Driveways, Parking, Bicycles, and Pedestrians: Balancing Safety and Efficiency

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ABSTRACT

Many roadways located in urban areas, especially dense commercial areas, are subjected to on-street and adjacent off-street parking demands; however, local access via driveways is an essential component of these complex urban corridors. Vehicles entering and exiting these driveways and the interaction of these vehicles with parked cars, other moving motorized vehicles, bicycles, and pedestrians present challenges for a safe and efficient roadway corridor.

The location and design of these driveways, together with parking and bicycle facilities, generate sight distance challenges that impact both pedestrian and bicyclists. The application of various access management strategies at driveways has direct implications for pedestrians and bicyclists. This paper investigates the type and nature of impacts, including conflicts, sight distance, operations, and safety at driveway locations as they impact pedestrians, bicyclists and drivers. Conflicts, safety and relative speed between vehicles and pedestrians are used to show the impact on pedestrians of various access management techniques at driveways. The paper also analyses appropriate design geometrics to provide adequate sight distance for safety at driveways with and without bicycle lanes.

Parked vehicles often obstruct the driver's view of legally approaching motor vehicles and bicycles. In many locations, vehicles exiting driveways must edge out into the active travelway before the driver has an unobstructed view. Examples of good driveway placement and design are used to illustrate how these potentially hazardous ingress-egress locations can be safely addressed. Examples of undesirable situations are also critiqued to explain the nature of the operational and safety problems.

Scenario situations of driveways with various geometric configurations, operational conditions, and on-street parking layouts are analyzed and evaluated. These demonstrate the relationship between sight distance, speed, on-street parking, and the lateral placement of sidewalks and landscape buffers.

The impacts of access management techniques affecting pedestrians at driveways are generally determined to be beneficial. For most techniques, there are fewer conflict points between motor vehicles and pedestrians at driveway locations, and these conflict points are more widely separated than at locations where access management techniques have not been applied. Also, the number of conflicts and relative speeds between motor vehicles and pedestrians are reduced by most access management techniques.

The driveway locations and design analysis demonstrates the value of bicycle lanes in providing enhanced sight distance. Current practices permit the longitudinal placement of on-street parking too close to driveways. Roads with bike lanes should exclude on-street parking when speeds exceed 30 mph so as to provide adequate sight distance without creating sporadic on-street parking spacing. Roads that do not have bike lanes present should exclude on-street parking when speeds exceed 25 mph.

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Background

A key objective of access management is to provide safe access to local activities while preserving the utility of the major street or highway. In general, access management concepts and techniques complement and enhance pedestrian and bicycle operations. However, a comprehensive view of access management strategies and the concomitant impacts on pedestrian and bicycle operations would assist in the appropriate application of access management, particularly at locations with on-street parking.

Overview of Pedestrian Issues

In conflicts between motor vehicles and pedestrians the absence of the protection of a vehicle body to protect the pedestrian is a critical issue making the pedestrian a vulnerable user of the transportation network. In 2006, 4,784 pedestrians were killed in motor vehicle crashes in the United States. The majority of these fatalities occurred in urban areas (74percent) and at non-intersection locations (NHTSA, 2006). Isolating the characteristics of pedestrian crashes at driveways is particularly difficult due to crash report coding limitations. However, a review of 5,000 pedestrian crashes in one FHWA study (Hunter et al., 1996) determined that 8 percent of pedestrian crashes occurred at driveways while children younger than the age of 10 were overrepresented in crashes at driveways and alleys.

Pedestrian Objectives

The primary goal of pedestrian facility design is to provide a route that is continuous, direct, convenient and safe. But, it must be remembered that pedestrians are quite varied in characteristics, values, abilities and disabilities. Table 1 depicts important human factors that should be considered for pedestrians.

Walking or crossing speed is important when pedestrians cross the active lanes of a highway or driveway. For those pedestrians with a slower walking speed, the potential time of conflict with vehicles is increased.

The agility of a pedestrian in avoiding potential crashes with vehicles and bicycles varies dramatically. A mature person may simply step up onto a curbed island to avoid vehicles, where the unsighted and those in wheelchairs have only limited means of escape when attempting to avoid crashes. The perception-reaction time determines how long it would take pedestrians of various types to react to a potential hazard. The height of pedestrians is critical for sighting by drivers. This is especially important for turning maneuvers at intersections and into driveways. Cognitive ability refers to the mental state of pedestrians when a hazard is presented. Fragility reflects the relative potential for serious injury or death. The combined impacts of all these factors reflect the vulnerability of various pedestrians. Clearly, the interaction between pedestrians and vehicles where access management techniques and strategies are employed could lead to serious consequences if not properly designed.

Table 1. Pedestrian Human Factors

	Children	Middle Age	Senior	Unsighted	Wheelchair	Hearing Impaired
Walking Speed*,[1,2,3] (fps)	3-4	4	2.5 - 3.3	2	2 – 3.5	4
PIEV Reaction time[2,3,4] (sec.)	3	2.5	3	4	3.5 – 5.1	2.5
Crash Avoidance Agility**	Good	Excellent	Fair	Poor	Poor	Good
Height (ft)	3-4	4-7	4-6	4-7	4-5	4-7
Cognitive Ability**, [4]	Lack of knowledge	Average	Tends towards confusion	Alert	Alert	Alert
Fragility**, [4]	Very fragile	Fragile	Very fragile	Fragile	Fragile	Fragile

* Walking speed (mean) for pedestrian using "walker," 2.07 fps
** Estimated
[1] Source: Perry, 1992
[2] Source: Schoen & Norensell, 2006
[3] Source: Suerrier & Jolibois, 1998
[4] Source: Staplin et al., 2001

The variety of human characteristics for pedestrians and the range of these characteristics create the potential for different consequences resulting for different pedestrians under similar circumstances. Unsighted pedestrians have different needs than those in wheelchairs. The different human factors and their ranges must be kept in perspective. We know, for example, that pedestrians have serious injuries and fatalities in crashes that increase non-linearly with an increasing speed of impact with vehicles as depicted in Table 2.

Table 2. Percent of Pedestrian Fatalities in Crashes

Speed	20 mph	30 mph	40 mph
Percent Injury	15 %	45 %	85 %
Relative Energy	1.0	2.25	4.0

Source: UK DOT, 1987

One key critical human factor is the fragility of a person. This issue is further complicated by the fact that the pedestrian will be unprotected in collisions with automobiles.

Analysis of Pedestrian Issues at Driveways

A number of different measures may be used to analyze the impact of various access management strategies on pedestrians. Table 3 shows these potential analytical measures.

Table 3. Analytical Measures

Conflicts	Orientation – front, side, rear Number - count Severity – level of protection
Relative Speed	Vehicle speed – pedestrian speed
Visibility	How visible or conspicuous is pedestrian to vehicle driver

Conflicts are a traditional method to determine the safety and effectiveness of traffic operations. The conflicts typically vary in severity or relative importance. The conflicts of greatest interest are those between pedestrians and vehicles although the conflicts among vehicles create added workload for the pedestrian to see, analyze, comprehend, and determine their impact. The major types of applicable conflicts are frontal, side and rear conflicts. The location and number of each reflects the relative impact of the access management strategy on pedestrians. These conflicts are mitigated by the protection provided, so a conflict that is fully protected by a roadside barrier is of no consequence.

Relative speed is another important analytical measure. This measure contributes both to accident potential and accident severity. The faster the vehicle, the less chance there is to avoid a vehicle. This higher speed results in a more severe impact when the collision does occur.

The level of visibility is very important. It depends on where the pedestrian stands in the visual sight field and ambient lighting. The height of the pedestrian also plays a role in the sighting of the pedestrian.

Access Management Technique Scenarios

The effectiveness of a variety of access management techniques are summarized in Table 4 where the way in which each technique contributes to safety and improvement of traffic operations is depicted. This table indicates what the impacts of various access management techniques are on pedestrians.

In the table, the numerous solid dots reflect the beneficial consequences that access management techniques have on pedestrians. The addition of left-turn lanes, right-turn lanes, and isolated left-turn bays increase conflict points and conflicts, but they also control the conflicts with the separate signal phases to the net benefit of pedestrians.

Table 4. Access Management Techniques by Category of Effectiveness

Access Management Techniques	Reduce Number of Conflict Points between Veh/Ped	Separate Pedestrians from Veh Conflict Areas	Reduce Conflicts between Veh & Peds	Reduce Speed Differential between Veh & Peds
Access Spacing and Design				
Unsignalized access connection spacing	●		●	●
Corner clearance	●	●	●	○
Driveway channelizing islands		●	●	○
Right-in/right-out only	●	●	●	●
Indirect access	●	●	●	●
Indirect left-turn (jughandle)	+	+	+	+
U-turn in lieu of direct left-turn	○	○	○	●
Driveway Design		○	●	●
Auxiliary Lanes				
Left-turn deceleration lane	+	+	●	●
Right-turn deceleration lane	+	+	●	●
Isolated left-turn bay	+	+	●	●
Continuous two-way left-turn lane	+	+	+	+
Continuous right-turn lane	○	○	○	●
Acceleration lanes				
Alternative Access and Administrative Techniques				
Acquisition of access rights	●	●	●	○
Internal access to outparcels and internal circulation	●	●	●	
Frontage road	+	○	●	●
Service road (other than frontage road)	+	○	●	●
Vehicle use limitations/traffic generation budget	●	○	●	

KEY: ● Major effect (reduction or separation)
○ Secondary effect (reduction or separation)
+ Increase in effect

Table format based on: Stover, V. G., *Access Management Techniques: A Tool Box for Practitioners*. Teach America, Quincy, Florida.

Access management techniques that may directly influence pedestrian operations and safety are summarized in the following paragraphs.

Reduce Number of Driveways

Contrary to first thought, reducing the number of driveways does not necessarily reduce the potential number of conflicts between motor vehicles and pedestrians; however, closely spaced driveways present conflicts that the drivers are less likely to be able to respond to. The number of driveway operations for the block face is relatively unchanged. For example, cutting the number of driveways by half doubles the number of driveway operations on the remaining driveways. Thus, the conflict locations are reduced by half, but the total number of actual conflicts is unchanged. Higher volumes of traffic at the driveways compound the conflicts with pedestrians. Where a reduction in driveways reduces the distance and duration over which pedestrians are exposed to traffic. The relative speed at these driveways remains unaffected.

Compounding the number and location of driveways introduces conflicts resulting from mainline and crossing driveway movements where driveways are spaced very near each other. As shown in Figure 1, driveways in close proximity create a more severe condition because the drivers of the crossing vehicles must be aware of the vehicular conflicts as well as the conflict with pedestrians. Where a number of very tightly spaced driveways are eliminated, the conflicts are reduced because the operations of nearby driveways do not compound the conflicting effects at the subject driveway.

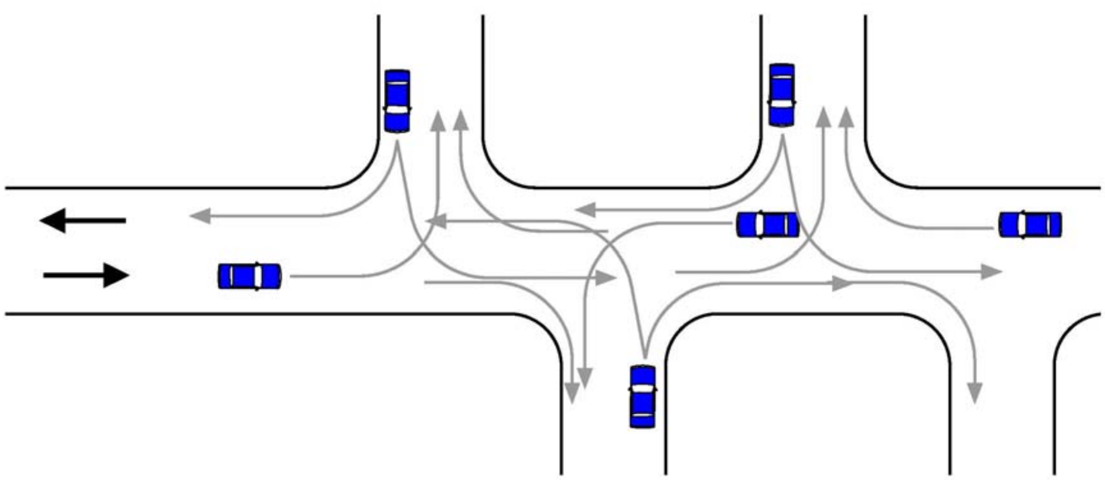

Figure 1. Crossing Conflicts Compounded by Nearby Driveways

Driveway Geometrics

1. Driveway Radius and Width

A study conducted at Oregon State University showed that, in general, entering driveway speeds are not significantly different with pedestrians present or not present (Hodgson, Layton & Hunter-Zaworski, 1998). Drivers do not slow down to reduce the hazard to pedestrians at driveways. In fact, at some locations, drivers were observed to increase speed significantly to avoid a pedestrian crossing.

Research has shown that driveways with curb return radii from 0 to 30 feet, and entry widths from 0 to 15 feet have average entering speeds from 7 to 13 mph. At times the curb radii is flattened to serve large trucks more effectively or to increase entering speeds, but for curve radii flatter than 35 feet, entering speeds remain low. A 50 feet radius curve may be used to enhance large semi-truck operations, but increases expected operating speeds very little. As shown below, a speed increase to 17 mph may result, based on the equation for safe speed on curves.

$$V = \sqrt{15R_{ft}(e + f)} \qquad (1)$$

$$V = \sqrt{15(50)(0 + .4)} = 17\,\text{mph}$$

Where:
- V = speed (mph)
- R = radius (ft)
- e = super elevation
- f = typical side friction

Consequently, a pedestrian with a walking speed of 3mph waiting to cross a typical driveway will have a maximum average speed differential of 13 mph -3 mph ≅ 10 mph, since the entering vehicle speed is 9 to 13 mph on average for typical driveway geometrics. The relative speed only increases to a 14 mph speed differential with a 50 ft radius curb return.

A greater problem is the longer crossing distance that results for pedestrians with a large flat radius, where the width at the curb on the street is 2R+W, or twice the curb return radius plus the throat width.

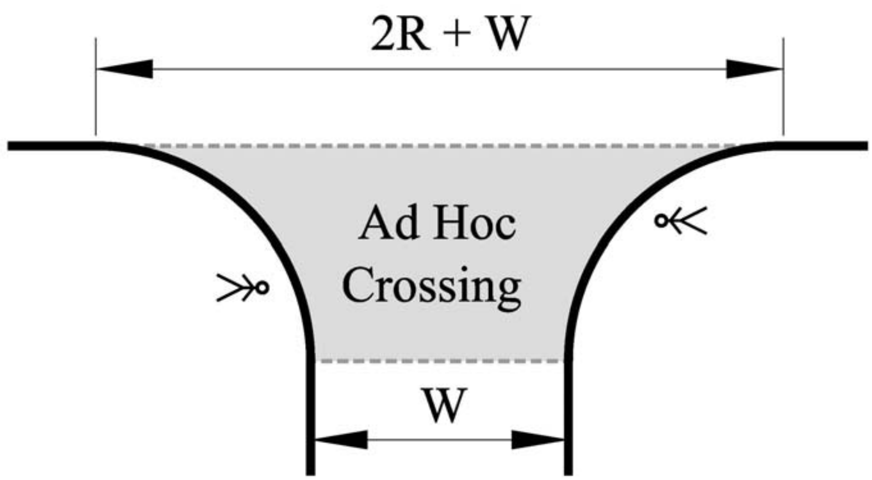

Figure 2. Ad Hoc Pedestrian Crossing

For a 50 feet curb return radius, the "ad hoc crossing" would be about 2(50) + W, exposing the pedestrian for that longer distance, or 100 feet longer than the 50 feet radius. These conflicts may be at slightly higher speeds as the driver may be decelerating into the curve.

The total number of conflicts is 4 with 2 for entering vehicles and 2 for exiting vehicles. Of those, 2 conflicts are from behind and 2 from the front. The pedestrian is not protected from any of these conflicts by barriers or traffic control. However, the conflicts from behind present a greater hazard since approaching vehicles are less visible.

A final concern is for multilane driveways where the pedestrian crossing the driveway may have the unexpected hazard of a vehicle turning in an adjacent lane rather than the anticipated driveway lane.

2. Sidewalk Locations

The location of the sidewalk at a driveway can impact;

- sight distance,
- profile slope of the driveway, and
- cross slopes of the sidewalk across the driveway.

Sight distance is impaired if the sidewalk is located at the back of the curb (curb-attached) because of the likelihood that parked cars, street furniture, trees and poles will visually block sight distance. A setback sidewalk where the sidewalk is separated from the curb by a buffer provides more visual clearance and separation between the edge of the street and the driveway.

The profile slope of the driveway may also be too severe where the sidewalk is placed at the back of the curb. A maximum desirable algebraic difference in grade of 12 to 14 percent is needed to avoid scraping the front and rear bumpers as the vehicle enters the driveway (Hodgson et al., 1998). Sidewalks placed adjacent to the curb require steep entry grades and incur high values of algebraic difference in grade with the street cross slope. Also, a steep cross slope for the sidewalk across the driveway often results. By locating the sidewalk with a setback away from the curb, a flatter driveway profile is possible. ADA requires that the cross slope of the sidewalk be 2 percent or less. The buffer separated sidewalk can have a flatter cross slope and also meet ADA requirements for the driveway profile.

With the location of the sidewalk at the back of the curb, other undesirable impacts on pedestrians occur. For the return radius driveway design, pedestrians must step down into the driveway, and according to ADA, a ramp should be provided. For the dustpan and dropped curb designs, a warped three-dimensional sloping surface results, presenting variable footing for all pedestrians and an uneven path for persons with disabilities.

3. Right In / Right Out Driveways

At locations where the operation of the driveway is controlled to “right in” and “right out”, the impact on pedestrians is reduced. The only conflicts occur between right-turning vehicles entering the driveway, and right-turning vehicles exiting the driveway. Both the drivers and the pedestrians have fewer conflict points and conflicts to watch and analyze. The left-turns are handled at the intersection on separate phases as a left turn or a U-turn movement.

4. Driveway Channelizing Islands

The addition of raised islands at driveways provides added refuge for the pedestrians, so in general, the resulting impact on pedestrians would seem to be less. However, “pork chop” islands have been found to be ineffective as a traffic control, so pedestrians are susceptible to the errant driver at the “pork chop” island. The likelihood of such an occurrence is probably much less than the benefit provided by the added refuge from the islands.

5. Medians

   a. Non-traversable Medians vs. Two-Way Left-Turn Lanes

   Medians provide a refuge for pedestrians crossing an arterial. Raised medians with a width of 6 feet or more are required by ADA. Safety research has shown that raised medians are safer than undivided highways or two-way left-turn lanes.

   Where a non-traversable median replaces a two-way left-turn lane, the pedestrian-vehicular crash rates can be reduced by 60 percent at intersections and 40 percent or more at midblock locations with many of those crashes at driveways (Parsonson et al., 1993 & 2000). The left-turn movement is then eliminated or controlled at midblock resulting in fewer expected left-turn crashes at driveways.

   b. U-Turns in lieu of Direct Left-Turn

   Where left-turns have been blocked midblock by a non-traversable median, the vehicle/pedestrian conflicts at driveways in the midblock region are eliminated. Where the U-turn is made at an intersection downstream, the additional conflicts may occur and the unusual character of the U-turn conflict may be slightly more hazardous. This is especially true where the U-turn may be made on the paired left-turn phase. However, often the pedestrian signal does not permit crossings during that phase.

6. Corner Clearance

Corner clearance at intersections, when properly applied, assures that conflicts entering and leaving the roadway from driveways do not occur too close to the intersection. Driveways are placed back upstream or farther downstream from the intersection to eliminate conflicts with arterial street traffic at the intersection. This also eliminates conflicts between pedestrians and driveway vehicles at the intersection, where conflicts are the most numerous. The net result is pedestrians directly benefit by the appropriate corner clearance.

7. Left and Right Turn Lanes

Where a left turn lane is added at a signalized intersection, the conflicts from the left turning vehicles are separated and controlled by the separate phasing they receive and the separation provided by the left turn bay. Pedestrian movements are controlled to separate them from the vehicular flow; therefore, pedestrians are exposed to fewer conflicts and protected from conflicting vehicle movements. The smoother operations into and through the intersection reduce the level of conflict at driveways upstream and downstream of the intersection.

Right turn lanes also give pedestrians a safer situation by reducing and controlling conflicts. And, at very high volume locations, an exclusive phase can be provided for these movements. The only disadvantage to pedestrians is the longer walking distance due to the added lane width. Where a right-turn lane is provided at a driveway, entry speeds are reduced (Hodgson et al., 1998).

Analysis of Alternative Access and Administrative Techniques

Acquisition of Access Rights
Where access rights are acquired by the state or local jurisdiction, the access will typically be eliminated or controlled to a higher standard. Therefore, pedestrians will not be impacted as much by a driveway serving the parcel.

Internal Access to Outparcels and Internal Circulation
Internal access to outparcels and interparcel circulation eliminates the driveways that would access the other parcels from major streets. Speeds of operations on-site will be significantly less than on a major street. Overall conflicts and relative speeds between vehicles and pedestrians will be reduced. However, the provision for effective pedestrian facilities on-site must not be overlooked.

Vehicle Use Limitation
Any limitation on vehicle use or change in zoning would be expected to reduce volumes and employ sound access management strategies with the likely reduction in impact to pedestrians.

Alternate Access
Alternate access can be provided by frontage roads or service roads. These roads can provide access at lower volumes (i.e. conflicts) and lower speeds. Although additional conflict points may be generated, the net result is conflicts that are spread out and less severe.

Summary of Analysis for Pedestrian Issues

Access management techniques and strategies are, in general, beneficial to pedestrians. Even where there are negative impacts, there are typically concomitant positive consequences that outweigh the negative. As an example, the midblock crossing for pedestrians requires pedestrians to follow a less direct path resulting in added inconvenience; however, the major intersections from which they are removed operate more smoothly and safely, for both vehicles and pedestrians.

Of the active or direct access management techniques, only continuous two-way left-turn lanes and indirect left-turns negatively impact pedestrians with increased conflict points, increased conflicts, and increased relative speed with vehicles present. Some administrative and alternative access techniques tend to remove or control where and how vehicles enter the major street, thereby reducing conflicts. These access techniques also reduce vehicular volumes and limit speeds to the benefit of pedestrians.

Overview of Bicycle and Parking Issues at Driveways

Basic access management principles are, in general, compatible with bicycle facilities. The complex urban environment where bicycle facilities, on-street parking, pedestrian access, and driveways must be accommodated, however, introduces potential hazards at these driveway locations. The placement and geometric configuration of bike lanes and on-street parking at driveways should permit adequate visibility without encroachment on standard facility operations. The driveway in the proximity of a bike lane, parking, and active motor vehicle lanes introduces potential hazardous locations that should be considered.

The first crash that was recorded in the United States was a bicyclist-vehicular crash that occurred in New York City in 1896 (Kane, 2007). Räsänen and Summala (1998) identified two underlying factors to bicycle-vehicular crashes: failure to detect the other user and violation of expectation of the behavior of the other user. This is consistent with the "looked-but-failed-to-see-errors "discussed by Herslund and Jørgensen (2003).

In terms of safety statistics, available results are limited, given conventional crash coding practices that do not necessarily distinguish between bicycle-vehicular crashes at driveways. This is confounded by the general lack of information regarding the presence of a bicycle lane and on-street parking in crash databases. More general crash characteristics are however available. A 1996 study funded by FHWA, studied 3,000 bicycle crashes and found that 18percent of the bicyclist-vehicular crashes resulted in severe and fatal injuries and that approximately two thirds of bicyclist-vehicle crashes occurred in urban areas. Bicyclists under the age 10 were overrepresented in crashes at driveways and alleys (Hunter et al., 1996). During 2006, a total of 773 bicyclists were killed nationwide and 66.8 percent of these crashes occurred at non-intersection locations. With on-street parking, the danger of a bicyclist impacting opening doors exists but no statistics are available to quantify this problem (Hunter et al., 2006).

Bicycle Objectives

Bicycle travel is a convenient and economical mode of transportation; however, many cyclists are reluctant to use bicycle facilities due to potential safety concerns. A well designed bicycle facility can diffuse these concerns, but fundamental design issues such as continuous bicycle facilities with good connectivity are only one aspect of this design. The American Association of State and Highway Transportation Officials (AASHTO) *Guide for the Development of Bicycle Facilities* emphasizes that the purpose of a bike lane is "to improve conditions for bicyclists on the streets" (AASHTO, 1999). In recent years the treatment of bike lanes at intersections for public streets has helped improve the interaction of motor vehicles and bicycles at these potentially hazardous locations. A similar focus is needed at driveways where the bicyclists must interact with motor vehicles turning into and out of driveways. At these locations there is often on-street parking positioned between the bike lane and the curb face, and parking vehicles must encroach on the bike lane. It is appropriate, therefore, to review current design approaches, sight distance issues, and placement strategies for bicycle facilities at complex urban driveway locations.

Bicycle Lanes and On-Street Parking State of the Practice

An urban commercial driveway, as shown in Figure 3, may include a sidewalk, a buffer between the curb face and sidewalk, on-street parking, a bike lane, and motor vehicle lane(s). At some locations, the on-street parking, bike lanes, or a buffer may be excluded in the design. This summary reviews these common urban components and their geometric configurations.

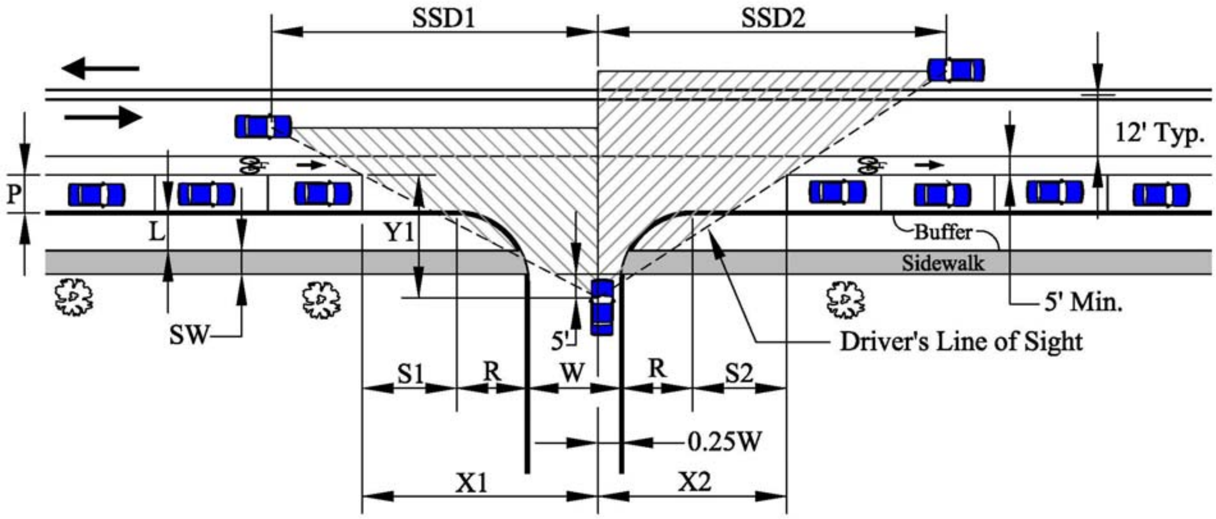

Figure 3. Components of On-Street Parking with a Buffer Strip

When a bike lane is located adjacent to on-street parking, the bike lane should be positioned between the motor vehicle lanes and the parking as shown in Figure 3. Widths of the bike lane and parking area combination may vary. The AASHTO (1999) *Guide for the Development of Bicycle Facilities* suggests that at locations where parking is permitted, the bike lane should have a minimum width of 5 feet with a total width of the bike lane and parking equal to 11 feet, where a curb is not present, and 12 feet when a curb is present. Where parking volume or turnover is high, an additional 1 to 2 feet of width may be appropriate. Specific widths for the on-street parallel stalls can range from 7 feet to 8 feet (Weant & Levenson, 1990; FHWA, 2003; ODOT, 1999).

The longitudinal setback of on-street parking at an intersection or driveway is a critical safety component. The *Manual on Uniform Traffic Control Devices* (2003) as well as many local and regional standards recommend a longitudinal no parking zone length of 20 feet upstream and downstream of crosswalks at intersections. Bloomington, Indiana, as an example, requires that no parking spaces should be located within a minimum of 30 feet of an intersection, and further suggests that larger setbacks may be appropriate. The State of Washington *Pedestrian Facilities Guidebook* (Otak, 1997) recommends a minimum 50 feet longitudinal parking setback from intersection crossings, while the ITE *Design and Safety of Pedestrian Facilities* guide suggests this setback should be as much as 100 feet for streets with travel speeds above 45 mph (ITE, 1998). Each of these setback guides are based on visibility of a pedestrian in a crosswalk or standing at the corner.

Stover and Koepke (2002) recognizes the need for visibility between drivers at driveway locations and suggest that for speeds of 30 mph, the longitudinal parking setback at intersections should be at least 380 feet, with an absolute minimum value of 250 feet.

The width of the buffer strip or landscape buffer can vary dramatically. Many jurisdictions use curb-attached sidewalks that have no available buffer while other jurisdictions require buffer strips up to widths of 10 to 20 feet. A *Policy on Geometric Design of Highways and Streets* (AASHTO, 2004) recommends a border area (buffer plus sidewalk) with a minimum width of 8 feet and a preferred width of 12 feet or more for urban arterial locations.

Geometric Influence on Sight Distance

At driveway locations there are three common types of sight distance that should be considered. Intersection sight distance enables a driver exiting a driveway to see clearly in both directions and then safely exit the driveway. Decision sight distance permits motorists on the adjacent street to see a driveway, make a decision regarding that driveway (such as a lane change maneuver or a stop), and then successfully execute that decision. This decision sight distance should be a fundamental method for determining driveway locations. The third sight distance is stopping sight distance for motorists on the street. Stopping sight distance provides adequate visibility so that a motorist can safely stop if an unexpected hazard should enter the vehicle's path. This potential hazard would likely be a vehicle that is exiting a driveway. Though all three sight distance conditions are important, it is critical that stopping sight distance, at a minimum, be achieved to ensure safety to the travelling public.

Required Stopping Sight Distance for Approaching Vehicles

Driveway designs should always accommodate stopping sight distance, yet few of the current on-street parking longitudinal setbacks in the vicinity of driveways adhere to this requirement. AASHTO (1999, 2004) provides guidance for determining the required stopping sight distance for motor vehicles as well as bicycles. Stopping sight distance is comprised of the distance a vehicle travels during the driver's perception-reaction time plus the braking distance. As a general rule, a perception-reaction time of 2.5 seconds is commonly used for road design; however, the *Access Management Manual* (TRB, 2003) suggests that in urban and suburban regions a driver is more alert and a 1.5 second perception-reaction time may be more appropriate for access management design. Table 5 demonstrates the required stopping sight distance for both the 1.5 second and the 2.5 second perception-reaction time.

Table 5. Required Stopping Sight Distances for Motor Vehicles and Bicycles

Speed (mph)	Perception-reaction Distance [PRT](ft)		Braking Distance on Level Terrain(ft)	Stopping Sight Distance (ft)			
	Based on 1.5 sec.	Based on 2.5 sec.		Calculated $SSD_{1.5}$	Rounded $SSD_{1.5}$	Calculated $SSD_{2.5}$	Rounded $SSD_{2.5}$
Motor Vehicle Values							
20	44.0	73.3	38.4	82.4	85	111.7	115
25	55.0	91.7	60.0	115.0	115	151.7	155
30	66.0	110.0	86.4	152.4	155	196.4	200
35	77.0	128.3	117.6	194.6	195	245.9	250
40	88.0	146.7	153.6	241.6	245	300.3	305
45	99.0	165.0	194.4	293.4	295	359.4	360
50	110.0	183.3	240.0	350.0	350	423.3	425
Bicycle Values							
10	22.0	36.7	13.3	35.3	40	50.0	50
15	33.0	55.0	30.0	63.0	65	85.0	85
20	44.0	73.3	53.3	97.3	100	126.7	130
25	55.0	91.7	83.3	138.3	140	175.0	175
30	66.0	110.0	120.0	186.0	190	230.0	230

As shown previously in Figure 3, a visibility triangle for motor vehicles and bicycles should be maintained that, at a minimum, provides stopping sight distance for motor vehicles and bicycles approaching a driveway from each direction. Figure 4 further depicts these visibility triangles as a set of similar triangles with a required motor vehicle stopping sight distance (SSD1) and a required bicycle stopping sight distance (X_{Bike1}) approaching the driveway from the left. Also shown in Figure 4 is the required motor vehicle stopping sight distance (SSD2) from the driveway's right approach. The companion bicycle stopping sight distance is easily achieved if the motor vehicle stopping sight distance criteria on the right approach is met.

The various roadway elements directly influence the driver's available line of sight. For example, the width of the sidewalk plus the buffer strip will shift the lateral stopping position of a vehicle exiting the driveway and directly impact sight distance. It is important, therefore, to consider all adjacent geometric components when locating on-street parking. Based on similar triangles as shown in Figure 4, a location for the beginning of the longitudinal placement for on-street parking that accommodates stopping sight distance requirements for motor vehicles approaching a driveway from its left is determined using the relationship shown in Equations 2 through 5.

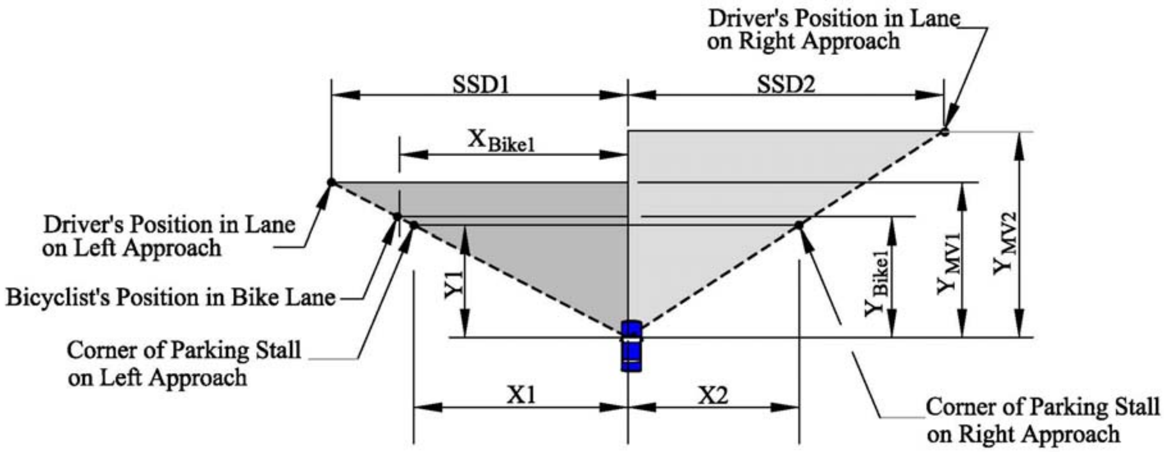

Figure 4. Similar Triangles Based on Stopping Sight Distance

$$\frac{SSD1}{Y_{MV1}} = \frac{X1}{Y1} \quad \text{or} \quad X1 = \frac{SSD1 \times Y1}{Y_{MV1}} \tag{2}$$

$$Y_{MV1} = \frac{1}{2}V + B + P + L + SW + 5 \tag{3}$$

$$Y1 = P + L + SW + 5 \tag{4}$$

$$X1 = \frac{3}{4}W + R + S1 \tag{5}$$

Where:

- $SSD1$ = Required stopping sight distance for a motor vehicle approaching from the left side of the driveway (ft)
- Y_{MV1} = Lateral distance from the center of the motor vehicle lane on the left approach to the driver's position in the vehicle exiting the driveway (ft). This value assumes the driver's eye position, for the vehicle exiting the driveway, is in the center of the exit lane and located laterally 5 feet from the stop bar.
- $X1$ = Longitudinal distance from driver position in the vehicle exiting the driveway to the first on-street parking stall for the left approach (ft)
- $Y1$ = Lateral distance from edge of on-street parking adjacent to active travel lanes to the driver position in the vehicle exiting the driveway (ft)
- V = Width of motor vehicle lanes (10 ft to 16 ft typical)
- B = Width of bicycle lane (4 ft to 6 ft typical)

P = Width of on-street parking (7 ft to 10 ft typical)
L = Width of landscape buffer from curb face to edge of sidewalk (0 ft to 20 ft typical)
SW = Width of sidewalk (4 ft to 20 ft typical)
W = Width of driveway throat (15 ft to 35 ft typical)
R = Radius of curb return (0 ft to 30 ft typical)
*S*1 = Longitudinal setback from the left curb return to the first on-street parking stall to the left of the driveway as depicted in Figure 3 (ft)

Based on the appropriate reaction time and widths common to a jurisdiction, a set of curves can be easily developed using the relationship indicated by Equations 2 through 5. For example, the curves shown in Figure 5 represent the relationship of the longitudinal distance from the driver position in the vehicle at the driveway exit to the first on-street parking stall (X1) and the lateral distance from the edge of on-street parking (adjacent to the travel lane) to the driver position in the driveway vehicle (Y1). These values are based on a stopping sight distance for a 1.5 second perception-reaction time. For the purposes of this figure, the value of the motor vehicle lane width, V, is assumed to be 12 ft and the value of the bicycle lane width, B, is assumed to be 5 ft.

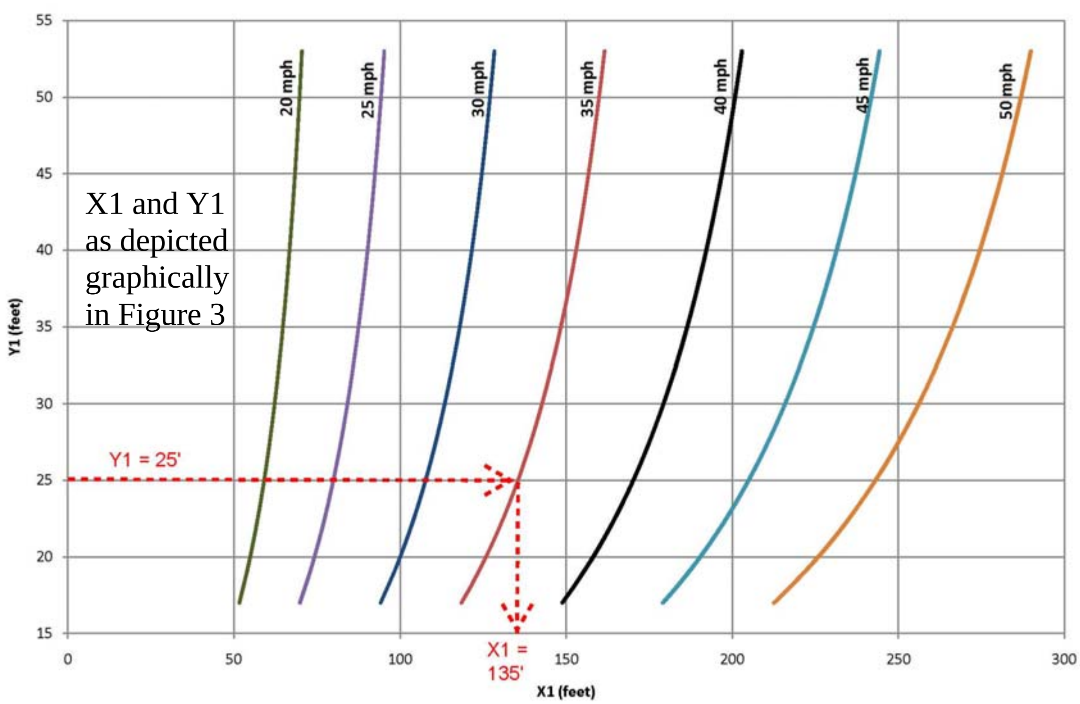

Figure 5. Longitudinal Parking Placement (X1) versus Lateral Driveway Vehicle Position from the Extreme Edge of Parking (Y1) for the Left Approach Motor Vehicle Stopping Sight Distance (PRT = 1.5 sec., V=12', and B=5')

The required longitudinal placement for parking that accommodates the bicycle stopping sight distance can be determined using another similar triangle from Figure 4, and as demonstrated by Equations 6 and 7.

$$\frac{X_{Bike1}}{Y_{Bike1}} = \frac{X1}{Y1} \quad \text{or} \quad X1 = \frac{X_{Bike1} \times Y1}{Y_{Bike1}} \tag{6}$$

$$Y_{Bike1} = \frac{1}{2}B + P + L + SW + 5 \tag{7}$$

Where:

X_{Bike1} = Required bicycle stopping sight distance on the left approach (ft)
Y_{Bike1} = Lateral distance from the center of the bike lane on the left approach to the driver's position in the vehicle exiting the driveway (ft)

Figure 6 depicts the relationship between X1 and Y1 based solely on the required bicycle stopping sight distance for the bike lane immediately adjacent to the on-street parking. The curves represent the relationship of the longitudinal distance from the driver position in the vehicle at the driveway exit to the first on-street parking stall (X1) and the lateral distance from the edge of on-street parking (adjacent to the travel lanes) to the driver position in the driveway vehicle (Y1). These values are based on a stopping sight distance for a 1.5 second perception-reaction time. For the purposes of this figure, the value of the bike lane width, B, is assumed to be 5 ft.

The relationships for on-street parking for the right approach (see Figure 4) similarly enable evaluation of the longitudinal parking setback from the driveway to parking on the right side of the driveway as it relates to the available stopping sight distance. This relationship is further developed as depicted by Equations 8 through 11.

$$\frac{SSD2}{Y_{MV2}} = \frac{X2}{Y2} \quad \text{or} \quad X2 = \frac{SSD2 \times Y2}{Y_{MV2}} \tag{8}$$

$$Y_{MV2} = \frac{3}{2}V + B + P + L + SW + 5 \tag{9}$$

$$Y2 = Y1 = P + L + SW + 5 \tag{10}$$

$$X2 = \frac{1}{4}W + R + S2 \tag{11}$$

Where:

$SSD2$ = Required stopping sight distance for motor vehicle approaching from the right (ft)
Y_{MV2} = Lateral distance from the center of the motor vehicle lane on the right approach to the driver's position in the vehicle exiting the driveway (ft)
$X2$ = Longitudinal distance from driver position in the vehicle exiting the driveway to the first on-street parking stall for the right side of the driveway (ft)

Y2 = *Y*1 as previously defined
V, B, P, L, SW, W, and R as previously indicated
*S*2 = Longitudinal setback from the right curb return to the first on-street parking stall to the right of the driveway as depicted in Figure 3 (ft)

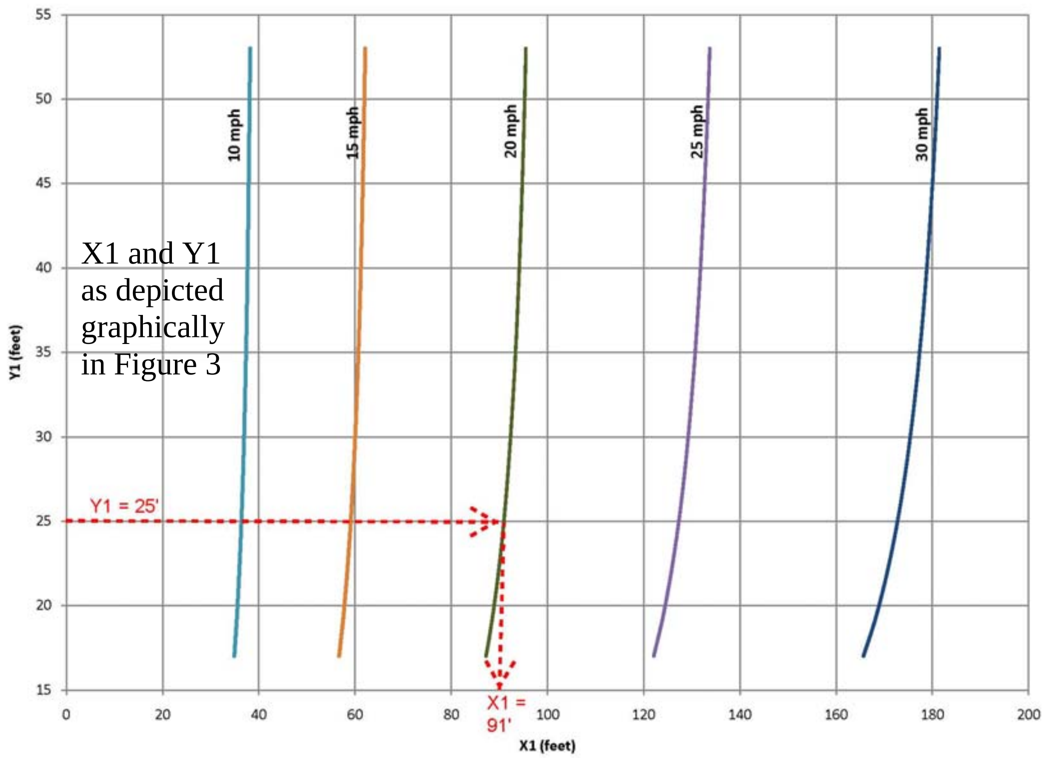

Figure 6. Longitudinal Parking Placement (X1) versus Lateral Driveway Vehicle Position from the Extreme Edge of Parking (Y1) for the Left Approach Bicycle Stopping Sight Distance (PRT = 1.5 sec. and B = 5')

Based on the appropriate reaction time and widths common to a jurisdiction, a set of curves can also be developed using the relationship indicated by Equations 8 through 11. The curves shown in Figure 7 represent the relationship of X2 and Y2 as they relate to the stopping sight distance for a 1.5 second perception-reaction time with a 12 feet motor vehicle lane width and the 5 feet bicycle lane width previously indicated. Due to the additional width of at least one more motor vehicle lane, the values for the left approach longitudinal parking setback (X2) are less than those for the right approach longitudinal parking setback (X1). Since the motor vehicle lane(s) is located closer to the driveway than the companion bike lane and the expected speeds by the motor vehicle are considerably greater than those by bicycles, the required longitudinal parking setback based on the bicycle stopping sight distance from the driveway's right approach will always be less than that required for the closer motor vehicle lanes.

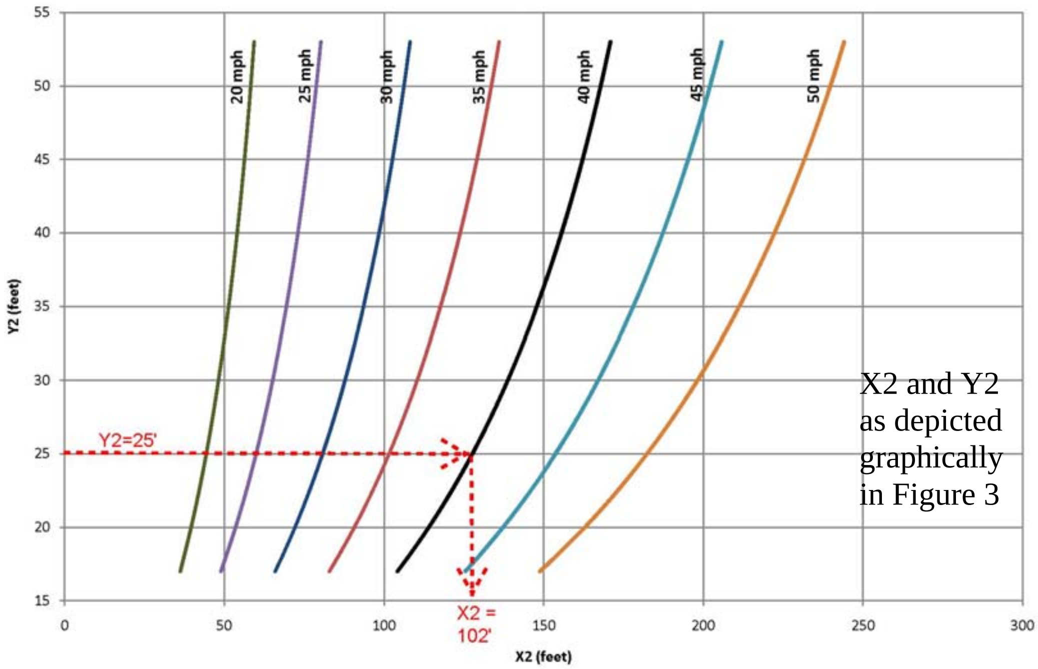

Figure 7. Longitudinal Parking Placement (X2) versus Lateral Driveway Vehicle Position from Extreme Edge of Parking (Y2) for the Right Approach Motor Vehicle Stopping Sight Distance (PRT=1.5sec, V=12', and B=5')

Equations 2 through 5 can be combined to create an equation that directly calculates the value of S1 based on a given motor vehicle stopping sight distance for the left approach. Similarly, Equations 4 through 7 can be combined to determine the minimum value of S1 based on bicycle stopping sight distance for the left approach. Finally, Equations 8 through 11 can be combined to determine the minimum value for the right approach longitudinal parking setback (S2). These three new equations are represented by Equations 12 through 14.

S1 based on motor vehicle stopping sight distance:

$$S1_{MV} = \left(\frac{SSD1 \times (P + L + SW + 5)}{\frac{1}{2}V + B + P + L + SW + 5} \right) - \left(\frac{3}{4} \times W \right) - R \qquad (12)$$

S1 based on bicycle stopping sight distance:

$$S1_{Bike} = \left(\frac{X_{Bike1} \times (P + L + SW + 5)}{\frac{1}{2}B + P + L + SW + 5} \right) - \left(\frac{3}{4} \times W \right) - R \qquad (13)$$

S2 based on motor vehicle stopping sight distance:

$$S2 = \left(\frac{SSD2 \times (P + L + SW + 5)}{\frac{3}{2}V + B + P + L + SW + 5} \right) - \left(\frac{1}{4} \times W \right) - R \qquad (14)$$

Note: For a two-lane road, the $\frac{3}{2}$ *value in the denominator reflects 1.5 motor vehicle lanes representing the distance to the center of the closest lane on the right approach. For a four-lane highway, a value of* $\frac{5}{2}$ *should be substituted.*

The use of Equations 12, 13, and 14 as well as Figures 5, 6, and 7 are demonstrated in the following example.

Example Calculation of Longitudinal Parking Setback based on Stopping Sight Distance
Problem Statement: An urban two-way road with one motor vehicle lane (12' wide) and one bike lane (5' wide) in each direction of travel has on-street parking, motor vehicle operating speeds of 35 mph, bicycle operating speeds of 20 mph and geometric dimensions of P=8', L=6', SW=6', W=20', and R=10. A perception-reaction time of 1.5 seconds can be assumed for this location.
Calculate the S1 value based on motor vehicle stopping sight distance: Per Table 5, SSD_{MV} (35 mph) = 195' Using Equation 12: $$S1_{MV} = \left(\frac{195 \times (8+6+6+5)}{\frac{1}{2}(12)+5+8+6+6+5} \right) - \left(\frac{3}{4} \times 20 \right) - 10 = 110'$$ Alternatively using Figure 5 and determining that Y1 = P + L + SW + 5 = 25', we find that X1=135'. $S1 = X1 - \left(\frac{3}{4} \times W \right) - R = 135 - 15 - 10 = 110'$

<u>*Calculate the S1 value based on bicycle stopping sight distance:*</u> Per Table 5, SSD_{Bike} (20 mph) = 100’ Using Equation 13: $$S1_{MV} = \left(\frac{100 \times (8+6+6+5)}{\frac{1}{2}(5)+8+6+6+5} \right) - \left(\frac{3}{4} \times 20 \right) - 10 = 66'$$ Alternatively using Figure 6 and with Y1 = 25’ (calculated previously), we find that X1=91’. $S1 = X1 - \left(\frac{3}{4} \times W \right) - R = 91 - 15 - 10 = 66'$
<u>*Select final S1 value:*</u> Use the larger value, so since 110’ > 66’, **the parking setback for the left approach (S1) at this location would be 110’**
<u>*Calculate the S2 value based on motor vehicle stopping sight distance:*</u> Per Table 5, SSD_{MV} (35 mph) = 195’ Using Equation 14: $$S2 = \left(\frac{195 \times (8+6+6+5)}{\frac{3}{2}(12)+5+8+6+6+5} \right) - \left(\frac{1}{4} \times 20 \right) - 10 = 87'$$ Alternatively using Figure 7 and since Y2 = Y1 = 25’, we find that X2=102’. Since $S2 = X2 - \left(\frac{1}{4} \times W \right) - R = 102 - 5 - 10 = 87'$ Using either method we find that **the parking setback for the right approach (S2) at this location would be 87’**

Landscape Buffers versus Curb-Attached Sidewalks

The use of a sidewalk buffer (landscape buffer) creates a road environment with additional separation between pedestrians and active traffic or on-street parking activities. This region also is commonly used for bus stops, landscape treatments, and minor utilities. Often in complex urban regions there is limited right-of-way, and the buffer strip must either be narrowed or possibly even eliminated. Though the exclusion of a buffer is not advisable, many current streets have curb-attached sidewalks. Figure 8 demonstrates that sight distance issues remain similar to those previously indicated in Figure 3. The same computational methods and figures can be used with a zero value for width of the landscape buffer (L=0) inserted into the equations provided.

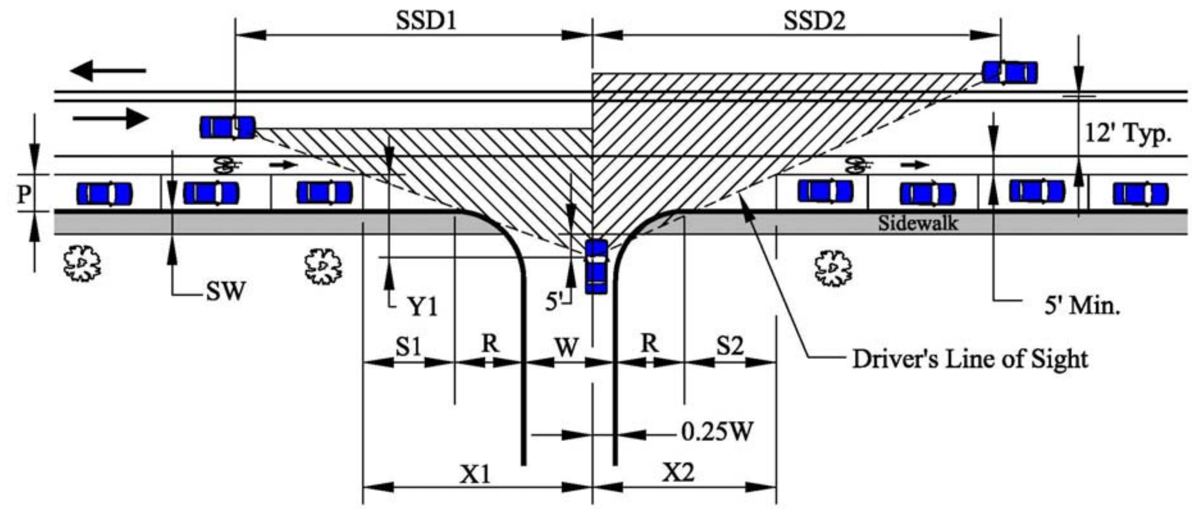

Figure 8. Components of On-Street Parking without a Buffer Strip

At locations where a buffer strip is not present, the width of the sidewalk will primarily influence the recommended stop position for a vehicle exiting the driveway. Table 6 demonstrates the differences in longitudinal parking setback resulting from example buffer widths. For the purposes of this table, perception-reaction times of 1.5 seconds as well as 2.5 seconds are depicted to demonstrate the differences obtained using these assumptions. Table 6 also shows longitudinal parking setback values for a two-lane road as well as a four-lane road. As can be seen, one additional travel lane positioned between the driveway and the right approach permits a reduction in the right longitudinal parking setback of 20 to 25 feet. The longitudinal parking setback for the left approach is unaffected by the additional travel lanes. The values shown in this table are provided for comparison purposes and based on example geometry values (V=12', B=5', P=8', SW=6', W=20', R=10', Motor Vehicle Operating Speed = 35 mph, and Bicycle Operating Speed = 20 mph).

Table 6. Longitudinal Parking Setbacks for Various Buffer Options with Bike Lanes

Width of Buffer (ft)	Two-Lane Highway				Four-Lane Highway			
	S1 (ft)		S2 (ft)		S1 (ft)		S2 (ft)	
	PRT=1.5 sec.	PRT=2.5 sec.	PRT=1.5 sec.	PRT=2.5 sec.	PRT=1.5 sec.	PRT=2.5 sec.	PRT=1.5 sec.	PRT=2.5 sec.
0	99	133	73	98	99	133	54	73
2	103	139	78	104	103	139	58	79
4	107	144	83	110	107	144	62	84
6	110	149	87	115	110	149	66	89
8	114	153	90	120	114	153	70	94
10	116	156	94	124	116	156	73	98
Assumptions: V=12', B=5', P=8', SW=6', W=20', R=10', Speed$_{MV}$ = 35 mph, and Speed$_{Bike}$ = 20 mph								

Bike Lanes and Additional Sight Distance

As previously indicated, the addition of bike lanes improves operating conditions for bicycles; however, an additional benefit of bike lanes is that they also provide approximately 5 feet of additional lateral space that can be used to improve sight distance for motor vehicles. The presence of a bike lane can also influence the parking setback. Table 7 demonstrates the required longitudinal parking setbacks for a variety of buffer widths (similar to Table 6 values) when a bike lane is not present. For the specific example demonstrated in Table 6 and Table 7, the longitudinal parking setback for the left approach (S1) when a bike lane is not present must be increased by approximately 20 to 30 feet to achieve visibility similar to that available when a bike lane is present. This required increase of S1 is the same for a two-lane or a four-lane road. Similarly, the longitudinal parking setback for the right approach (S2) should be increased a length of approximately 12 to 15 feet for a two-lane highway and 7 to 9 feet for a four-lane highway. These relative differences are specific to the 35 mph example; however, similar parking setback requirements can be expected at all speeds.

Table 7. Longitudinal Parking Setbacks for Various Buffer Options without Bike Lanes

Width of Buffer (ft)	Two-Lane Highway				Four-Lane Highway			
	S1 (ft)		S2 (ft)		S1 (ft)		S2 (ft)	
	PRT=1.5 sec.	PRT=2.5 sec.	PRT=1.5 sec.	PRT=2.5 sec.	PRT=1.5 sec.	PRT=2.5 sec.	PRT=1.5 sec.	PRT=2.5 sec.
0	123	165	85	113	123	165	61	82
2	127	169	90	120	127	169	65	88
4	130	173	94	125	130	173	70	93
6	132	177	98	130	132	177	74	99
8	135	180	102	135	135	180	77	102
10	137	182	105	139	137	182	81	108
Assumptions: V=12', B=0', P=8', SW=6', W=20', R=10', $Speed_{MV}$ = 35 mph, and $Speed_{Bike}$ = 20 mph								

Defacto Driveway Usage and Encroachment on Sidewalk

Based on the calculations included in this paper, many jurisdictions using parking setbacks of 50 to 100 feet currently have substandard sight distance for drivers with perception-reaction times of 1.5 seconds and dramatically substandard conditions if perception-reaction times of 2.5 seconds are used for calculating stopping sight distance. When inadequate sight distance occurs, the driver of a vehicle exiting a driveway will likely drive the vehicle forward in an effort to gain visibility. When this occurs, portions of the on-street parking, buffer, and sidewalk could be affected. Figure 9 demonstrates graphically this driveway behavior. The schematic labeled as "a" shows a location characterized by a combined parking plus buffer lateral distance that will accommodate the storage of one vehicle without blocking the sidewalk or encroaching on the bike lane. Schematic "b" depicts an unsuitable configuration where the combined parking plus buffer (nonexistent in this case) do not provide adequate storage for the vehicle. This scenario results in the vehicle either blocking the sidewalk as shown or encroaching on the bike lane operations. As a result, the use of inadequate parking setbacks creates undesirable behavior that will directly impact bicycle and/or pedestrian operations. If defacto driveway behavior is expected at a location, therefore, increased lateral widths are a critical geometric element for safe and efficient operations of all modes.

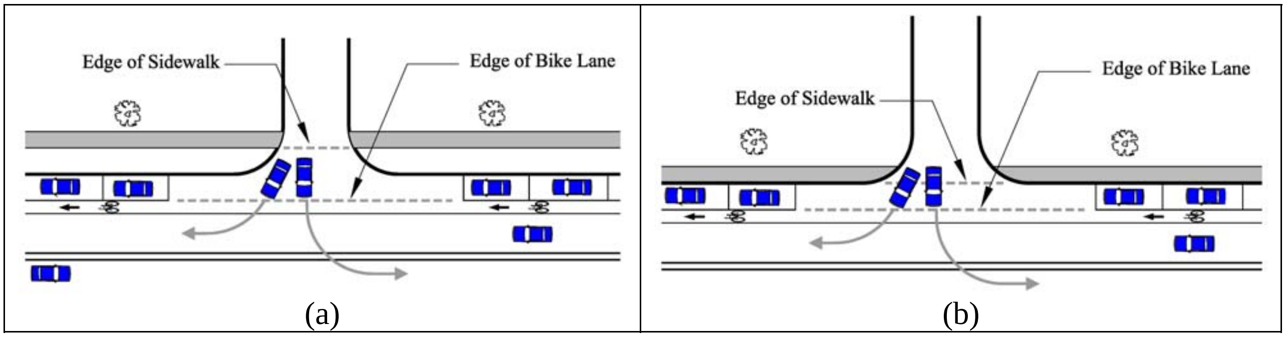

Figure 9. Defacto Driveway Configurations

Establishing Safe On-Street Parking Boundaries with and without bike lanes

The computational procedures outlined in this paper demonstrate the influence of road geometry and on-street parking on the safety of the facility. The alert condition perception-reaction time is included in this summary to demonstrate that common setbacks are often deficient even if a driver has a heightened sense of alertness. Though this information is important, a facility that will accommodate all potential users including those with slower reaction times is prudent and should be considered for design applications.

Table 8 demonstrates the different longitudinal parking setbacks for the left approach (S1) and the right approach (S2) on urban streets with motor vehicle lane widths of 12 feet, and parking, buffer, and sidewalk widths of 8 feet, 6 feet, and 6 feet respectively. This table also demonstrates the influence of a bike lane on overall visibility. As shown in Table 8, setbacks greater than approximately 120 feet are shaded. In general, a longitudinal setback of 120 feet on each side of the driveway would create at least 280 feet of space free of parking (120' left approach setback + 10' left curb return + 20' driveway throat + 10' right curb return + 120' right approach setback). For any complex urban street, there will ultimately be a secondary safety issue if there is sporadic on-street parking with large gaps, so it is reasonable to assume that setbacks greater than 120' are not desirable. Based on this 120 feet assumption, it is possible to determine that there are operating speeds above which parking should not be provided due to safety issues. For the alert 1.5 second perception-reaction time, roads with speeds above 35 mph but that have bike lanes should not have on-street parking. Similarly, for roads that do not have bike lanes, roads with speeds above 30 mph should not include on-street parking. For the 2.5 second perception-reaction time, stricter thresholds apply. For roads where a bike lane is present, on-street parking is not suitable for speeds above 30 mph while roads that do not have bike lanes should exclude on-street parking when speeds exceed 25 mph. These conclusions are based on the controlling left approach setback values. As previously noted, the presence of a bike lane provides additional sight distance resulting in more generous speed allowances for on-street parking without compromising safety and operations.

Table 8. Parking Setback Requirements for Typical Urban Street

Speed (mph)	Perception-Reaction Time of 1.5 sec.			Perception-Reaction Time of 2.5 sec.		
	S1 (ft)	S2 2-lane (ft)	S2 4-lane (ft)	S1 (ft)	S2 2-lane (ft)	S2 4-lane (ft)
Bike Lane Present						
20	34	29	20	55	45	33
25	55	45	33	83	66	50
30	83	66	50	114	89	68
35	110	87	66	149	115	89
40	145	113	87	187	144	112
45	180	139	108	225	173	135
50	218	167	131	270	206	162
No Bike Lane						
20	44	34	24	68	52	37
25	68	52	37	100	75	55
30	100	75	55	136	101	76
35	132	98	74	177	130	99
40	173	127	96	221	162	124
45	213	157	119	265	194	149
50	257	188	144	318	232	178

Values shown are based on 12’ lane widths, 5’ bike lane widths (where applicable), 8’ wide on-street parking, a 6’ landscape buffer, and a 6’ sidewalk

Note: Shaded regions represent required longitudinal parking setbacks from the curb return that are greater than 120’

Summary of Analysis for Bicycle and Parking Issues at Driveways

Using simple geometric procedures and typical road geometry, it is easy to determine that current methods for determining the placement of on-street parking in the vicinity of driveways do not meet sight distance requirements. The addition of a bike lane between the motor vehicle lanes and the on-street parking provides additional sight distance and, as a result, enables better visibility of driveway operations. The use of a landscape buffer between the curb and sidewalk helps to separate pedestrians from the road operations but also provides additional space to enable vehicles exiting a driveway that does not have adequate sight distance to drive forward without encroaching on the operations of the bike lane or the sidewalk. Finally, on-street parking with large no-parking gaps adjacent to driveways can also pose a hazard. As a result, roads with bike lanes should exclude on-street parking when speeds exceed 30 mph. Roads that do not have bike lanes present should exclude on-street parking when speeds exceed 25 mph.

Interaction among Pedestrians and Bicycles at Driveways

In addition to the interactions between motor vehicles and pedestrians and interactions between motor vehicles and bicycles, additional conflicts that can be expected at driveway locations include those between bicyclists or conflicts between pedestrians and bicyclists. Though crash data is minimal for these unique crashes, this section briefly reviews potential issues with these rarely reported crashes.

Conflicts between Bicyclists

Crashes between bicyclists are often grouped into the non-vehicle crash category (Hunter et al., 2006). Isolating characteristics of crashes occurring on facilities with bicycle lanes and on-street parking is problematic, particularly because non-motorized crashes are often grouped under the other or unknown vehicle category, making it difficult to distinguish crashes between bicyclists. Information regarding the presence of bicycle lanes and on-street parking is also rarely captured in crash databases. It is however likely that wrong-way riding and uneven pavement surface would likely each contribute to crashes between bicyclists.

Conflicts between Bicyclists and Pedestrians

Bicyclist-pedestrian crashes are also grouped under non-motor vehicle crashes (Hunter et al., 2006). There are no available statistics regarding bicyclist-pedestrian crashes at driveways. In this case the presence of a sidewalk and driveway at the crash location would be necessary to identify this particular crash type. However, in reviewing likely conflicts, it is likely that bicyclists that enter driveways without slowing down sufficiently would increase the likelihood of crashes with pedestrians crossing driveways. Larger parked vehicles such as SUVs may restrict sight distance for a bicyclist entering a driveway. Violation of expectations can also occur when either user assumes right of way.

Conclusions

The effectiveness of the various access management techniques are summarized in Table 4 where the manner in which the techniques contributes to the safety and improvement of traffic operations is reflected. This table shows what the impacts of the access management techniques are on pedestrians.

Access management techniques and strategies are in general beneficial to pedestrians. Even where there are negative impacts, there are typically concomitant positive consequences that outweigh the negative. As an example, the mid-block crossing for pedestrians requires pedestrians to follow a less direct path with added inconvenience; however, the major intersections from which they are removed operate more smoothly and safely for both vehicles and pedestrians.

The inclusion of on-street bike lanes in the vicinity of driveways, however, generally improves the available sight distance for motor vehicle and bicycle interactions. When bicycles and on-street parking co-exist, the bike lane enables the placement of on-street parking to be located closer to the driveway entry; however, the longitudinal parking setbacks at driveways and intersections commonly used in practice do not provide enough sight distance to permit the required stopping sight distance. The addition of a landscape buffer improves sight distance and also creates an additional space that permits the defacto driveway behavior common to driveways where adequate sight distance is not available.

In total, access management techniques generally are compatible with pedestrian and bicycle operations, but it is critical that designers consider ways to develop these facilities so that all transportation modes can function properly without encroachment on safe and efficient operations due to deficient design elements.

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