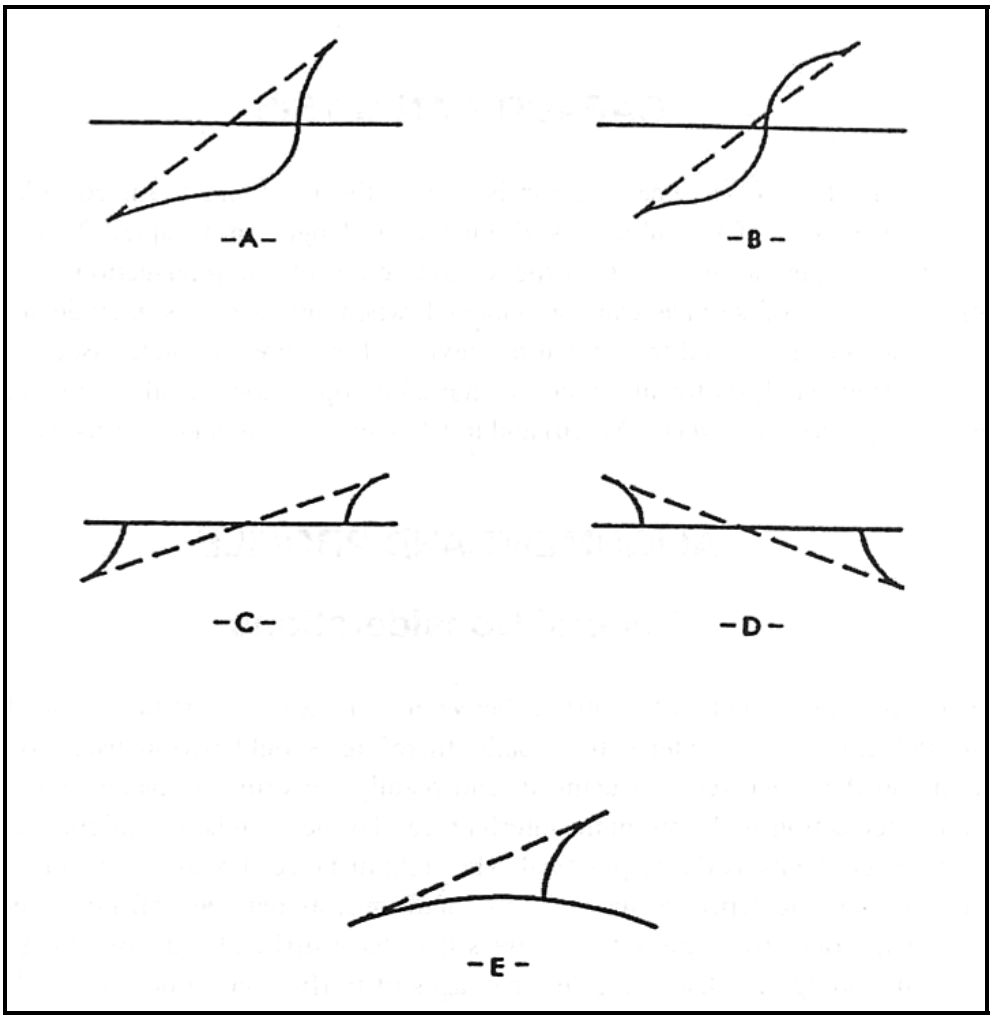


Diagram (E) shows a treatment for skewed intersections on curved highway sections. This diagram shows an options for locations in which an intersection is created between the curve and a road extension from one of the tangents. Intersections on curved sections of highway should be avoided whenever possible. The combination of curved approaches and superelevated cross-slopes makes the task of designing and driving these sections of roadway complicated and difficult.

A lower-cost option that can be considered to address problems associated with skewed intersections is to signalize the intersection. Signalization would lessen the potential for crashes associated with poor visibility during crossing and turning movements, although signalization can lessen problems but not eliminate them completely. Signalization at skewed crossings can be difficult because they often require inordinately long spans to align the signal faces with the approach lanes and the use of long visors, louvered signal faces, directional lenses. The skewed

intersection shown in Figure 5 illustrates this problem. At this location a single span was crated using two luminaire support poles connected at a point above the middle of the intersection.

Figure 5. Signal Installation at a Skewed Intersection



Sight distance

Another critical design feature of intersections is the provision of adequate sight distance. To facilitate safe movements around intersections it is necessary to provide an unobstructed view of the intersection area for approaching vehicles. Intersection sight distance must be sufficient for drivers to anticipate and avoid potential conflicts with crossing and merging traffic streams. Thus, the dimensions of obstruction-free envelops are a function of the physical conditions around the intersection, driver behavior, design speeds, and acceleration-deceleration distances.

Unlike highway segments in which sight distance is provided continuously for drivers along the mainline highway, sight distance at stop controlled intersections is intended to provide clear lines of vision for crossing and entering from the minor approaches. Sight distances must be adequate to permit drivers to determine if conditions exist to allow them to safely enter the mainline traffic stream and accelerate without significantly impeding traffic on the mainline highway. For crossing and turning maneuvers at stop controlled intersections these distances are measured from a driver's eye at the minor road departure position to a vehicle approaching from the right or left on the major road.

The specific design for any of these conditions can vary somewhat from location to location based on several factors, including the assumed design vehicle and the approach angle of the intersecting roadways. The following sections briefly highlight the general considerations for various cases of intersection control. Although a detailed discussion of the specifics of each case is outside the scope of this book, readers are encouraged to review the *Green Book* and other relevant design resources included in the bibliography references. (Note to reviewers: Should the Green Book curves be included here as well, or will they add too many more figures?)

Case A – Intersections with No control
In this case sight distance provisions are based on rules-of-the-road practice, which "requires" vehicles on the left to yield to vehicles on the right when no control devices are present at an intersection. The no-control case requires clear sight envelopes that permit drivers to see other approaching vehicles at a point where they can stop or adjust their speeds to avoid crashes. If it is not feasible to provide sight distances under these conditions, consideration must be given to lowering the approach speeds or installing a stop sign on one or more of the approaches.

Case B – Intersections with Minor Road Stop Control
Stop controlled intersections require obstruction-free sight envelopes that permit drivers on the minor street to see vehicles approaching from the left and right of the major street. There are three sub-cases that may be considered at these locations. The first, *Case B1*, provides the departure sight triangle required for drivers turning left from the minor street onto the major street. In this case, adequate sight distance must be provided both to the drivers left, to allow the driver cross these lane(s), and to the right to allow the driver time to accelerate his vehicle from a stop so as not to interfere with operations on the major road.

Case B2, is concerned with providing an adequate departure sight triangle for drivers turning right from the minor road onto the major road. The computational procedure is similar to Case B1 in which minor road drivers must complete the turn maneuver and accelerate so as not to significantly effect operating speeds on the major roadway. Although in this case they do not need to look both ways to cross another intersecting lane. The time gap required for right turns is typically less than for left turns.

In *Case B3*, sight distance is provided for major street crossing maneuvers from the minor street such as may be the case at locations where turns are prohibited. In most cases the sight distances required for Cases B1 and B2 will also provide adequate distances for crossing maneuvers. However, it should be checked directly when these maneuvers are not permitted and in other cases, such as wide major intersecting roads and when a high percentage of heavy vehicles, when longer distances may need to be provided.

Case C – Intersections with Minor Road Yield Control
The sight distance requirements for yield-controlled intersections allow approaching vehicles to cross or turn without coming to a stop if no conflicting vehicles are approaching on the major road. The sight distances required under these conditions are in excess of those for stop control conditions (Case B) and are similar to those of the no control case in which only vehicles on the yield controlled approaches would need to stop or adjust their speed.

Case D – Intersections with Traffic Signal Control
Obstruction-free sight envelops at signalized intersections should be maintained such that the first stopped vehicle on any approach should be visible to the driver of the first stopped vehicle on all of the other approaches. Sight distance should also be available for left turning vehicle drivers to see and select suitable gaps in the opposing traffic stream. If however, the signal will be operated in a two-way flashing operation during periods of diminished volume, then the sight envelopes defined in Case B should be provided on all of the minor approaches. Additionally,

any approaches with right-turn-on-red permissive movements should also incorporate the sight distances describe in Case B2.

Case E – Intersections with All-Way Stop Control
Sight distance requirements a all-way stop controlled intersections are similar to Case D in that the first stopped vehicle on any approach should be visible to the driver of the first stopped vehicle on all of the other approaches. Because of the small envelop that such conditions would entail, all-way stop intersection control is often a favorable option at locations in which sight the distances associated with any other form of control cannot be attained.

Case F – Left Turn Locations From the Major Road
Adequate sight distance should be provided at all points where permissive left turns are (and will, in the future, be) allowed. AASHTO guidelines (1) state that an independent Case F evaluation would not be required when stopping sight distance in both directions of the major and Case B and C sight distance have been provided from the minor street.

Corner Clearance
The ability of vehicles to complete turning movements at highway-to-highway and highway-to-driveway intersections is dependent upon adequate clearance around corners. The use of corner curb radii that are too small will require vehicles to slow substantially to complete turning maneuvers and can often result in vehicles (particularly large trucks with large turning radii) to ride up over curbs potentially harming pedestrians as well as control and landscape features. Overly large corner curb radii result in unnecessarily large intersections with wide-open areas of unused roadway, which can confuse both drivers and pedestrians.

The selection of a design corner clearance is dependent on the design speeds of the intersecting roadways and the amount of truck traffic at the intersection. In developed areas with higher design speeds and truck volumes, corner curb radii in the range of 30 to 50 feet are typically appropriate. In urban areas where there is a substantial pedestrians presence and limited truck traffic, curb radii in the range of 15 to 25 feet are appropriate (1).

The provision for adequate corner clearance may be achieved in several ways. AASHTO discusses the use of three different techniques including:

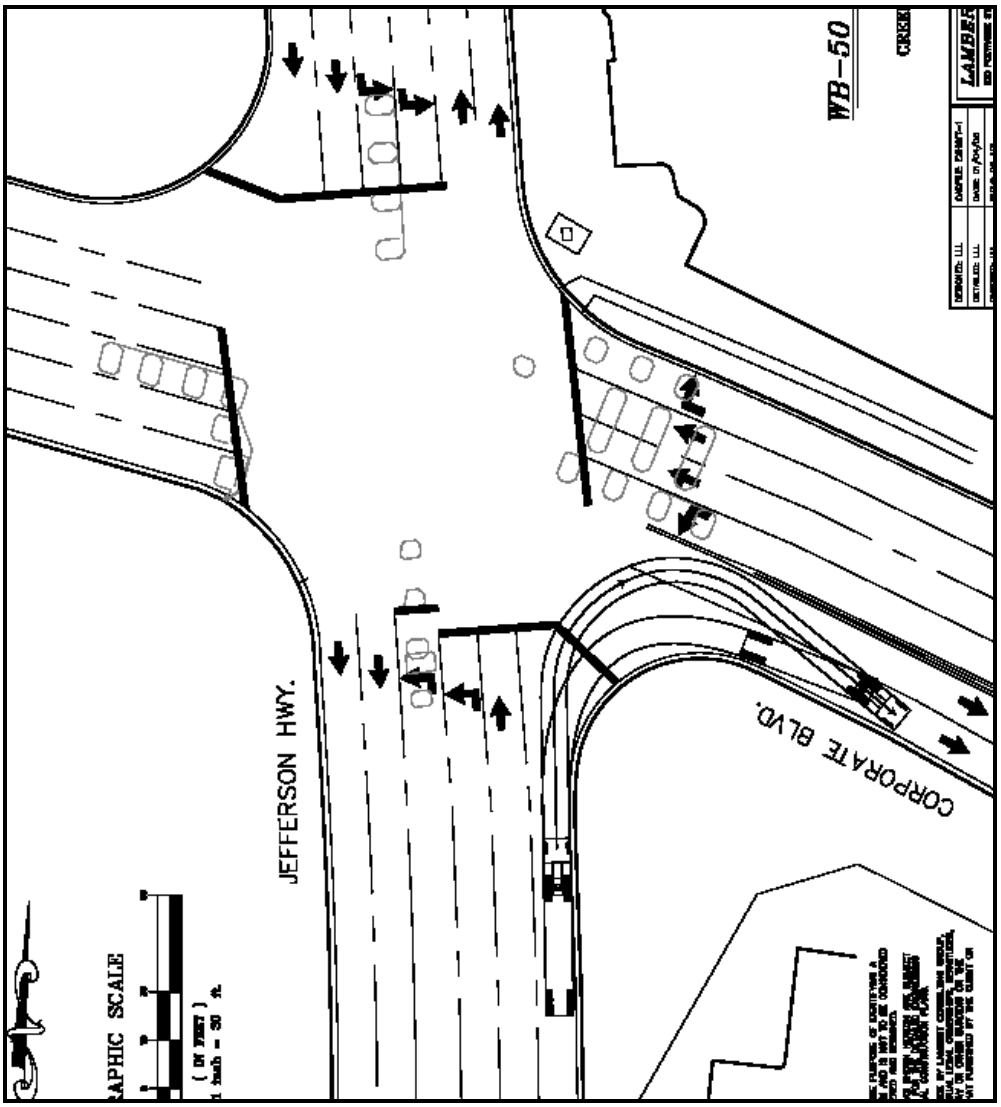
- A single radius joining the edge of pavement of the approaching and departing roadways;
- A taper-radius-taper design, in which the edge of the approaching lane is tapered into the curve, then taper out of the curve into the departure pavement edge;
- A three centered compound curve, in which the corner curb is transitioned from a large radius, to a smaller radius, then back to a larger radius before meeting the departure lane.

The AASHTO recommendation for the sizes of particular design radius treatment for a specific intersection is based on the design vehicle.

The adequacy of corner clearance for turning vehicles can also be checked during the design process using commercial available software. These programs can superimpose the path of a specified turning vehicle directly onto a design drawing. Figure 6 shows the results of an analysis to determine the adequacy of a proposed intersection redesign to accommodate WB-50 design vehicles. The presence of an oblique angle intersection at this location led to concerns

that large vehicles would not be able to complete right turning maneuvers. The turning analysis eliminated this concern and showed that a channelizing island would not be advisable at this location, despite the large amount of open paved area.

Figure 6. Intersection Turning Analysis



(source: Lambert Consulting Group, LLC, 2004)

Channelization

Channelization is a design technique used to simplify movements, increase capacity, and improve safety within the vicinity of an intersection. It accomplishes these by relocating and eliminating points of conflict and separating and restricting vehicular and pedestrian movements into specific and clearly defined paths. Channelization can be accomplished in several ways including using islands, medians, and various traffic control devices including flush-level pavement markings where it is not possible to use an island or where snow removal is a concern.

Like any design or control measure that restricts movement, channelization can have positive and negative consequences. The intended benefits of channelization include a reduction in the number of conflicts and crashes and a decrease in crash severity; a streamlining of movements at intersections, including the elimination of left turns to reduce delay to right turners and the prohibition of wrong-way entry. The drawbacks of channelization are typically associated with the added delay and travel time required because of the elimination of certain turn movements. Several of these concepts are illustrated by the following examples that describe the intent of channelization.

Discourage or eliminate undesirable or wrong-way movements – Channelization can be used to eliminate wrong way movements or, if this is not possible, discourage the completion of movements. Examples of this are "right in-right out" or "pork chop" island as shown in Figure 7. Benefits of these islands also include the reduction of queued traffic in parking lots and exit driveways and the elimination of "dangerous" left turns into busy streets.

Figure 7. Right in-Right Out Island



Clearly define vehicle travel paths – Channelization can be used to delineate exclusive turn lanes so that vehicles do not drive through the intersection where a receiving lane is not available on the departure side of the intersection as shown in Figure 8. These features also eliminate confusion about which is the proper lane or direction of travel, particularly at skewed intersections or those with large open pavement areas.

Figure 8. Channelization to Delineate an Exclusive Right Turn Lane



Encourage desirable operating speeds – This can be accomplished by using channelizing features to "bend" or "funnel" movements to slow traffic near merging, weaving, and crossing areas. They can also be used to open up travel and turning lanes to promote higher operating speeds in high-speed/high-volume locations, thereby keeping traffic moving and reducing the potential for severe crashes.

Separate points of conflict – To ease the driving task, channelization techniques such as adding raised islands near turning lanes will move the location of merging and diverging conflicts away from other areas of conflict nearer to the intersection thresholds. This separation is particularly important in areas of overlapping maneuvers where channelization allows drivers to make one decision at a time. An example of an application of a separation island adjacent to a left turn lane is shown in Figure 9. The combination of the raised island and the center median at this location removes decelerating, slowing, and stopped traffic from the through traffic lanes to reduce conflicts and rear-end crashes. This design can also be used to eliminate or reduce the potential for unwarranted left turns from driveways just prior to the intersection.

Facilitate the right angle crossing of traffic and flat angle merging maneuvers – At locations where roads intersect at flat angles, channelization can be used to control the angle of conflict by creating a perpendicular turning lane. An example application of this purpose is shown in Figure 10. At this location a channelizing island has been used at an acute three-leg intersection to create a perpendicular meeting between the two roads.

Figure 9. Left Turn Lane Separation Island



Figure 10. Island Used to Create a Right Angle Intersection



Provide a safe refuge for pedestrians and other non-motorized vehicle users – Channelization features such as islands can also shield non-motorized users in the within the intersection area, reducing the exposure of these vulnerable groups without significantly reducing the overall efficiency of vehicle operations. This concept is illustrated by the intersection in Figure 10. At this location, pedestrians are able to use the raised island as a stopping point between the approaching and departing street lanes during the short green phase given for minor street traffic. Pedestrian movements at this island are also facilitated by pedestrian ramps located at the ends of each crosswalk.

Locate and protect traffic control devices and facilitate the desired traffic control scheme – Channelization features such as islands and medians can be used to align turning movements, locate stop bars, help to make traffic control features (like traffic signal heads) more visible. An example of this can be seen in Figure 9 where the left turn lane control has been installed on the median on the opposite side of the intersection. Channelization features can also be used to locate other roadside hardware such as traffic signal controller cabinets (shown in Figure 10), signal strain wire poles (as shown in Figure 8), luminaire supports, and similar items.

Facilitate high-priority movements – Channelizing features can be used to designate high priority movements at intersections. In these instances the highest volume movements and/or the intersecting roadway with the highest functional classification with priority would receive preferential treatment. This type of treatment can also be used to maintain consistency route continuity at intersection locations.

Design of Channelizing Islands

For the most part, channelizing islands at intersections are unique features and each must be designed independently to fit a specific location and set of operating criteria. The principles that should be followed when designing channelizing islands include the following (12):

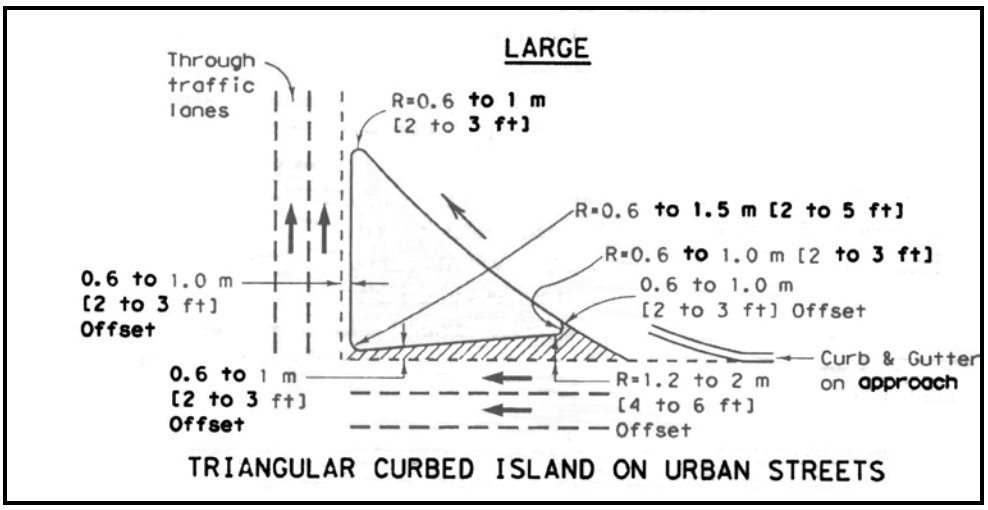
- Channels created by islands at intersections should appear natural and convenient to drivers.
- Islands should be large enough to be effective. The minimum suggested size of islands in an urban area is 50 square feet and 100 square feet in rural areas, although 100 square feet is the preferred minimum for both.
- Islands should be clearly visible in all weather and lighting conditions.
- Islands should favor major flow movements.
- Channelizing islands should separate conflicts so that drivers and pedestrians need only to deal with one decision at a time.
- Island should be designed with careful consideration given to the design speed of the intersecting roadway. Approach ends of islands should be delineated and offset from the roadway edge.

Island designs at intersections fit into one of three categories, including *directional islands* used to control and direct vehicle movements; *division islands* used to separate opposing flows and alert drivers to crossing streets; and *refuge islands* used to aid and protect pedestrians near crosswalk areas. Islands may also be raised or flush. *Raised islands* are typically four to six inches higher than the roadway edge and may be boarded by barrier or mountable curbs. *Flush islands* include a variety of treatments including raising them above the pavement just slightly (one or two inches); the application of pavement markings, “buttons,” rumble strips (also known

as “jiggle bars”), and other types of contrasting surfaces. Flush islands may also be unpvaed where they are formed by the pavement edges of existing roadways. In areas where snow plowing may be necessary, flush islands are the preferred design.

The size and orientation of islands near intersections are dictated by the alignment of the intersecting roadways and their associated travel path edges. Proper island design must minimize the potential for vehicle impacts and reduce their severity. This is most often accomplished by offset the approach ends of islands from the edge of travel lane them tapering them inward. Another technique is the use of rounded approach noses that may also be sloped downward on their approach ends. The general design dimensions of corner islands for urban roadways in shown in Figure 11.

Figure 11. Design Dimensions for Large Corner Islands in Urban Conditions



(source: 1)

Another design considerations for islands is their surface treatment. Islands may be paved or landscaped. Paved islands are typically easier to maintain, though they are typically not as aesthetically pleasing. The use of colors that contrast with the pavement surface is desirable because they allow the island to be more clearly seen by drivers. As a result, concrete islands are commonly used with asphalt roadways and vice versa. Brick pavers are also used in areas where aesthetics are important.

Other concerns include the need to adequately slope the surface of the island to facilitate drainage and to keep the island free of sight obstructions and collision. Thus, all landscaping features should be kept below the clear vision envelop and should not incorporate other fixed hazards.

Turning Lanes

Intersections with suitably high turning traffic may require exclusive-use turning lanes. In addition to providing a storage area for queued vehicles, turning lanes also provide an area outside of the through lanes for drivers to decelerate prior making their turns. Because of the

obvious safety benefits of separating queued vehicles, some highway agencies require the use of left turn storage lanes at all signalized intersections. In cases where turning volumes are substantial and opposing through traffic is high, dual, and occasionally triple, turn lanes are used. The obvious disadvantages of multiple turn lane approaches are the additional right-of-way required for their construction and the added crossing distance for pedestrians.

The length of turning lanes is determined by the amount of turning volume. The Highway Capacity Manual(2) suggests the use a left turn length at signalized intersections for left turning volume greater than or equal to 100 vehicles per hour (vph), dual left turn lane for left turn volumes greater than or equal to 300 vph, and right turn lanes for hourly right turn volumes greater than or equal to 300 vph (2). The HCM also recommends the use of additional through lanes for each increment of 450 vph of through volume. The length requirements for turning lanes at unsignalized intersections are not as clear-cut, although several local highway agencies have developed localized standards of guiding in their use.

Turning lanes at intersections also require the use of transition tapers to carry traffic from an adjacent lane into the lane. The specific length of this taper is based primarily on the length required for vehicles to decelerate, which is itself a function of the roadway's design speed and approach grade steepness. AASHTO suggests taper transition rates of between 8:1 and 15:1 (longitudinal:transverse).

In addition to their operational benefits along high volume roadways, turning lanes can also yield safety benefits at low volume and unsignalized intersections. In low volume and rural areas turning lanes enhance safety by moving stopped and slowed vehicles from the through traffic stream. This reduces the occurrence of rear-end, side-swipe, and run-off-the-road types of crashes. An example of a turn lane at a low volume rural intersection is shown in Figure 12. Here, a separate left turn lane has been constructed to accommodate left turning traffic. Because of the moderate to low volumes present in this area, the storage length of the turn lane was 50 feet, the minimum local standard.

A more recent treatment of left turn lane at intersections, design to enhance safety, is the use of *positive offsets* at the approach threshold (3). Although primarily for use on divided highways with adequate medians, the positive offset shifts queued turning traffic away from the through lanes so that left turning drivers have a less obstructed view of opposing through and right turning traffic. An example of this concept is shown in Figure 13.

Figure 12. Left Turn Lane at a Rural Unsignalized Intersection

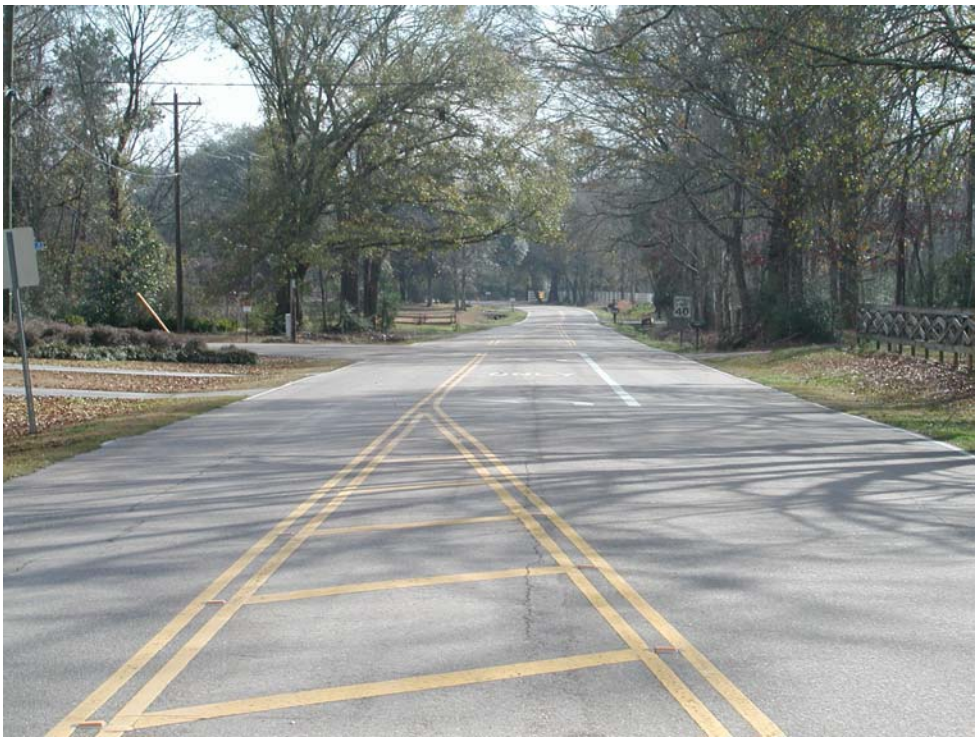


Figure 13. Offset Opposing Left Turn Lanes on a Divided Highway



Vertical Alignment

The task of designing vertical alignments in the vicinity of intersections is more complicated than road segments because they must accommodate vehicle and pedestrian movements from multiple directions. Intersection profiles should be designed to promote both safety and mobility by maximizing sight distances and facilitating vehicle braking. Grades should be kept as flat as possible without affecting the ability to efficiently drain the intersection area. The following sections discuss the requirements for intersection profile design and highlight techniques that can be used (or avoided) to enhance the quality of the design.

Profile Grades

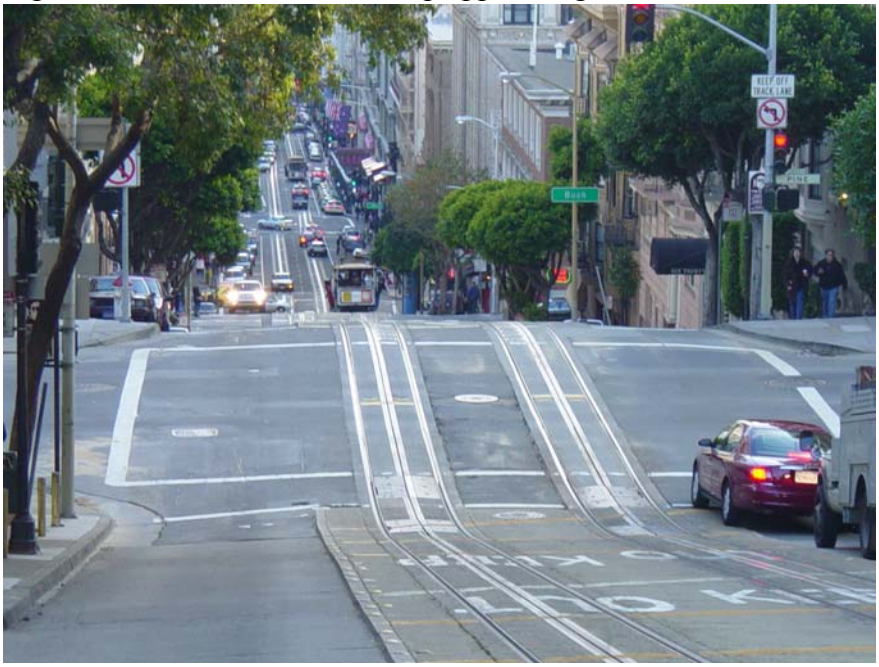
Experience has shown that ability of passengers cars to stop and accelerate on grades of 3 percent or less is not significantly different from level surfaces. Grades steeper than 3 percent can, on the other hand, increase the distance needed to bring vehicles to a stop and degrade the ability of vehicles, especially large trucks, to accelerate from a stop. Since most drivers are not able to estimate the additional distance needed to stop or accelerate because of the effect of the steeper grade, it has been recommended that profile grades steeper than 3 percent be avoided on intersecting roadways and where such provisions would make the construction of the intersection un acceptably expensive, grades greater than 6 percent should not be exceeded (1).

On steep approach grades, it is also desirable to include flatter profiles immediately leading to the intersection thresholds. These areas, commonly known as “storage platforms” provide a flatter storage area for stopped vehicles and reduce the abruptness of profile changes within the intersection. The resulting profile of this design is analogous, though in the vertical plane, to Diagram B in Figure 4 for horizontally realigning skewed intersections. An illustration of this concept at an intersection with very steep approach grades can be seen in Figure 14. This photograph, from San Francisco, CA, shows the use of short monotonic vertical curves in advance of the intersection. The resulting profile over a long grade creates “stair-steps” at each intersection to flatten each intersection area, as shown in Figure 15.

Intersecting Grades

Intersecting roadway cross slopes also create a design challenge. Since pavement cross slopes at intersections meet at opposing angles, care must be taken to ensure rideability. Although both roadways have to be considered, it is typically the profile and cross slopes of the major highway that receive a higher priority. The cross slopes of the major road are carried through the intersections and the minor road is adjusted to fit it. It is common practice, however, to flatten the profiles and cross slopes of both roads within the intersection so that they do not create a ramping effect in one or more approach directions. This is typically accomplished by rounding the pavement cross slopes to form a gently sloping “tabletop” within intersection that allows runoff to drain toward the outside curb radii. When a new road creates an intersection with an existing road, the existing roadway may even have to be reconstructed for a short distance in advance of the intersection so that the rounded cross slopes can be achieved.

Figure 14. Intersection with steep approach grades



(photo source: David Wickens)

Figure 15. California Street, San Francisco, CA



(photo source: David Wickens)

Grade and cross slope design must also facilitate the drainage of surface run off at intersections. This starts by guiding flow in the predominant direction of fall of the intersecting roadways while eliminating, or at least minimizing, sheet flow across the intersection. The tabletop design discussed earlier helps to direct surface runoff to the outsides of the intersection. While the specific design would be dictated by the vertical profiles and cross slopes of the two roads, runoff on curbed roadways in usually intercepted by a catch basin or outflow channel in each quadrant of the intersection. In open ditch designs, run off would flow over the shoulder in into the roadside area.

The design of grades, cross slopes, and drainage features can also be complicated by divided highways, medians, and other channelization features. In each of these cases it is important to check the both the amount and direction of run off to make sure that no water will be trapped or impounded in low spots at the edges of these features. One effective method to avoid inadvertent low points is to mark pavement surface spot elevations to determine the direction of flow, then plot profiles of all edge of pavement or gutter elevations within the intersection influence area to locate flat segments and low points that may impound water.

Cross-Section

The cross section design of highways is concerned with the layout of lanes, shoulders, medians, sidewalks, curbs, embankments, drainage features, and pavement thickness; and in particular, the widths and slopes of these features. Cross section design also includes the design of the roadside area; particularly protecting drivers from various hazards adjacent to the roadway. Cross-section design at intersections includes many of these same features, although their design largely guided by the cross sections of the intersecting roadways. Some of the key cross-section elements at intersections include medians, adequate slopes for drainage and turning movements and the interaction of vehicles with pedestrians and bicyclists.

Medians at intersections act similar to islands in that they separate opposing traffic streams, reduce pavement area, provide areas of pedestrian refuge, and provide an area to locate various traffic control and lighting features. Another significant, though more indirect, benefit of medians is that they can be used control access by eliminating left turns into and out of adjacent properties. Intersections medians also have some disadvantages. If not designed with embedded left turn lanes, wide medians can cause *left turn interlock*, a condition that occurs when opposing left turn movements cross paths. Other safety and operational disadvantages of medians at intersections include increases for the potential for wrong-way entries and minimum green times for pedestrian crossings. The Green Book (1) describes the design of several features of intersection medians, including their width and sloped treatments for approach noses.

The accommodation of non-motorized users must also be incorporated in the intersection cross section design. Intersections in urban area must include sidewalk areas and access ramps for the disabled. In pedestrian-oriented areas, intersections can also be designed with narrowed approach widths to form nubs, bulbouts, bump-outs, and knuckles. These narrowing techniques provide dual benefits in that they tend to reduce operating speeds in the vicinity of intersections and they provide additional space for pedestrians to queue prior to crossing and reduce the length of the crossing. An example of a bump-out can be seen in the upper left quadrant of the intersection in

Figure 16. At this location pedestrian crosswalk areas have also been more clearly defined by the use of brick pavers.

Figure 16. Cross-section Enhancement at a High Pedestrian Intersection



(source: http://www.pedbikeimages.org)

Other cross section enhancement techniques include vertical measures such as raised intersection tables and crosswalks that can be used to restrict speed around high pedestrian volume intersections.

UNCONVENTIONAL DESIGN CONFIGURATIONS

To improve both the operational efficiency and safety characteristics of intersections, engineers have continually developed more innovative design and control strategies. Since the intersection locations with the highest potential for improvement, both in terms of operational and safety performance, have along high volume corridors, most of these innovations have been concentrated on arterial roadways. This section highlights the general safety and operational characteristics, benefits, and costs of several types of unconventional designs for arterial/collector intersections. These designs are regarded to be "unconventional" because they incorporate geometric features or movement restrictions that would be permissible at standard four (and three) leg at-grade intersections. Such elements include the elimination and/or relocation of various through and turning maneuvers, the use of indirect turning movements, and the inclusion of roundabout designs.

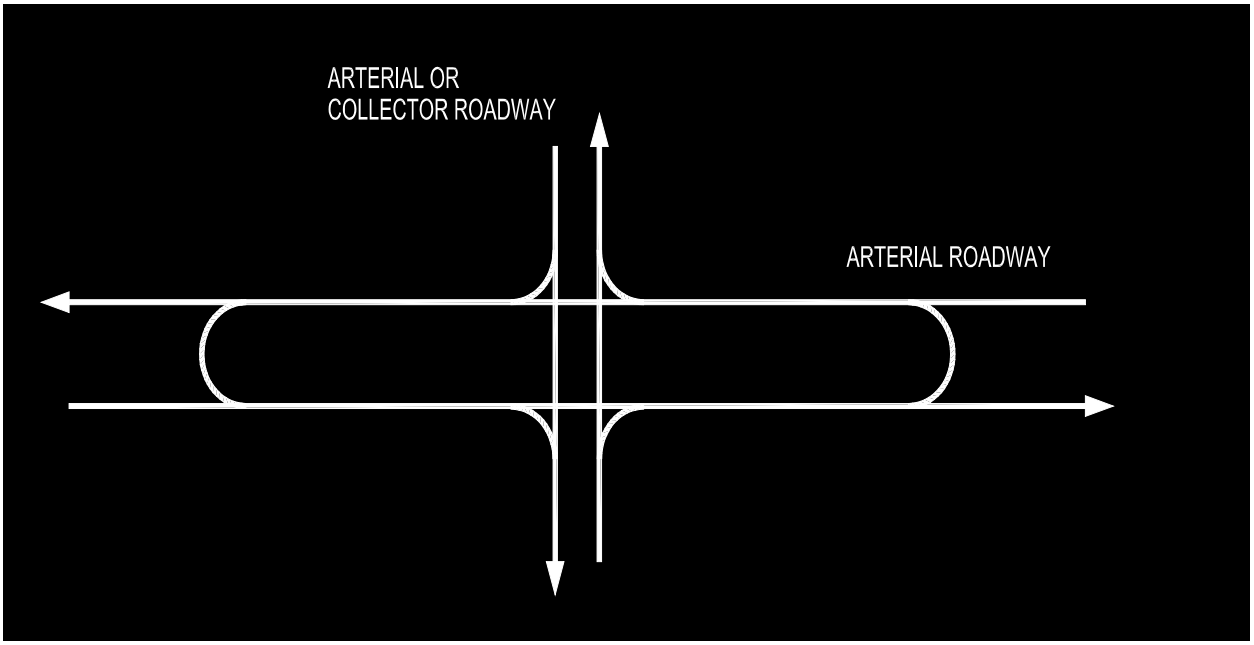
The common theme of most of these designs is to improve the overall operation of the intersection by favoring heavy volume arterial street through movements. Typically, these benefits are created by moving or eliminating conflicting left turn movements to and from the minor cross street, thereby reducing the number of signal phases (and their associated start delay and clearance times), and allowing the intersection to operate in a simple two-phase operation. Not surprisingly, these benefits occur at the cost of increased delay, travel times, and travel distances to the major street left turning traffic and most minor street movements.

The following sections describe the basic layout and operation of these designs and the benefits and drawbacks of each with respect to analogous four leg at-grade designs. They also discuss the locations and conditions under which they are thought to be most appropriate. The information presented here has been summarized from numerous research and practitioner reports. These are included in the reference and bibliography sections at the end of this chapter.

Median U-Turn Intersection

The primary objective of the median U-turn design is to remove all left turn traffic from the main intersection. In this configuration all left turn movements are converted to right turns at the intersection then, using a uni-directional median crossover to make a U-turn on the major highway, drivers may complete their change of direction. Figure 17 shows a schematic diagram of a typical median U-turn intersection.

Figure 17. Median U-Turn Intersection Diagram



This type design favors the major street through movement because time from the signal cycle does not have to be allocated to protected left turn phases. Since it is possible to control the median U-turn intersection with a two-phase cycle, it also eliminates lost-time associated with

the left turn phases and facilitates coordinated progression along high volume arterial corridors. This design also removes or relocates all of the conflicts that would normally be associated with left turn movements. Thus, crashes *directly* associated with left turn movements are eliminated. It should be noted that the exposure to crashes associated with higher right turn and U-turn volumes would likely increase, although these types of crashes are generally less severe than left turn crashes.

The main disadvantages associated with the use of median U-turn intersection designs are associated with the added stopping and delay impacts to left turning traffic. Although despite this fact, this design has been shown to improve total intersection delay and travel time conditions under certain volume conditions. Median U-turn designs also require significantly larger rights-of-way along the major street (AASHTO recommends a 60 foot median to accommodate large trucks) and require the use of multiple signal installations (typically three, one for the main intersection and one for each of the two median cross-overs) instead of just one.

From a non-motorized user standpoint, this design presents fewer threats to crossing pedestrians. Although this design requires a longer time to cross the major roadway, the median can serve as a refuge area for pedestrians. It should also be noted that the longer crossing distances could also require longer minimum green times or two-cycle pedestrian crossing signals.

Median U-turn intersections are the most common type of unconventional design in the US. They are most appropriate for high volumes arterial roadways with medium to low left turning traffic and within corridors where it is possible to acquire the right-of-way required for its construction.

Superstreet Median Intersection

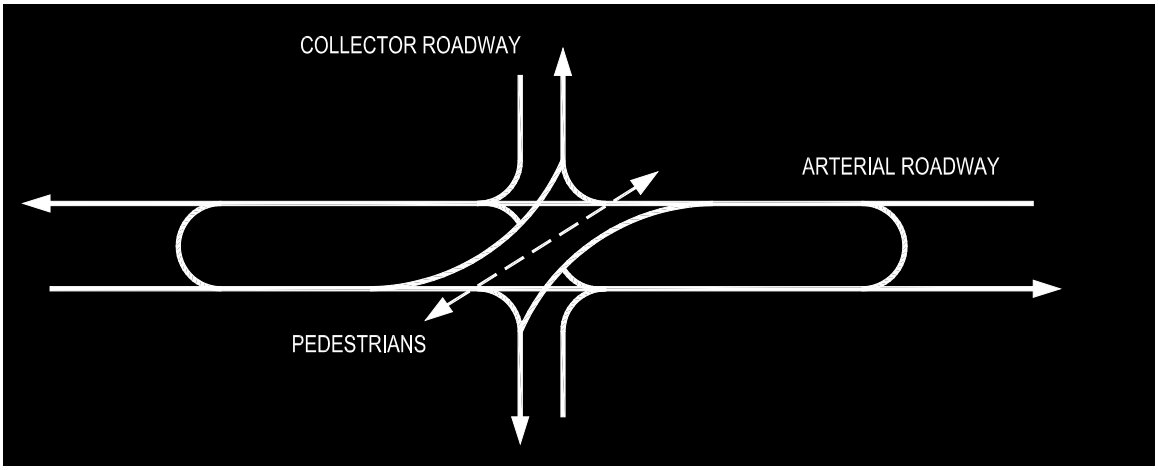
The superstreet median intersection design is a variation on the median U-turn theme. The primary difference is that the left turning traffic on the major street uses directional median crossovers that channel the traffic into the cross street receiving lanes as shown in Figure 18. The effect of this configuration is that it allows a four-approach intersection to operate as two separate three approach intersections and allows each direction of the major street to operate on an independent timing pattern. Although this intersection has not actually been constructed, it was conceived in 1987 and the similar left-turn crossovers have been used in practice.

Like the median U-turn intersection, this design favors the through movement on the major roadway. Although here left turns are permitted directly from the major street so they benefit from decreased delay. Because of the ability to independently control the major street directions, the superstreet design permits coordinated progression for the major street regardless of its spacing relative to upstream and downstream intersections.

The most significant disadvantage of the superstreet design is that it does not permit through or direct left turn movements from the minor roadway. Through traffic on the minor roadway is required to follow the same travel path as the left traffic, with an additional right turn. Similar to median U-turn designs it is thought that unfamiliar drivers may be somewhat confused by this configuration. In this design, pedestrians are required to cross the major street at an angle

"parallel" to the left turn crossovers. While this design presents fewer threats to crossing pedestrians, it also requires a longer time to cross the major roadway.

Figure 18. Superstreet Median Intersection Diagram



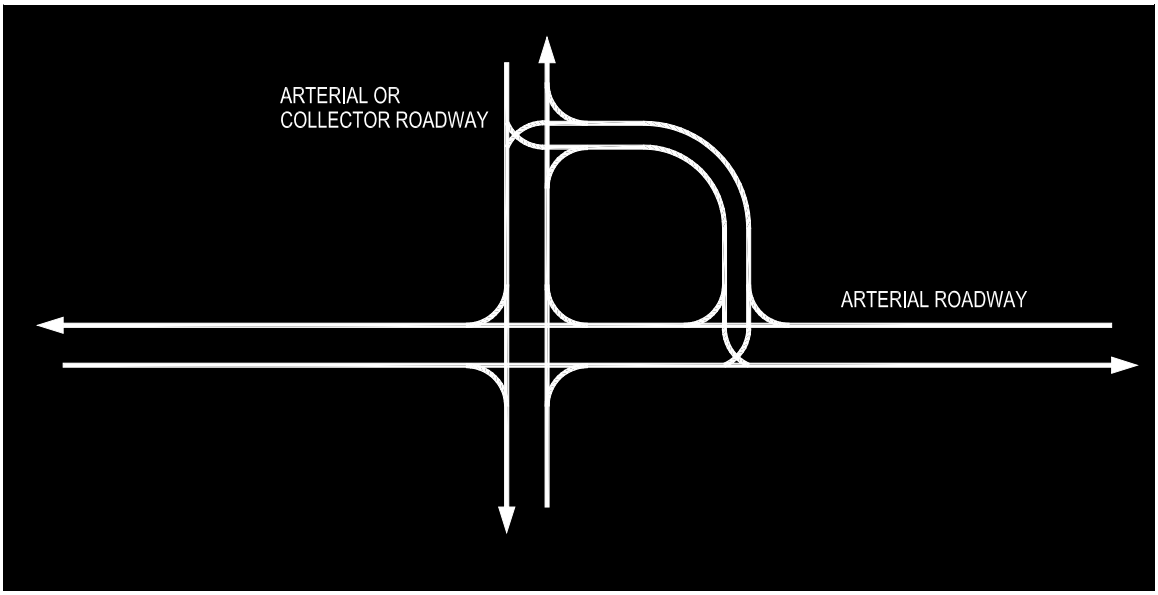
Superstreet median intersection deigns are most appropriate for locations that feature high arterial volumes that conflict with medium to low left turners, particularly in suburban areas where development adjacent to the road generates most of the conflicting traffic. An existing wide median or ability to acquire of the required right-of-way is also a requirement. The design would also be useful where major street traffic is directionally balanced and/or where the spacing or signal timing at adjacent intersections does not permit effective progression to be implemented in a conventional design.

Single Quadrant Roadway Intersection

The single quadrant roadway intersection removes left turning traffic from the main intersection. It operates by using a by-pass road in one of the intersection quadrants that rings the main intersection. As shown in Figure 19, all left turn movements from both roads are completed prior to or after the main intersection on a by-pass road. A key component in this configuration is the coordination of the signals at the three intersections.

The design permits the main intersection to operate on a two-phase cycle. The left turning movements into and out of the quadrant roadway occur during the phase that overlaps the coinciding movement at the main intersection, thus minimizing (or even eliminating) the number of stops required to complete the left turn. The length of the quadrant roadway and the locations of its accompanying intersections are dictated by a trade-off between the amount of storage required for left turn queuing and distance and time required to travel to the intended direction. The issues of both spacing and signal coordination are not unlike the location and timing requirements of the median U-turn intersection.

Figure 19. Single Quadrant Roadway Intersection Diagram



Unlike the median U-turn and superstreet configurations, the quadrant roadway does not require a wide median for U-turn maneuvers. However, this design does require an entirely separate right-of-way for the quadrant roadway. While this is an obvious drawback because of the cost, the quadrant roadway could also provide access to and from developments within the selected quadrant. Some other advantages of this design include a reduction in conflict points at the main intersection (although these conflicts would be moved to other locations) and reduced intersection widths that would decrease pedestrian clearance times.

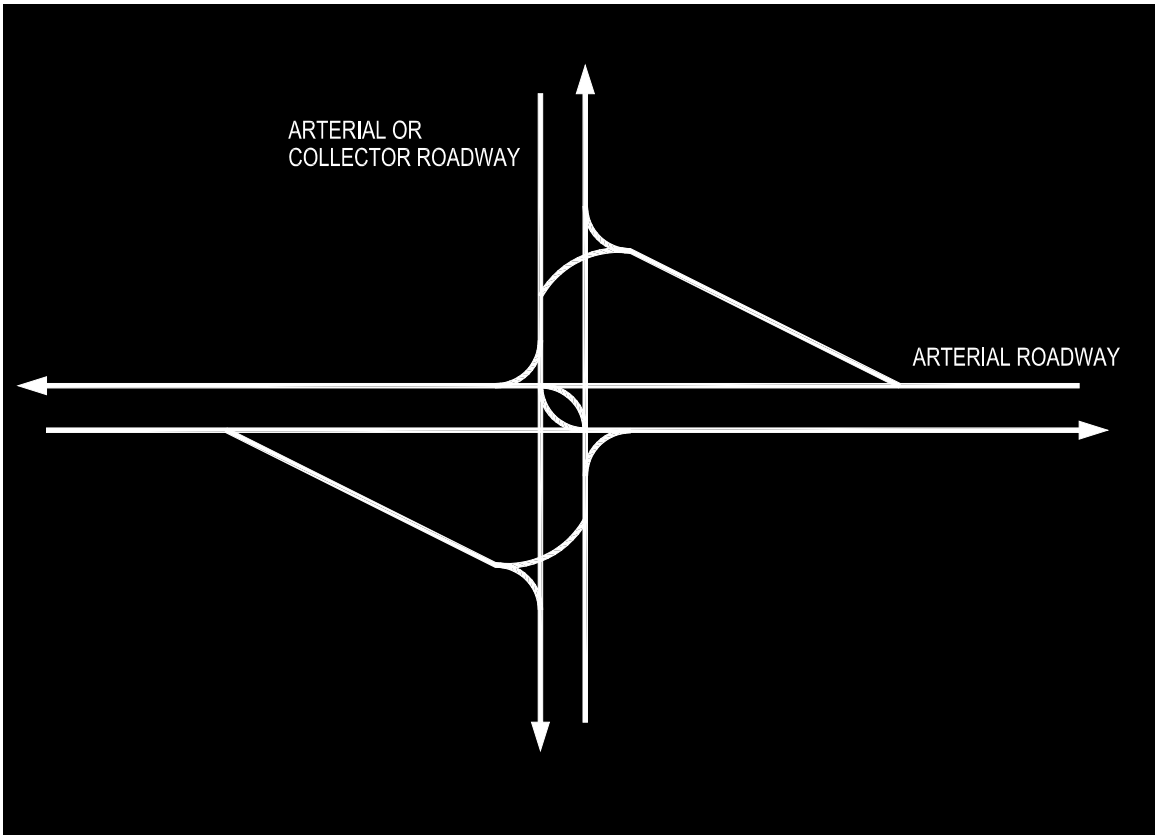
The most obvious disadvantage of the quadrant roadway is the additional travel distance required to make left turns. Depending on the traffic conditions and signal timing, additional travel time and stops would also be experienced by left turning traffic. This configuration could also be more confusing than the prior designs in that the left turn movements are not the same for different directions. Left turns for two of the approach directions would be made prior to the main intersection and the other two approaches would initiate their left turn maneuvers after the main intersection.

Currently, there are no quadrant intersections in operation in the US (<- confirm). However, simulation studies have showed that the amount of stopped delay and system travel time would be less than that of an equivalent conventional intersection, with average reductions of 22 percent in these measures at the main intersection. Despite the added travel time for left turns it was also interesting to note that the simulation study showed that the total travel time required for these movements was not significantly different from similar movements at a conventional intersection (18).

Jughandle Intersection

The jughandle intersection configuration is a design that also incorporates separate turning roadways similar to the quadrant intersection. The principle of the jughandle design is to remove all turning traffic (including right turns) from the main intersection by shifting them from the major street approaches and onto an adjacent ramp as shown in Figure 20. Like the quadrant intersection, the turning maneuvers would be completed at an intersection created between the ramp and the minor highway then proceed through the main intersection. Unlike the quadrant design, however, separate ramp roadways are used for the two major street approaches and (if acceptably low volumes are present) left turns from the minor street would be permitted on to the major roadway.

Figure 20. Jughandle Intersection Diagram



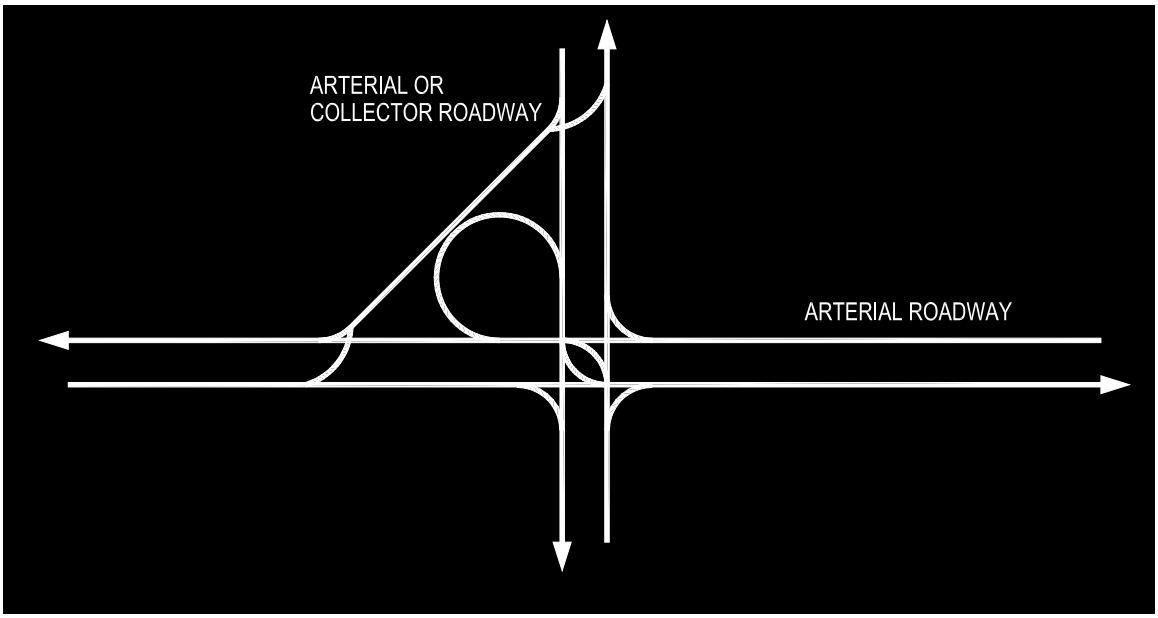
Like the other unconventional intersection designs, this configuration favors the major street through movements, thus it is best suited to high volume arterial roadways with moderate to low left turn volumes. Since it does not require median crossover maneuvers, it can also be used in narrower right-of-ways. The main disadvantages include the inconvenience to left turning traffic in the form of additional travel time, distance, and stops over a more conventional intersection design. The costs to provide right-of-way and construct the jughandle roadways can also be a significant drawback. From a pedestrian standpoint, this design would require an additional

roadway crossing as pedestrians along the major and minor roadways would also be required to cross at the ramp intersections.

In the US, jughandle intersections have been most widely used by the New Jersey Department of Transportation. These intersections have been in operation on hundreds of miles of arterial highways in New Jersey for decades. Simulation studies of the jughandle configuration showed that while its performance was approximately similar to median U-turn and conventional designs, it consistently performed below these designs in terms of overall travel time (19).

A variant of the jughandle design with some aspects of quadrant intersection is the single quadrant "left turn loop" intersection. In this design, left turning maneuvers from the major roadway are moved to a loop and ramp in one of the intersection quadrants. As shown in Figure 21, drivers from the one of the major approach directions complete left turns in advance of the main intersection. These left turns can usually be accomplished without the need for signal or sign control since there are a number of readily available gaps that result from the signal control of the main intersection. Drivers from the opposing direction complete left turns on the a loop ramp.

Figure 21. Left Turn Loop Intersection Diagram



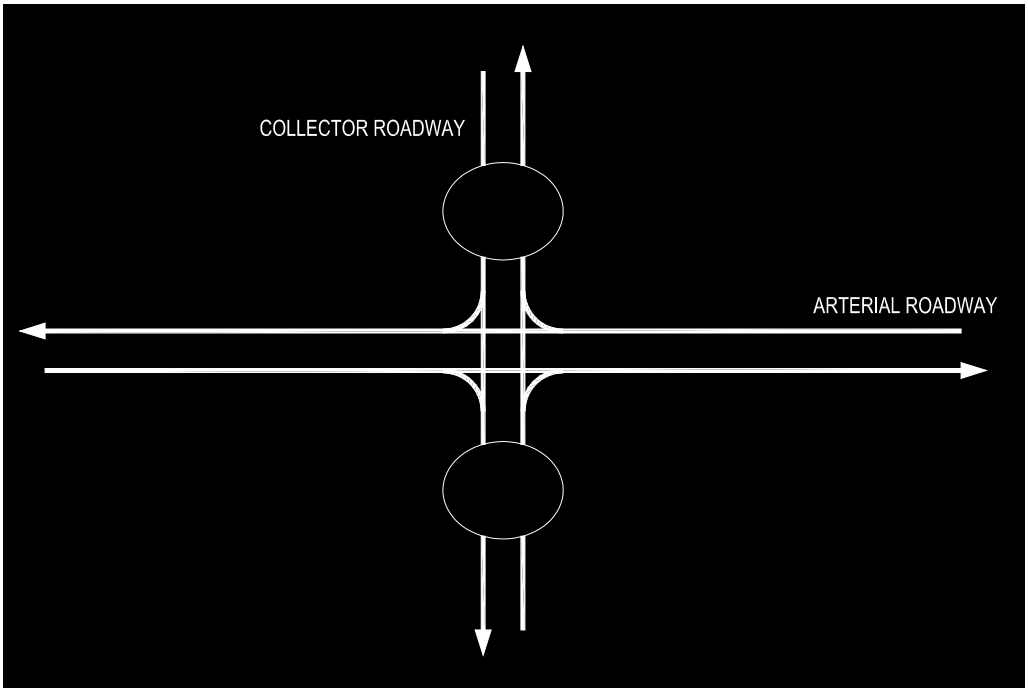
This design was used by the Michigan DOT on high volume traveled corridors at intersections with heavily traveled minor cross streets. Similar to the previous designs, the left loop configuration removes major street left turn conflicts from the main intersection and permits the intersection to operate in a two or three phase sequence. Despite the additional travel distance left turn maneuvers on the loop road can be completed at relatively high speed and are uninterrupted/opposed by other traffic streams so they can be completed relatively quickly.

Two of the main disadvantages to the left turn loop is that it requires two left turns from one of the major street approaches, while requiring left turners from the other major approach direction to cross the intersection twice. This design also renders one of the intersection quadrants un-developable.

Bowtie Intersection

Like the previous configurations, the goal of the bowtie design is also to eliminate left turns from the intersection and to simplify the phase pattern of the control signal. The primary difference between the bowtie and the other designs is that the left turning traffic from the approaching roadways uses two roundabouts located on the minor road, as diagrammed in Figure 22. Aside from the change in direction taking place on the minor (rather than the major) roadway, this configuration also eliminates the need for turning traffic to stop during the crossover maneuver. In the bowtie design, vehicles are not required to yield when entering the roundabouts (because there are only two entrances). The distance between the main intersection and the roundabouts depends on the amount of storage space required for minor street approach queuing and the size of the roundabouts would depend on the design speed and design vehicles in a particular location.

Figure 22. Bowtie Intersection Diagram



In addition to the advantage of reducing conflicts when compared to a conventional intersection, the bowtie design also reduces stops and delay for major street through traffic. This design also negates the need for a wide median and an increased wide right-of-way on the major roadway. From a pedestrian standpoint, crossings of the major roadway are made easier because of the two-phase signal operation and narrower crossing distances.

The bowtie also has several disadvantages. One of the most significant is the travel distance for left turning traffic from the major street and all traffic (through and left turning) from the minor street. Vehicles completing any of these maneuvers would be required to drive through segments of both roundabouts. Given the unfamiliarity of US drivers with roundabouts, it has been suggested that this could add to driver confusion and could lead to a disregard of the left turn prohibition at the main intersection. Another disadvantage of this design is the need for additional right-of-way on the minor street to construct the roundabouts.

The bowtie design has not been used for any at-grade intersections in the US, although the concept has been used at a freeway interchange on I-70 in Vail, Colorado and extensively at interchanges throughout Great Britain, where they are known as "teardrop" interchanges. They operate similar to a standard diamond configuration with the added benefit of eliminating the need for stop of signal controlled ramp terminals.

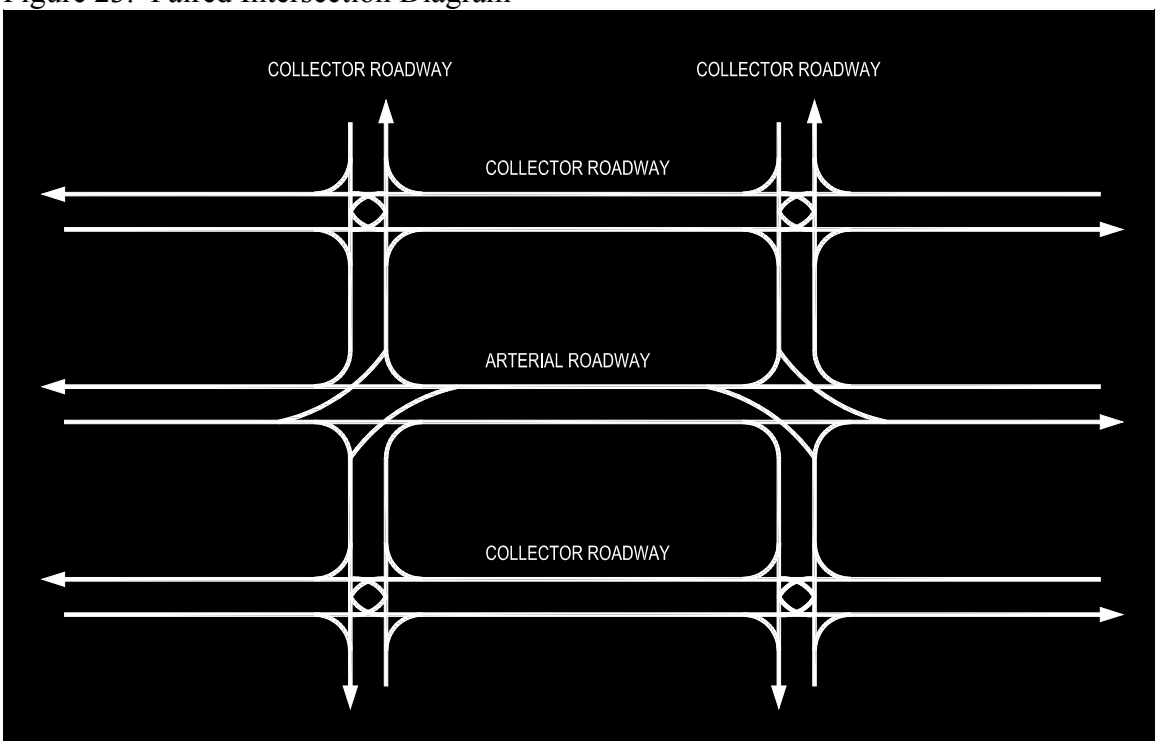
In at-grade applications, bowtie intersections are best suited to arterials where it is not possible to construct wide medians. From an operational standpoint, analyses have shown that they would be most appropriate for locations that include high volume arterial volume with low to medium left turn and low to median minor street volume. Once the left turn volumes becomes to too high, the additional delay experienced by these drivers will begin to outweigh the benefits to the arterial through traffic. High entry volumes on the minor approaches to the main intersection would also result in the need for additional storage on the minor approaches.

Paired Intersection

Paired intersections facilitate flow on an arterial roadway through the use of parallel two-way collector roads. The paired intersection concept is one of the more complex unconventional designs. The configuration involves the coupling of adjacent intersections along the major highway in which left turns from the major roadway to the minor cross street can be made using directional median crossovers at one of the intersections, then from the minor cross-street to the major roadway at the other intersection using directional crossovers as shown inFigure 23. To maintain complete circulation within the arterial corridor, the parallel collector roads must be offset several hundred feet from the major roadway to avoid conflicts between turning and queued vehicles. The offset should also be adequate to permit development of the properties adjacent to the major roadway.

The advantages of the paired intersection design are similar to that of the superstreet design, including the ability to maintain coordinated progression in both directions of the major highway since the left turns would not conflict with one another. The main disadvantages of this design are associated the ability to construct the required parallel collector roads, or where potential parallel roadway already exist, the ability to convert them to operate in conjunction with the major roadway. In the case of the former, and to a lesser extent the latter, this would involve significant capital investment. The paired intersection can also be confusing to drivers in determining which location is suitable for turning. It also requires two additional roadway crossings for pedestrians compared to one in a conventional design.

Figure 23. Paired Intersection Diagram



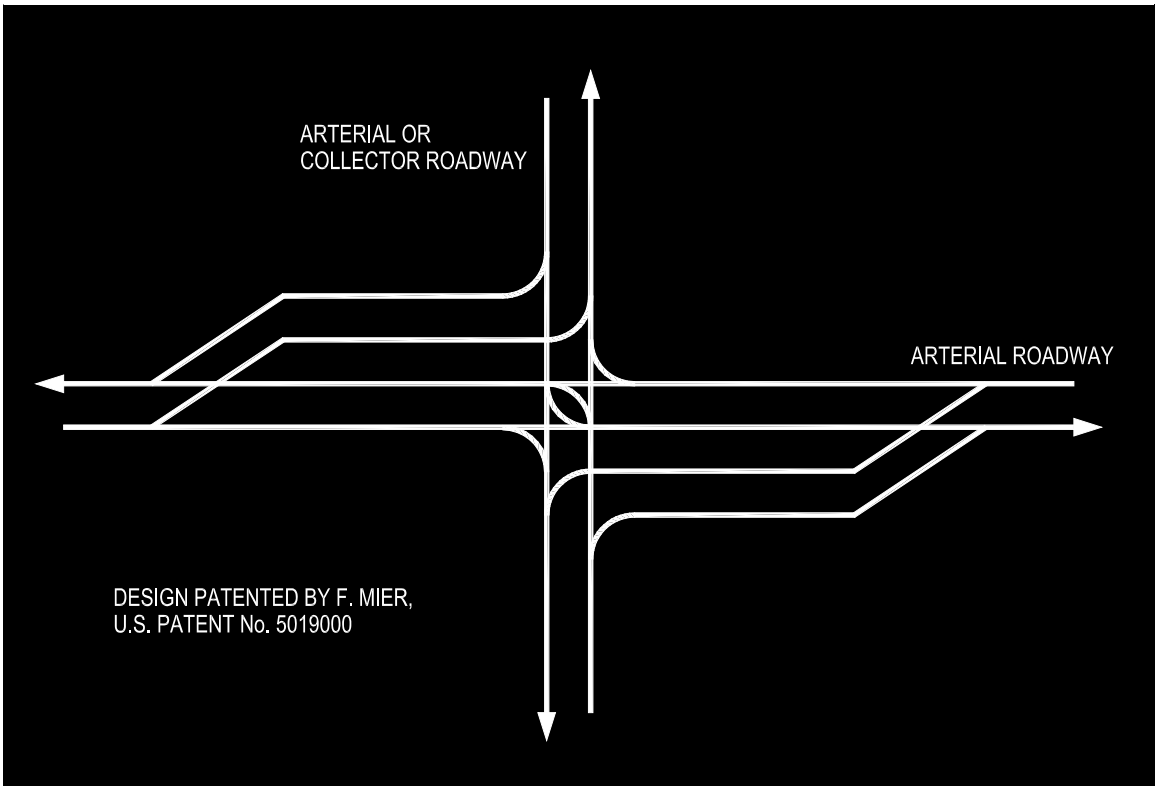
The concept of "pairing" intersections for the purpose of focusing left turn movements is fairly common, particularly in urban central business districts where left turns into and out of major traffic attractors/generators are commonly separated and channelized. However, the only real application currently in development is in Raleigh, North Carolina where it was used as an alternative to the construction of a freeway. As a result, the paired intersection design does not have a track record suitable for significant performance assessment.

Continuous Flow Intersection

The continuous flow intersection is another complex unconventional intersection design in terms of the amount and proximity of channelizing and control features. The level of innovation in this configuration has allowed led its inventor, Fransico Mier of El Cajon, California to receive a US patent for the design and agencies wishing to implement the design must obtain the rights from the inventor.

The basic concept of the continuous flow intersection is to move left turn traffic from all approaches of the main intersection across the opposing traffic lanes prior to the main intersection as illustrated in the schematic diagram of Figure 24. Left turn maneuvers are then completed simultaneously and unopposed with their accompanying and opposing through movements. The location of the left turn lanes also allows the main intersection to operate on a two phase signal. If right-of-way availability or other costs are issues, ramps in one or more of the quadrants could also be eliminated in favor of a three-phase signal.

Figure 24. Continuous Flow Intersection Diagram



Under high volume conditions, the left turn crossover movements prior to the intersection could also be signalized. Although this signal would not necessarily impact the overall operation since the crossing phase could be coordinated with the signal at the main intersection. Since this design does not require wide medians for crossovers it can be used in narrower corridors.

The continuous intersection also has some disadvantages. Since drivers need to be aware of the need to make left turns prior to the intersection, clear guidance must be given to warn them of the impending roadway and guide them into the appropriate lanes. Because of the multiple lane crossings within the intersection, pedestrian would also need to be guided and informed of the vehicle approach direction. Other disadvantages include the need for U-turn opportunities because access to and egress from intersections quadrant developments would be difficult for most approach movements.

The continuous flow intersection would be most appropriate for high volume arterials with few needs for U-turns. Another important consideration is the level of development near the intersection. Because of the locations of the left and right turn lanes, continuous flow intersections do not provide easy access to and from adjacent properties.

Since this development of the continuous flow intersection configuration has occurred relatively recently, there have not been a large number of applications of this design. Several have been recently constructed in Mexico and one at a T-intersection with ramps in a single quadrant was constructed on Long Island, New York in 1994. Although unconfirmed, the planned

construction of continuous flow intersections has been rumored in more than ten North American cities (20).

Split Intersection

The split intersection separates directional traffic flows on a major highway into two offset one-way roads as illustrated in

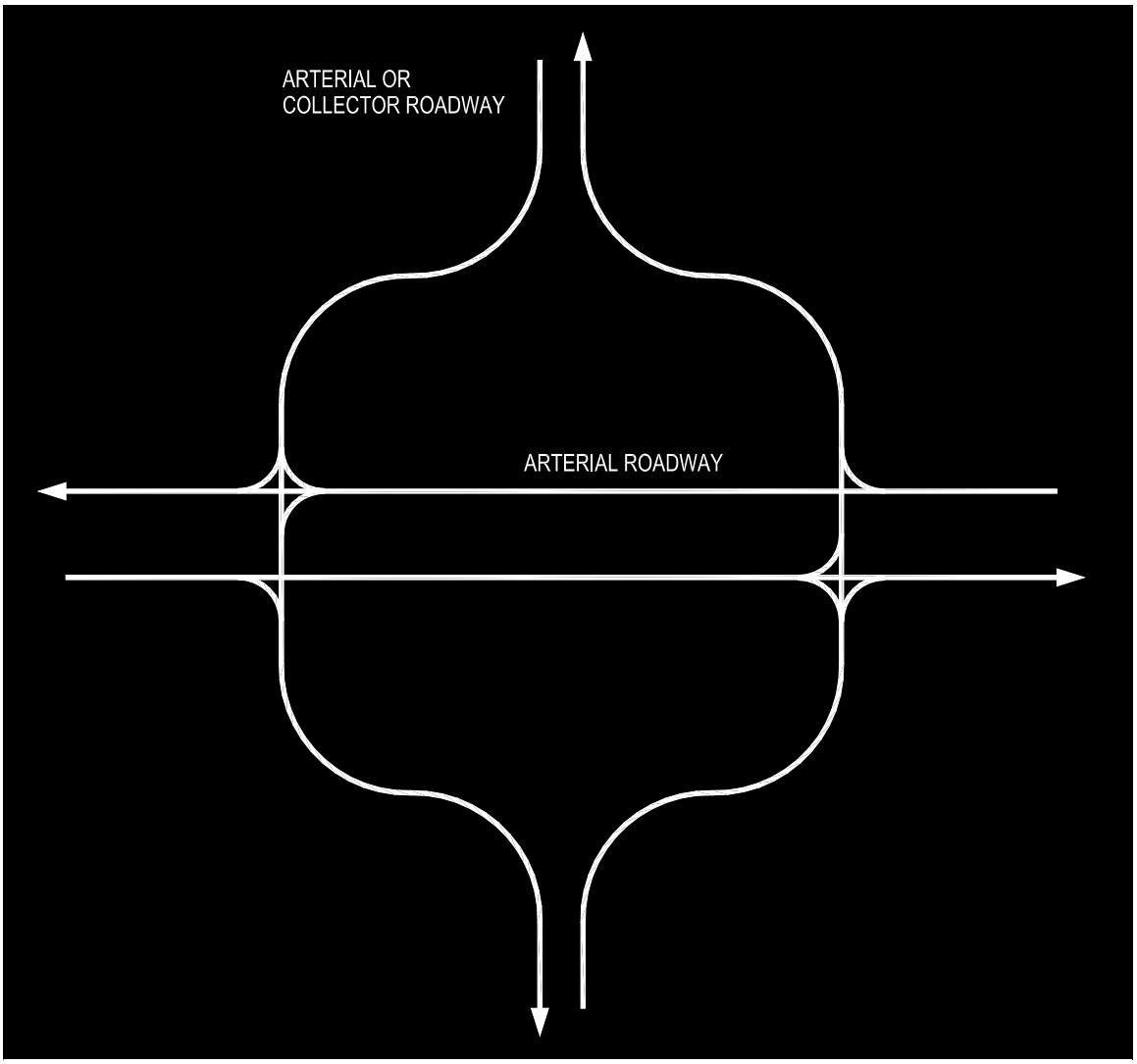
Figure 25. The resulting configuration is similar to an at-grade diamond interchange without a separate bypass for through traffic (21). This separation of flows has been shown to reduce delay and eliminate turning conflicts compared to a conventional four-legged intersection. The majority of the delay reduction results from the elimination of one of the four traffic-signal phases of the intersections. This effectively adds more green time to the cycle for left-turning vehicles and reduces lost time associated with start-up delay and all-red phases. For the most effective operation, it is suggested that the two intersection should be controlled by coordinated signals

The advantages of split intersections are an increase in capacity and a reduction in overall delay (21, 22) over a conventional four approach design. At a cycle length of 120 seconds and maximum turning volume, the capacity of a split intersection has been shown to be approximately 35 percent higher than conventional configurations. The split configuration also eliminates and separates some conflict points relative to a conventional intersection. This, combined with the reduction in the number of signal phases, would be expected to demonstrate a net positive effect on safety.

The three most significant disadvantages of split intersections the high initial costs associated with its construction, right-of-way acquisition, the likelihood of stopping at two intersections instead of one if the two signals were not well-coordinated, and possible wrong-way movements by unfamiliar drivers (23, 24). Although the effect of split intersections on pedestrians has not been well documented, it adds in addition intersection to cross.

Split intersection designs are not common in the US, although several conventional intersections in Israel have been converted to a split design since 1975 with overall positive effects. This design is considered to be most appropriate for use on isolated and congested suburban intersections with high left-turning volumes that are expected to experience traffic growth. This configuration is also regarded to be useful as a transition step to a grade-separated diamond interchange with a bridge on the through roadway.

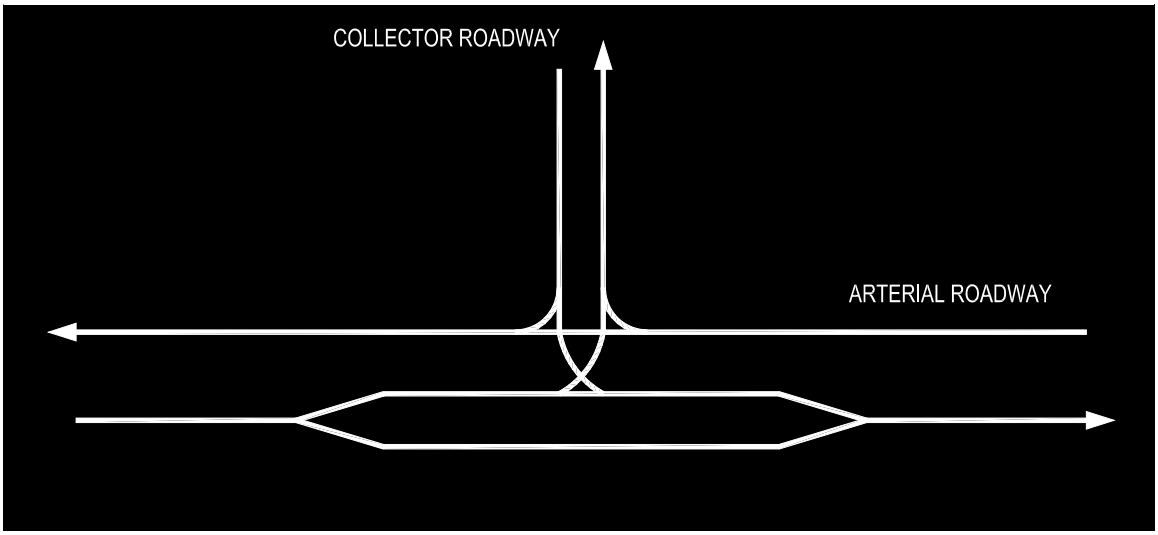
Figure 25. Split Intersection Diagram



Continuous Green T-Intersection

The continuous green T intersection was developed specifically for three-approach "T" intersections in which a minor collector roadway ends at major roadway. In this configuration, illustrated in Figure 26, through traffic from one (or more) of the major street approach lanes flows continuously through the intersection while the median lane of this approach is used for left turning traffic on to the minor street. Left turns from the minor road would be received by the departure side of the major left turn lane. For the most effective operation it is recommended that the left turn lane(s) be separated from the through lane(s) by an island or other channelizing feature to discourage potentially hazardous last-minute weaving maneuvers into and out of the turn lane.

Figure 26. Continuous Green T-Intersection



In this configuration, movements to and from the minor street and the interrupted minor street approach are controlled by a two or three-phase signal. A three-phase signal would be the most appropriate for heavier volumes, since the major street left turns would be in conflict with the opposing major street through movements.

The obvious advantage to this design is the elimination of stops and reduced delay for through traffic in one direction of the major highway. The biggest disadvantages associated with continuous green T-intersections are its impact on pedestrians since the design does not permit any protected crossings. Although it is not an inexpensive solution, the pedestrian crossing issue can be overcome with the installation of pedestrian bridges or tunnels. Other disadvantages compared to a traditional T-intersection include a lack of access to and from the properties adjacent to the continuous flow lane(s) and the increased potential for lane changing conflicts prior to the initiation of the median through lane.

Continuous green T-intersections are best suited for locations with high major street through volumes and low to moderate left turn volumes from the minor street and where no pedestrian crossings are expected. They have been used by the Florida Department of Transportation with overall positive results. Other highway agencies have also used a variation of this design in which left turns from the minor roadway are channelized into a merging lane within the median, this variation also requires a slightly wider.

Roundabouts

Modern roundabouts are circular intersections that incorporate channelized approaches, yield control, and design geometry that facilitate moderate operating speeds, typically less than 30 mph (10). They differ from other types of circular intersections (rotaries, traffic circles, etc.) in terms of their operational traffic patterns. Under the right conditions, a properly designed roundabout is thought to offer safety and efficiency benefits greater than conventional intersections (3).

Roundabout designs offer significant improvement over earlier traffic circle designs because they incorporate the following features (3):

- Approach yield control, thus traffic in the circle always maintains the right-of-way;
- Low design speeds for circulating traffic;
- All traffic is forced to divert from a straight-line path through the intersection;
- No parking is allowed within or near the circle; and
- No pedestrian traffic is permitted in the circle.

The typical capacity of a single-lane roundabout is about 30,000 vehicles per day. Recent research studies have provided evidence that single lane roundabouts have shown both safety and capacity improvements over the conventional intersections they replaced. A detailed discussion on all of the design and operational requirements and characteristics of roundabouts is included in Chapter 3 of this book and in the Federal Highway Administration's publication, *Roundabouts: An Informational Guide* (10).

ACCESS CONTROL AND MANAGEMENT

One of the key ingredients for safe and efficient intersection operation is the minimization of conflicting movements within its functional area. The preceding sections of this chapter have discussed ways in which this can be accomplished, including the use of various geometric and traffic control measures. Another effective means to minimize conflicting movements around intersections is to control access to and from adjacent land developments in the vicinity of the intersection. The "systematic control of the location, spacing, design, and operation of driveways, median openings, interchanges, and street connections to a roadway" is known as *access management* (13).

The purpose of access management is to "provide vehicular access to land development in a manner that preserves the safety and efficiency of the transportation system" (13). It is commonly accomplished through the use of median treatments, auxiliary lanes, and the appropriate spacing of traffic signals. Other methods include the use of common driveways in which multiple developments share a single access point to a roadway and frontage roads that separate local and pass-through traffic into separate roadways. Access management techniques can be particularly beneficial at intersections because they can be used to control the location of merging, diverging, and crossing traffic streams. A key principle of intersection access management is the avoidance of intersections between roadways having significantly different functional classifications; for example, a local residential street and a busy arterial. One of the ways that these can be avoided is by using coordinated systems of collector-distributor roadways to transition traffic up and down the functional hierarchy. The use of these techniques have been shown to decrease traffic crashes by as much as 50 percent, increase capacity by as much as 45 percent, and reduce time delay by as much a 60 percent.

A detailed discussion of access management planning, design, and administrative issues can be found in the Transportation Research Board's *Access Management Manual* (13). The following

sections highlight several key access management principles and techniques as they pertain specifically to intersections.

Intersection Corner Clearance

The access management term used to describe the separation distance of access points from an intersection is called *corner clearance*. Inadequate corner clearance at intersections, particularly those with high volumes, can result in diminished capacity and an increased numbers of conflicts. Poor corner clearance conditions occurs at intersections because they concentrate traffic volume from two or more roadways. As a result, they are prized locations for commercial developments, particularly those that rely on short "in-and-out" transactions like gas stations, fast food restaurants, convenience stores, and banks. Because of their desire to maximize accessibility and the use of small property sizes, these establishments have no other choice than to locate one or more driveways within the intersection functional area. This adds to the number of traffic conflicts at intersections. For these reason AASHTO advises against the use of driveways within the functional intersection area (1).

To avoid these situations, TRB recommends the establishment of land use policies that require corner clearance distances consistent with those required along the same route and the use of engineering studies to evaluate the impact of the traffic movements in the vicinity of a proposed driveway (13). When these measures do not work, developers may be asked to construct access points at locations as far a possible from the intersection, use directional right-in/right-out driveway designs, and use shared-access driveways with adjacent properties.

Access Location and Design

Since the key principle of effective access management is to keep access points outside of the functional intersection area, it is necessary to determine the limits of this area. In general, the upstream functional intersection area is made up of three constituent parts, including:

- the distance traveled during the perception-reaction process, d_1;
- the distance required to decelerate while a driver maneuvers to a stop, d_2; and
- the distance required for queue storage, d_3.

The perception-reaction distance (d_1) is assumed to be the distance covered during a 1.5 second interval (2.5 seconds in rural conditions) while moving at the approaching road's design speed. The deceleration/maneuver distance and queue storage length can vary significantly between urban, suburban, and rural locations. In rural locations, where speeds are typically high and volumes typically low, most of this length in made of d_2. In urban and suburban areas, where the opposite is typically true of volume and speed, the majority of the functional distance is made up of d_3. Representative functional distances for various combinations of area type and speed are shown in

Table 2.

A determination of the downstream functional area can be made using intersection sight distance requirements. This allows a driver to pass through an intersection before considering potential conflicts at a downstream intersection.

Table 2. Functional Intersection Distances

TABLE 8-4 Representative Examples of Upstream Functional Intersection Distances

Location	Speed (mph)	Distance Traveled During Perception–Reaction Time, d_1 (ft)	Maneuver Distance, d_2 (ft)	Perception–Reaction Plus Maneuver Distances, $d_1 + d_2$ (ft)	Queue Storage Length, d_3 [a] (ft)	Upstream Functional Distance $d_1+d_2+d_3$ (ft)
Rural	50	185	425	610	50[b]	660
	60	220	605	825	50	875
	70	255	820	1045	50	1095
Suburban	30	110	160	270	375[c]	645
	40	145	275	420	250[d]	670
	50	185	425	610	125[e]	735
Urban	20	45	70	115	500[f,g]	615
	30	65	160	225	500[f,g]	725

[a] Queue storage needs to be determined for each approach to each intersection using methods such as those discussed in Chapter 10.

[b] Minimum storage of two automobiles or one truck.

[c] Example of storage for 15 automobiles.

[d] Example of storage for 10 automobiles.

[e] Example of storage for 5 automobiles.

[f] Example of storage for 20 automobiles.

[g] Dual left-turn lanes can reduce the queue storage length.

(source: 13)

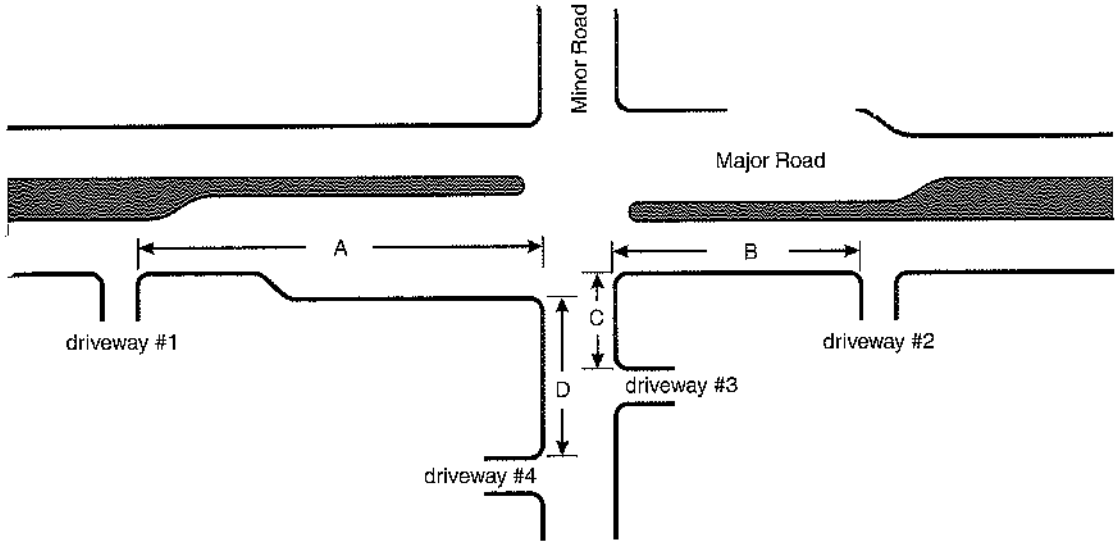
To facilitate the task of determining where access driveways should be located near intersections, a seven-step process has been developed (13) to determine the location and size of "windows of access," including the following:

1. Locate all nearby intersections.
2. Arrange the intersections in order of functional importance.
3. Define the upstream functional area (i.e., $d_1 + d_2 + d_3$) of each intersection.
4. Define the downstream functional area of each intersection.
5. Identify the window in which direct access can best be provided. Larger sites allow greater flexibility, in terms of the building location, site circulation plan, and driveway design.
6. Determine the level of flexibility in the site access and circulation plans to accommodate changing traffic conditions.
7. If the access widow is small or non-existent, determine:
   - The level of interference will result from allow the direct site access from the abutting street.
   - The expected safety and operational problems

- Whether or not the level of traffic necessary for the development to be successful can be accommodated. And if it can not, determine how much traffic can be accommodated and at what times of the day.

Figure 27 illustrates the location the upstream and downstream clearances at a highway-to-highway intersection. Although, not included here, readers are encouraged to review the *Access Management Manual* (13) for recommended distances.

Figure 27. Intersection Corner Clearance Dimensions



Clearance Type	Sample Clearance Criteria
A – Upstream on the major roadway	Separation would equal or exceed the functional distance of the intersection $d_1 + d_2 + d_3$ in Figures 8-13 and 10-5. Sum the distances from Table 8-3 plus Table 10-2 plus queue storage.
B – Downstream on the major roadway	Separation would equal or exceed: 1) the upstream functional dimensions of the driveway (sum of the distances from Tables 8-3 and 10-2), or 2) the influence distance (Table 9-8). Minimum separation is no less than the stopping distance (Table 9-5).
C – Approach side on the minor roadway	Queuing (Tables 9-12 and 9-13).
D – Departure side on the minor roadway	Separation of the intersection from entering and exiting maneuvers at the driveway (Figure 9-11)

1) Maneuver distances and methods for estimating queue storage are discussed in greater detail in the section on Auxiliary Lanes in Chapter 10, "Access Design."
2) The distance traveled during the perception–reaction time (Table 8-3) and maneuver distance (Table 10-2) for left turns and right turns will be the same. However, queue storage length may be quite different, with the left-turn queue storage being larger than that for right turns. Minimum corner clearance will be determined by the one (left turns or right turns) that has the largest maneuver plus queue storage distance.

(source: 13)

INTERSECTION TRAFFIC CALMING

In some situations engineers may need to use design techniques to discourage high traffic volumes and high operating speeds. These efforts, commonly known as *traffic calming*, involve "the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behavior and improve conditions for non-motorized street users" (14). Most are popular in low speed and pedestrian-oriented locations like residential neighborhoods and core urban business districts. Traffic claming uses geometric techniques like changes in street alignment and the installation of physical barriers to enhance safety conditions and generally increase the livability of communities in which it is used. The objectives of traffic calming have ranged from the obvious traffic-related issues of lowering volumes and speeds to the mitigation of environmental-related problems such as reducing noise, vibration and air pollution. Detailed information on the principles of traffic calming as well as descriptions of successful practices can be found in the 1999 joint ITE-FHWA Publication, *Traffic Calming: State of the Practice* (14). Additional information, more specifically related to residential street design, can also be found in *Traditional Neighborhood Development – Street Design Guidelines* (15).

Since the intent of traffic calming is to discourage the direct and speedy movement of traffic, its use is obviously not intended for high speed-high mobility routes, although they may be used adjacent to such facilities to discourage cut-through maneuvers. Traffic calming techniques are most useful when they are applied at the system-level, throughout an entire neighborhood or even citywide. Calming can also be on a localized bases, within specific corridors or at a specific intersections.

Traffic calming techniques are generally categorized into those that are intended to reduce operatings speeds and those meant to reduce through volumes. Some common volume control measures that have been applied to intersections include: (Note to reviewers: Should I include figures from the ITE-FHWA Traffic Calming Book, or will they add too many more figures?)

- *Full closures* - These include the use of cul-de-sacs and dead ends on minor approaches to an intersection and at mid-block locations on local streets. Although these closures typically permit the passage of pedestrian and pedestrians traffic, they also have the limitation of prohibiting through traffic movements and accessibility for service and emergency response vehicles.
- *Half closures* – These measures include partial street closures and one-way closures that allow free pedestrian movement, but limited (emergency-only) inbound vehicular access.
- *Semi-Diverters* – Semi-diversion measures are similar to half closures, although the difference is that they are used in pairs to prohibit through movements across intersections. Basically, semi-diverters use physical barriers on the opposing minor approaches of an intersection only permit outbound traffic.
- *Diagonal Diverters* – These designs take the semi-diverter concept a step further by prohibiting all through movements at intersections. A diagonal diverter forces all traffic approaching the intersection to turn right or left; creating mirrored "L" movements. The physical separation of opposing sides of the intersection restricts the direct movement of traffic by requiring circuitous travel paths to reach certain destinations.
- *Median Barriers* – Median barriers are a restrictive form of channelization. In an intersection traffic calming application, barriers are designed to span the length of an intersection (or though several intersections) to prohibit all through movements across the

minor roadway and prohibit all left turns into or out of the minor streets. Medians barriers also have the added benefit of providing refuge areas for pedestrians crossing the major roadway.

- *Forced Turn Islands* – These are another channelization technique that encourage/prohibit certain turning movements, most commonly inbound and outbound left turns.
- *Other Volume Control Measures* – The last category of measures includes a variety of treatments including, star-shaped diverters in intersections to force all right turn movements and one way-two way islands that restrict and prohibit various through and turning movements.

REFERENCES

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

2. *Highway Capacity Manual*, Transportation Research Board, Washington D.C., 2000.

3. Hummer, J. E., "Intersection and Interchange Design," Chapter 14, *Handbook of Transportation Engineering*, 2004, pp. 14.1 – 14.27.

4. *Railroad-Highway Grade Crossing Handbook – Second Edition*, Federal Highway Administration, Report No. FHWA-TS-86-215, United States Department of Transportation, Washington D.C., 1986, 273 pp.

5. *Informational Guide to Highway Lighting*, American Association of State Highway and Transportation Officials, Washington D.C., 1984.

6. *Pedestrian Facilities Users Guide — Providing Safety and Mobility*, Federal Highway Administration Publication No. FHWA-RD-01-102, United States Department of Transportation, Washington D.C., 2002, 162 pp.

7. *Guide for the Development of Bicycle Facilities*, American Association of State Highway and Transportation Officials, Washington D.C., 1999.

8. *National Agenda for Intersection Safety*, Federal Highway Administration, United States Department of Transportation, Washington D.C., 2000.

9. Wilson, E.M., "Roadway Safety Tools for Local Agencies," National Cooperative Highway Research Program, Synthesis of Highway Practice 321, Transportation Research Board, Washington D.C., 2003.

10. *Roundabouts: An Informational Guide*, Federal Highway Administration, Publication No. FHWA-RD-00-067, United States Department of Transportation, Washington D.C., 2000.

11. *Manual on Uniform Traffic Control Devices*, Federal Highway Administration, United States Department of Transportation, Washington D.C., 2003.

12. *Transportation and Land Development*, Institute of Transportation Engineers, Washington D.C., 2002.

13. *Access Management Manual,* Transportation Research Board, Washington D.C., 2003.

14. *Traffic Calming*: *State of the Practice*, Institute of Transportation Engineers, Washington D.C., 1999.

15. *Traditional Neighborhood Development – Street Design Guidelines*, Institute of Transportation Engineers, Washington D.C., 1999.

16. *Traffic Engineering Handbook – Fifth Edition*, Institute of Transportation Engineers, Washington D.C., 1999.

17. Roess, R. P., E. S. Prassas, and W.R. McShane, "Traffic Engineering, Third Edition," Prentice Hall Publishing, New York, NY, 2004

18. "Recent Geometric Design Research for Improved Safety and Operations," National Cooperative Highway Research Project Synthesis of Highway Practice No. 299, Transportation Research Board,Washington D.C., 2001.

19. Reid, J.D., "Using Quadrant Roadways to Improve Arterial Intersection Operations," *ITE Journal*, Vol. 70, Issue 6, June, 2000, pp. 34-45.

20. Bragdon C.R., "Intermodal Transportation as a Means to Enhance Sustainable Cities in the 21st Century," [Online]. Available: (http://www.md.mos.ru/conf/safety/plen/klif.htm) [2004, February 2].

21. Bared, J.G. and E.I. Kaisar, "Advantages of the Split Intersection," *Public Roads*, Vol. 63, No. 6 May/June 2000. [Online].
Available: (http:// www.tfhrc.gov/pubrds/mayjun00/advantages.htm) [2003, December 29].

22. Polus, A. and R. Cohen, "Operational Impact of Split Intersections," Transportation Research Record, No. 1579, Washington, D.C., 1997.

23. Hakkert, S. and Y. Mahalel, "Estimating the Number of Accidents at Intersections: Single-Level Interchange or Splitting a Signalized Intersection," *Traffic Engineering and Control*, Aug./Sept. 1978.

24. Hakkert, S. and Y. BenYakov, "Single-Level Interchange or Splitting a Signalized Intersection," *Traffic Engineering and Control*, Aug./Sept. 1978.

25. *The Traffic Safety Toolbox: A Primer on Traffic Safety*, Institute of Transportation Engineers, Washington D.C., 1999.

BIBLIOGRPAHY

"Access Management - TRB Committee ADA70," Transportation Research Board, Washington D.C., 2003. [Online]. Available: http://www.accessmanagement.gov [2004, February 2].

"Image Library," Pedestrian and Bicycle Information Center, Chapel Hill, NC, 2004. [Online]. Available: http://www.pedbikeimages.org/ [2004, February 2].

"Intersection Safety," U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. 2004. [Online]. Available: http://www.tfhrc.gov/safety/intersect.htm [2004, February 2].

"Participant Notebook Index," U.S. Department of Transportation, Federal Highway Administration, Intersection Safety Workshop, Milwaukee, WS, November 2001. [Online]. Available: http://safety.fhwa.dot.gov/fourthlevel/intersec_workshop.htm [2004, February 2].

"Volume 5: A Guide for Addressing Unsignalized Intersection Collisions," National Cooperative Highway Research Program, Report 500, Transportation Research Board, Washington D.C., 2003. [Online]. Available: http://gulliver.trb.org/publications/nchrp/nchrp_rpt_500v5.pdf [2004, February 2].

Fitzpatrick, K. and Wooldridge, M., "Recent Geometric Design Research for Improved Safety Tools and Operations," National Cooperative Highway Research Program, Synthesis of Highway Practice 299, Transportation Research Board, Washington D.C., 2001.

Garber and Hoel, "Traffic and Highway Engineering, Fourth Edition," Brooks and Cole Publishing, Pacific Grove, CA, 2001

Hummer, J.E., "Moving More Cars Through the Same Space Using Unconventional Intersection Designs," Presentation to the North Carolina Department of Transportation Traffic Engineering Conference, Raleigh, NC, May 2003. [Online]. Available: http://www.doh.dot.state.nc.us/preconstruct/traffic/conference/reports/uid1.pdf [2004, February 2].

Safety Effectiveness of Highway Design Features - Volume VI, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. 1992.

Stidger, R.W., "10 Ways to Make Busy Commercial Streets Safer," Better Roads," Vol. 72, No. 9, September, 2002, pp. 18-20.