Bike Lanes Next to On-Street Parallel Parking

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HIGHLIGHTS

- Most crash data sources do not include crashes where a bicyclist comes in contact with the door of a parked motor vehicle because this crash type does not involve a *motor vehicle in transport*.
- Other sources show that "dooring" accounts for 12% to 27% of urban bicycle-motor vehicle crashes, making it one of the most common types.
- Most design guides used in North America permit bike lanes to be installed within reach of the doors of parked cars. By contrast, more recent guidelines for "separated" bike lanes on the curbside of parked cars require a buffer zone.
- Shared lane markings help to encourage bicyclists to ride away from the door zone and could be used in place of bike lanes that are too close to parked cars.

ABSTRACT

For decades it has been the conventional wisdom that crashes involving bicyclists and opening car doors are rare. This belief is based on motor vehicle crash reports, which exclude this crash type by definition. A review of recent studies of more complete data show that dooring crashes are one of the most common causes of urban bicycle-motor vehicle collisions, accounting for 12% to 27% of the total.

This paper reviews all available studies of bicyclist position in bike lanes adjacent to on-street parking. With bike lanes meeting current minimum standards, almost all bicyclists were observed riding within range of opening doors. However, when an additional three or four feet is provided between the bike lane and parked cars, hardly any bicyclists are observed in the door zone.

All of the design guides recently developed in North America for *separated* bike lanes include a buffer to account for the door zone when the bike lane is placed between on-street parallel parking and the curb. However, only the Ontario design guide has a similar requirement for *standard* bike lanes. The buffer requirement for standard bike lanes adjacent to on-street parking should be incorporated into all design guidance.

When there is not room for this necessary buffer, an alternative is to place a shared lane marking in the center of the travel lane. Observations of bicyclists under such conditions show that a significant proportion ride outside the door zone. Increasing this proportion may require lowering speed limits and repealing laws that create a presumption that bicyclists must always keep to the right of the travel lane.

KEY WORDS: bicycle, bicycling, bike lanes, separated bike lanes, cycle tracks, on-street parking

Conflicts of interest: none

INTRODUCTION

There has been a large increase in the number of marked bike lanes in North American cities in the past two decades. Many of these lanes have been added in older urban areas, where arterials often have on-street parking. One of the motivations for marking bike lanes is to make bicyclists feel welcome on city streets. However, government agencies and bicyclist organizations routinely warn bicyclists about the danger of suddenly opened door of a parked car – a problem known as “dooring” – even when bicyclists are using bicycle lanes.[1]

How frequently do bicyclists hit the opened door of a parked car? A recent paper argues that “past studies have shown that dooring crashes are a rare form of bicycle crash and are not relatively dangerous.” (*1*) Are either of these contentions supported by available data?

This paper reviews the available data on dooring crashes to determine their prevalence; reviews studies that include observational data on bicyclist position with respect to on-street parking in the presence of different lane widths and markings; and reviews design guidance for separated and ordinary bike lanes to determine how they account for the “door zone.”

PREVALENCE OF COLLISIONS WITH CAR DOORS

The main source of U.S. data on bicyclist crashes is the National Highway Traffic Safety Administration, which provides both a nationally representative sample of police-reported crashes and a complete inventory of road fatalities. However, both databases are restricted to crashes involving a *motor vehicle in transport*. Bicycles are not “motor vehicles” and parked motor vehicles are not “in transport.” Therefore, dooring collisions are excluded by definition from these databases, as well as from state databases and the Model Minimum Uniform Crash Criteria. (*2*) This exclusion may not be clear to data users: the NHTSA data includes the Pedestrian and Bicycle Crash Analysis Tool code for “Bicyclist Overtaking - Extended Door.” (*3*) In 2015, 2 crashes out of the 3,437 bicycle-car collisions in the sample (less than 0.1%) were given this code. North Carolina is the only U.S. state that routinely codes police-reported crashes using the PBCAT system. Of the more than 17,000 North Carolina bicycle crashes between 1997 and 2014, only 36 were coded as Extended Door, or 0.2%. (*4*) A Wisconsin study coded officially-recorded motor vehicle crashes involving bicyclists for the year 2003 using the PBCAT system. (*5*) Only 4 out of the 1,112 incidents were Extended Door, or 0.4%. These sources give the misleading impression that dooring crashes are exceedingly rare, but in fact they are excluded by definition from the sample universe and are only accidentally included. There is no warning in these sources that dooring crashes are undercounted.

Denver, Colorado conducted a bicyclist crash study using data from state crash forms that found that only 1.7% of bicycle-motor vehicle (BMV) collisions involved dooring (*6*). However, the Colorado state crash reporting form specifically says that “A bicycle accident is not a traffic accident unless it involves a motor vehicle in motion, regardless of injury. When a cyclist is involved in an accident on a bicycle only, and is injured, it is not a traffic accident. . . . When a cyclist collides with a parked vehicle, it is not a traffic accident.” (*7*). Therefore as with the U.S. national and North Carolina data, this does not accurately represent the true prevalence of this crash type.

[1] This paper is concerned only with parallel on-street parking. Angle on-street parking does not present a dooring hazard for bicyclists, although it does present a backing hazard, particularly with the more common back-out design.

Despite the exclusion of dooring crashes from motor vehicle crash data, there are other sources on its prevalence, which are summarized in Table 1. Dooring was the first, second, or third largest crash type in the sources that provided detailed analysis of crash type. Dooring should therefore be viewed as a highly significant BMV crash type, at least in areas with on-street parking.

City	Country	Data Type	% of BMV Crashes	Years	n	Conf. Int. (+/-)
Boston	USA	Police Incident Reports	13.6%	2009-2012	1,532	1.7
Boston	USA	EMS Reports*	11.6%	2009-2012	1,064	1.9
Cambridge	USA	Police Incident Reports	20%	2004-2009	539	3.4
Chicago	USA	Police Incident Reports	14.9%	2011-2015	9,501	0.7
Melbourne	Australia	Crash Reports	19.4%	2006-2010	2,180	1.7
New York	USA	Hospital	15.9%	2008-2011	382	3.7
New York	USA	Crash Reports	15.7%	2011	300	4.1
Toronto	Canada	Crash Reports	11.9%	1997-1998	2,572	1.3
Toronto	Canada	Crash Reports	14.6%	2014-2016	3,526	1.2
Vancouver	Canada	Insurance Reports	15.2%	2007-2012	2,994	1
Vancouver &Toronto	Canada	Hospital*	27.3%	2008-2009	690	3.3

*The universe of crashes was adjusted to eliminate incidents not involving a collision with a moving or parked motor vehicle.
Sources in order of listing: (*8*) (*9*) (*10*) (*11*) (*12*) (*13*) (*14*) (*15*) (*16*)

Table 1: Dooring Crashes as a Share of Bicycle-Motor Vehicle (BMV) Crashes

SEVERITY OF INJURY DUE TO OPENING DOORS

There are several ways in which a suddenly opening door can cause injuries. The bicyclist could come into contact with the door, which presents a sharp edge that could produce a cutting injury. If the bicyclist hits the center of the door with force, he or she could break the window glass. Contact with the door is almost certain to cause a fall, which can produce injuries via a collision with the asphalt. A bicyclist who falls can end up suddenly in the path of an approaching motor vehicle, with no time for the driver to stop; these incidents can be fatal. Even a small overlap between the end of the bicycle handlebars and the open door can cause the front wheel to turn suddenly to the right, which will immediately send the bicycle and rider to the left, into the path of approaching traffic.

With regard to injury severity, the Toronto study observed that for dooring crashes, “the injuries sustained were often more severe than average” and concluded that, combined with its frequency, “this type of crash would appear to be a very serious concern for urban cyclists.” (*14*) Transport for London reports that cyclists hit by car doors (or swerving to avoid them) tied for the second largest category of *serious* bicyclist injuries in London, representing about twice as many serious injuries as cases of bicyclists hit from the rear. (*17*). The University of British Columbia Cycling in Cities study of hospitalized bicyclists in Toronto and Vancouver found a 60% greater odds of serious injury when bicyclists were using roads with on-street parking compared to roads without.[2] (*18*) Nearly one out of three bicycle-motor vehicle collisions in the study were dooring collisions.

PREVENTING COLLISIONS WITH CAR DOORS

There are several ways dooring collisions can be prevented. Automobile occupants should look before opening a door: 41 of 50 U. S. states and eight of 10 Canadian provinces prohibit the opening of a door of a motor vehicle if it is unsafe to do so. Between 2013 and 2016, Virginia became the 41st U.S. state to adopt this rule and Quebec, British Columbia, and Ontario and the City of Chicago increased the fine for violating this rule, with the aim of reducing dooring collisions. However, after dark an approaching bicyclist failing to use a required headlight can be difficult to see. Even if most motorists look, apparently sufficient numbers do not, based on the data presented in the previous section, despite the legal requirement.

It is sometimes argued that the bicyclist should be responsible for stopping in time. When a door opens, stopping sight distance is a function of the bicyclist's speed and the distance between the bicyclist and an open door. Since a door can be opened very quickly, there is **no** speed at which a bicyclist can be sure to avoid a suddenly opened door that is within range of any part of the bicycle or rider. If the bicyclist can see that a car is unoccupied, he or she can be sure that there is no dooring hazard. But seeing inside vehicles is not reliable at night nor with vehicles that have tinted glass. In one case, a bicyclist was struck when a driver lying on his side kicked open the car door (*19*).

Almost all bicycle safety materials produced by states, cities, and advocacy groups recommend that bicyclists *always* stay a door's width away from parked cars, often specifying a distance of three or four feet. However, 44 U.S. states and six Canadian provinces require bicyclists to keep as close to the right edge of the roadway as "practicable" or "safe" (depending on the specific wording). Many of these statutes include an exception that permits bicyclists to leave the right edge "when reasonably necessary to avoid conditions including, but not limited to, fixed or moving objects, parked or moving vehicles, bicycles, pedestrians, animals, surface hazards, or substandard width lanes that make it unsafe to continue along the right hand curb or edge." While it is obvious that an open door constitutes a "condition" under this exemption, it is less obvious that the exemption applies to the *possibility* of a suddenly opening door. For example, when Long Beach (Calif.) sought permission from the California Traffic Control Devices Committee to experiment with an enhanced shared lane marking designed to encourage bicyclists to ride outside the door zone, "committee members had concerns over a California Vehicle Code provision that requires bicyclists to ride as far to the right as is reasonably safe." (*20*)

Five U.S. states, including three of the largest (California, New York, and Florida) have statutes explicitly requiring bicyclists to use bike lanes. Although these statutes generally have exceptions similar to those of the right edge of the roadway statutes, they may amplify the social pressure, sometimes backed up by overzealous policing, for bicyclists to stay in the bike lane even if that means riding within range of open doors.

[2] Calculated by the author based on data reported in Table 4 of the paper. There was a reported safety benefit of bike lanes only when comparing streets with bike lanes but *without on-street parking* to streets without bike lanes but *with on-street parking*. The presence or lack of on-street parking explains all of their finding that bike lanes were safer.

BICYCLIST POSITION WITH ON-STREET PARKING

How does the presence of bike lanes or other pavement markings affect the position of bicyclists? Are there changes that can be made to keep bicyclists out of the door zone? There are a number of studies that have examined how bicyclist position in relation to parked cars is affected by bike lanes of various dimensions and by shared lane markings placed at various distances from the curb. Before reviewing these studies, it is necessary to determine where bicyclists must operate to be clear of opening doors.

Extent of the Door Zone

To determine if the bicyclist is outside the door zone one must know the maximum of the reach of an open door at its furthest extent, which depends on the dimensions of the door and the car, and the distance between the car and the curb. Some two-door vehicles have doors that open as much as 3.75 feet. (*21*) Most passenger cars 6 feet wide, but many pickup trucks are 6.7 feet wide. Given that most jurisdictions permit parking up to 1 foot from the curb, 7 feet is a reasonable figure to use for the outer edge of a parked car with closed doors, representing either a well-parked pickup or a poorly-parked passenger car. Therefore, an open door can extend 10.75 (3.75 plus 7) feet from the curb, and to be outside the door zone, all parts of the bicycle and rider must be at least this distance from the curb when there is on-street parallel parking.

In the studies reviewed, the position of the bicyclist is generally measured using the position of the bicycle tire. This point represents the middle of the bicycle, not the outer edge. An additional distance needs to be added to account for the width of the bicycle and rider, and to add a margin of safety, given that a bicycle cannot be operated in a completely straight line. The AASHTO *Guide* uses 2.5 ft as the width of a bicycle and rider. (*22*) To account for the width beyond the tire one must add half of this amount or 1.25 ft. Therefore the *bicycle tire* must be at least 12 (10.75 plus 1.25) feet from the curb for the *bicyclist* to be outside the door zone.

This assessment roughly matches that of a recent NCHRP study, which found that "for parking lanes 7- to 9-ft wide, based on the 95th-percentile parked vehicle displacement and assuming an open door width of 45 in., the open door zone width of parked vehicles extends approximately 11 ft from the curb." (*21*) For a bicyclist to clear 11 ft from the curb, the bike tire must be no closer than 12.25 feet from the curb.

Bicycle Lanes

A review of prior research produced four prior studies of bicyclist position in the presence of bike lanes and on-street parking, all from the U.S. The preferred metric for evaluation is the share of observed bicyclists riding within the door zone, that is, with a wheel location within 12 feet from the curb. Since none of the studies provided the share of bicyclists outside the door zone as defined here, this figure was estimated.

A 1999 study measured the position of 638 bicyclists riding in bicycle lanes next to on-street parking in Fort Lauderdale and Hollywood, Florida. (*23*) The lane dimensions at the two sites are shown in the following table. The report provides the mean distance from bicyclist to outside bike lane stripe, which was used to calculate the distance from bike tire to parking lane line. (The parking lane width was not reported in the study, but was measured by this author using Google Earth.) Since the bike lane line was 12 or 12.5 ft from the curb, bicyclists would have to ride at least partly outside of the bike lane in order to be outside the door zone. The authors reported that "Bicyclists tended to center themselves in the middle of the [bike lane] in the presence of a parked motor vehicle." The study recorded only one observation of a bicyclist riding outside the bike lane (abreast of another bicyclist). Therefore almost all the bicyclists were operating within range of opening doors.

Location	Parking Lane (ft)	Bike Lane (ft)	Travel Lane (ft)	Mean Bike Tire to Right Edge of Bike Lane Distance (ft)	Mean Bike Tire to Curb Distance (ft)	Bike Tire 12 ft or More From Curb
A1A, Ft Lauderdale, FL	7.5	4.5	10.5	2.0	9.5	almost none
Hollywood Blvd, Hollywood, FL	7.5	5	12	2.2	9.7	none

Sources: (*23*), Google Earth, and author's calculations

Table 2: Bicyclist Position at Two Florida Sites

A 2005 study of Hampshire Street in Cambridge, Massachusetts looked at the effect of three cumulative treatments to a section of urban road, compared to a baseline of a 22-foot undifferentiated travel and parking lane with only a centerline marking:

- separating the combined travel and parking lane into a 10 ft travel lane and a 12 ft parking lane (treatment 1);
- add a bike lane symbol in the left portion of the parking lane (treatment 2); and
- add a lane line, 7 feet from the curb, separating the bike lane from the parking lane (treatment 3). (*24*)

The researchers observed bicyclists passing by four locations during peak hours under each of the four scenarios. The study dataset, with 1,228 observations, was obtained from one of the researchers. The percent of cyclists at least 12 feet from the curb was calculated (see Table 3). In the baseline, almost no bicyclists were riding outside the door zone. With the addition of a lane line dividing the parking lane from the travel lane, this increased to more than 4%. In every treatment tried, the vast majority of bicyclists (more than 95%) were riding within the door zone. The study notes that "for cyclists to travel completely outside the full door zone, the left handle bar would be in the travel lane. Cyclists may not have felt comfortable riding with a portion of their bicycle in a relatively narrow travel lane of 10 feet."

Treatment	Bike Lane (ft)	Parking Lane (ft)	Travel Lane (ft)	Total Half of Roadway (ft)	Bike Tire 12 ft or More From Curb	n
0	0	0	22	22	0.1%	279
1	0	12	10	22	4.4%	349
2*	0	12	10	22	4.6%	300
3	5	7	10	22	2.1%	300
TOTAL					4.0%	1,228

*Treatment 2 includes a bike symbol in left portion of wide parking lane.

Source: Data from (*24*) as tabulated by the author.

Table 3: Bicyclist Position on Hampshire St, Cambridge, MA

A 2009 study examined the riding location of bicyclists at selected locations with different lane configurations in three Texas cities. (*25*) The study included eight sites with bike lanes and on-street parking, one in Houston and the rest in Austin. The researchers estimated the riding position, with respect to parked and passing cars, of 39 cyclists who were hired for the project and instructed to ride as they normally would. According to the study, "paid cyclists were chosen to participate based on an effort to match the natural cycling population as closely as possible. . . . The researchers believed that, by not informing the cyclists of the study's goals, the paid cyclists would react to both passing vehicles and parked vehicles in the same manner as an average cyclist would." In 30% of the 3,198 observations where bicyclists were passing parked cars, they were simultaneously being passed by motorists.

The study did not report the width of parking lanes; these were measured by this author using satellite images. The study used 2.17 feet as the extension of an open door, based on a *4-door* Honda Accord with the door only *half open*. This figure underestimates by more than 1.5 ft the extent of the door zone hazard. To be outside of the door zone, the bicycle tire needs to be at least 5 feet from parked cars, not the 3.5 ft assumed in the study. Where a standard 5 foot bike lane was adjacent to a parking lane of 8 feet or less in width, as shown in Table 4, almost all observations showed the bicyclist riding in the door zone (tire less than 5 feet from parked cars). As in the Hampshire Street study, bicyclists would have had to ride on the bike lane line to be completely outside the door zone (although in the Austin cases, the adjacent travel lane was 1.5 to 2 ft wider). At one location with a wider-than-standard bike lane (Parkfield Drive North, site 2), almost half of the recorded bicyclist positions were outside the door zone. Where there was a wide (11 ft) parking lane, as on San Jacinto Blvd and 30th Street in Austin, the study found that almost no bicyclists rode within the door zone. In this configuration there was plenty of room for a bicyclist centered in the bike lane to be completely outside of the door zone.

Location	Parking Lane (ft)	Bike Lane (ft)	Travel Lane (ft)	Bicyclists Observed 5 ft from Parked Cars*
Georgian Drive	7.5	4.2	11.5	almost none
Parkfield Drive North, site 1	8	5	12.2	almost none
Parkfield Drive North, site 2	8	7.25	11.4	almost half
San Jacinto Blvd	11	5.8	11.3	almost all
W. 30th St	10.9	6	11.8	almost all

Source: (19).

Table 4: Bicyclist Position at Selected Sites with Bike Lanes in Austin, TX

The National Cooperative Highway Research Program commissioned a 2014 study, *Recommended Bicycle Lane Widths for Various Roadway Characteristics*, which included three locations with bike lanes adjacent to on-street parking in Cambridge, Mass. and Chicago, Ill. (*21*) Like the earlier Hampshire Street study, the experimental design was to observe bicyclist positions at the same study locations with different temporary pavement marking treatments applied. The final data included the location relative to the curb for 4,965 bicyclists passing the designated locations.

The researchers measured the distance between parked cars and the curb and found no statistically significant difference with parking lanes between 7 and 9 feet wide. As mentioned previously, they concluded that "the open door zone width of parked vehicles extends approximately 11 ft from the curb."

Therefore the position of the bicycle tire needs to be 12.25 ft from the curb. The researchers observed few bicyclists this far from the curb in the three sites with on-street parking.

Several different lane configurations were tested at each of the locations. At the Cambridge location, the existing 5 ft bike lane was reconfigured by adding a small (1 to 1.5 ft) buffer to the parked cars, narrowing the bike lane, and keeping the total bike lane plus buffer width constant at 5 ft. At the Chicago sites, there were two separate experiments:

- Widen the parking lane from 7 to 8 and then 9 feet while narrowing the bike lane from 6 to 5 and then 4 feet, keeping a constant 13 ft width of the parking and bike lane combined.
- Narrow the travel lane from 12 to 10 feet and narrow the bike lane from 6 to 4 feet in order to create a 2-ft hashed buffer between the bike lane and the parking lane and another 2-ft hashed buffer between the bike lane and the travel lane.

Changing the dividing line between parking lane and bike lane did not move bicyclists away from parked cars. However, "when a buffer was provided between a bike lane and a parking lane, bicyclists positioned themselves further away from the door zone of parked vehicles." The researchers found that with "a buffer space of only 1 to 2 ft, a sizable portion (40% to 60%) of bicyclists may still position themselves within the door zone of parked vehicles. Thus, when adjacent to narrow parking lanes, it is desirable to provide a wider buffer space up to a maximum of 4 ft."

At the experimental sites the total width from curb to outside lane line (travel lane, bike lane, parking lane combined) varied between 22 and 25 feet (compared to 22 ft on Hampshire Street and as much as 28 ft in the Austin cases). The only site with a significant share of bicyclists outside the door zone was the widest of these, Division Street, particularly when it was configured with a 2 ft. buffer. There was room to make a wider buffer of 3 or even 4 ft, but the additional 2 ft was used for a buffer from the adjacent travel lane. The lane configuration that best matches the researcher's conclusions about the door zone width was not tested. Therefore the two Austin cases of 11 ft parking lane adjacent to 6 ft bike lane are the only examples studied of a design with sufficient space for bicyclists to ride outside the door zone when centered within the bike lane.

In the final scenarios on Clark Street, the bike lane was shifted to the left one foot by narrowing the travel lane a corresponding amount. In addition, a 2 ft buffer was striped in what had been the left-most part of the parking lane. These two changes in combination produced the largest observed left-ward shift in the mean bicyclist position. In the final scenario for Division Street, the bike lane could have been shifted left by 1 or 2 feet, but instead a 2 ft buffer was added to the left of the bike lane. As on Clark Street, the left-most part of the parking lane was marked as a 2-ft buffer zone. The resulting leftward movement of the average bicyclist position was almost as large as for Clark Street. Even for the final Division Street scenario, the average bicyclist was still riding within the door zone, since the bicyclist *tire* was about 11 feet from the curb, leaving more than 1 foot of bicycle and rider within striking distance, at least of the widest car doors. It is likely that a configuration with a 7 ft parking lane, 3 ft buffer, 5 ft bike lane, and 10 ft travel lane, had it been tested, would have moved the average bicyclist over an additional foot, outside the door zone.

			Lane Widths (ft)					
Street	**City**	**n**	**Travel Lane**	**Bike Lane**	**Buffer**	**Parking Lane**	**Total**	**Mean Bicycle Tire to Curb Distance (ft)**
Massachusetts Ave	Cambridge, Mass.	280	10	5	0	7	22	10.4
		530	10	4	1	7	22	10.4
		327	10	3.5	1.5	7	22	10.3
Clark Street	Chicago, Ill.	134	11	6	0	7	24	9.4
		259	11	5	0	8	24	10
		399	11	4	0	9	24	10.1
		473	10	5	2	7	24	10.6
Division Street	Chicago, Ill.	306	12	6	0	7	25	10.1
		187	12	5	0	8	25	10.1
		337	12	4	0	9	25	10.5
		109	10	4	2 + 2	7	25	10.9

Source: (*21*)

Table 5: Bicyclist Position at Sites with Bike Lanes and On-Street Parking in Chicago and Cambridge

In summary, the research findings in the four studies on bicyclist positioning with bike lanes adjacent to parking show that:

- With minimal bicycle lane dimensions (5 ft bike lane adjacent to 7 ft parking lane), almost all bicyclists ride within the door zone. This is not surprising given that riding outside the door zone requires the bicyclist to be at least half outside the bike lane. Adding a buffer zone in this situation is of no benefit, as shown in the Massachusetts Avenue case.
- Narrowing the bike lane and widening the parking lane is somewhat beneficial, because it helps move the center of the bike lane further left.
- Striping a buffer zone between the parking lane and the bike lane may be more effective than widening the parking lane.
- The widest configuration tested in the NCHRP study, 25 feet from curb to outside travel lane line, was not sufficient to pull most bicyclists out of the door zone *as it was configured*. However it seems likely that using all of the 4 ft available buffer zone between the bike lane and the parking lane would have been successful. This is corroborated by the two Austin cases with 11 ft parking lanes (equivalent to 4 ft buffer plus 7 ft parking lane) where it was observed that no bicyclists rode in the door zone.

Shared Lane Markings

The *shared lane marking*, appearing for the first time in the 2009 Edition of the *Manual of Uniform Traffic Control Devices*, has multiple purposes, one of which is to “assist bicyclists with lateral positioning in a shared lane with on-street parallel parking in order to reduce the chance of a bicyclist's impacting the open door of a parked vehicle.” (*26*) A review of the literature produced four studies that measured bicyclist position on roads where SLMs were centered in the travel lane (see Table 6).

A study in Austin, Texas evaluated the placement of SLMs on several roads with two travel lanes in each direction and a posted speed limit of 35 mph. (*27*) The SLMs on Guadalupe Street were centered in the right-hand lane, 13.5 feet from the curb. The observed mean bicyclist tire distance to the curb increased from 11.1 to 11.5 ft after placing of the markings.

The City of Long Beach, California installed shared lane markings on Second Street, a four-lane boulevard with on-street parking in a business district with heavy parking use and slow travel speeds. (*20*). The travel lanes are 11 feet wide and the parking lane is 7.5 feet, marked with Ts. The posted speed limit is 25 mph, although generally traffic is much slower through this business district. SLMs were added, 14 feet from the curb, centered in the 11-foot travel lane, with the lane lines unchanged. A green strip, 5.5 feet wide with its right edge 11 feet from the curb, was painted continuously in the center of the right-hand lane. "Bikes in Lane" signs were also installed. The share of roadway bicyclists (that is, excluding those on the sidewalk) at least 11 feet from the curb increased from 15% before the installation to 44% afterwards. The share of bicyclists using the sidewalk decreased from 43% to 26%. The initial design included SLMs at the beginning of each 200-foot block. In April 2010, a second SLM was added near the end of each block. A few months after this change new counts found that the share of roadway bicyclists at least 11 feet from the curb had increased to 55% and the share of sidewalk bicyclists had decreased to 21%. Total bicyclist volume increased 94% compared to counts made before adding the SLMs.

A third study looked at the installation of SLMs on Washington Avenue in Miami Beach. (*28*) This site has an 8-foot parking lane and two 11-foot travel lanes in each direction and a posted speed limit of 30 mph. The SLMs were placed in the middle of the right-hand travel lane about 13.5 feet from the curb. The percent of bicyclists "near the center of the lane" increased from 12% to 35%.

A fourth study examined bicyclist positioning on 40th Street in Oakland, Calif. (*29*) The site has 8 foot parking lanes and two 12 foot travel lanes in each direction. Bicyclist position was measured in the base case and with SLMs centered in the right-most travel lane, 14 ft from the curb and Bicycles May Use Full Lane signs. Additional measurements were made with green pavement coloring added continuously in the right lane underneath the SLMs. The mean bicyclist distance from the curb increased from 8.8 ft to 9.4 ft with the regular SLM and to 10.6 ft with the enhanced SLM. (These figures are a weighted average of the "free flow" and "vehicles present" conditions reported in the study.)

Street Name	Location	Travel + Parking Lane (ft)	Center of SLM to Curb (ft)	Mean Bicycle Tire to Curb Distance (ft)
Guadalupe Street, SB	Austin, TX	19	none	11.1
			13.5	11.5
Second Street	Long Beach, CA	18.5	none	na
			14[a]	na
Washington Street	Miami Beach, FL	19	none	10.1
			13.5	11.0
40th Street	Oakland, CA	20	none	8.8
			14 [b]	9.4
			14 [c]	10.6

Notes: *a*. Also green painted area 11 ft from the curb and "Bikes in Lane" signs. *b*. Also Bicycles May Use Full Lane signs. *c*. Also green painted area 11.5 ft from the curb and "Bicycles May Use Full Lane" signs. SLM=Shared Lane Marking, -=not applicable, na=not available, WB=westbound, SB=southbound. Sources: (*30*), (*31*), (*27*), (*20*), (*28*), (*29*)

Table 6: Bicyclist Positioning with and Without Share Lane Markings

The following conclusions can be made from the studies of shared lane markings:

- Shared lane markings can help move bicyclists away from car doors.
- Based on the data reported in the 40th Street study, enhancing SLMs with a continuous green stripe can increase the distance of bicyclists from on-street parking.
- The biggest success in moving bicyclists out of the door zone was at Second Street in Long Beach, perhaps because of the slow speed of traffic. (The project also led to a large decrease in sidewalk bicycling and large increase in bicycle use overall.)

The modest effects of SLMs on pulling bicyclists away from parked cars may reflect the strong social pressures for bicyclists to stay out of the way of motor vehicles. Roadway design changes could be supplemented by eliminating statutes that require bicyclists to have an excuse to leave the right edge of the road, retraining police officers, educating the public, and passing and enforcing laws prohibiting harassment of bicyclists.

DESIGN GUIDELINES FOR BICYCLE FACILITIES ADJACENT TO ON-STREET PARKING

Standard Bike Lanes

A summary of the guidelines relating to bicycle facilities adjacent to parking from different guide books is shown in Table 7. The American Association of State Highway and Transportation Officials *Guide for the Development of Bicycle Facilities Fourth Edition* (2012) contains the following *minimum* dimensions: 5 foot bike lane adjacent to a 7 foot parking lane. (*22*) The AASHTO Guide *recommends* a wider parking lane (8 feet) and/or a wider bike lane (6 or 7 feet), particularly when there is high parking turnover. The National Association of City Transportation Officials *Urban Bikeway Design Guide* echoes AASHTO's guidelines for bike lanes adjacent to parking. (*32*).

Buffered Bike Lanes

The AASHTO Guide discusses buffers, either between the bike lane and the travel lane or between the bike lane and the parking lane, but provides no recommendation to use buffers, nor guidelines for their width. The NACTO Guide says that a buffered bike lane "encourages bicyclists to ride outside of the door zone when [the] buffer is between parked cars and [the] bike lane." The NACTO *Guide* also fails to provide guidance on the width of the buffer, but states that it can be considered part of the bike lane width. The *Ontario Traffic Manual* is the only North American source that was found in this review that requires buffers between a standard bike lane and on-street parking. (*33*) (The OTM provides one exception: "In a low volume, low speed constrained corridor, a minimum 1.8-metre wide bicycle lane may be provided without a buffer. However, the practitioner should consider the increased risk of collisions between cyclists and opening car doors or alighting passengers.")

		Bike Lane (ft)		Buffer (ft)		Parking Lane (ft)	
Type of Bike Lane	**Source**	**Min**	**Rec**	**Min**	**Rec**	**Min**	**Rec**
Standard	AASHTO	5	6 to 7	ns	ns	7	8
Standard	NACTO	5	7	ns	ns	7	ns
Standard	OTM	4.9	4.9	3.3	4.9	6.6	8.2
Separated	NACTO	5	7	3	3	ns	8
Separated	FHWA	5	7	3	ns	7	ns
Separated	OTM	4.9	5.9	2.6	3.9	ns	ns
Separated	MassDOT	5	6.5	2	6	8	ns

Notes: Min=minimum, Rec=recommended, ns=not stated. Sources: AASHTO (*22*), NACTO (*32*), OTM (*33*), FHWA (*34*), MassDOT (*35*)

Table 7: Minimum and Recommended Widths of Bike Lanes Adjacent to Parking

Separated Bike Lanes

In the past few years many cities in North America have installed bike lanes separated from the travel lanes by some physical element, often by designating the bike lane between parked cars and the curb. The AASHTO Guide recommends against placing bike lanes between parked cars and the curb; prior to the 2012 edition, the AASHTO Guide prohibited such placement. However separated bike lanes are included in the NACTO guide as well as the FHWA *Separated Bike Lane Planning and Design Guide* and the MassDOT *Separated Bike Lane Planning and Design Guide*. (*34*) (*35*) All of these guides require the use of a buffer zone between parked cars and the bike lane when there is on-street parking adjacent to separated bike lanes, as shown in Table 7. The NACTO Guide refers to a "desired" buffer of 3 feet between a separated bike lane and a parking lane and states that a separated bike lane "reduces risk of 'dooring' compared to a [standard] bike lane." The FHWA Guide expresses the need for a buffer more strongly: "a minimum 3 ft buffer should be used," adding that "a minimum buffer width of 3 feet is required to allow for the opening of doors and other maneuvers." The MassDOT Guide recommends a 6-foot buffer but adds that "street buffers may be narrowed to a minimum of 2 ft. in constrained conditions."

Shared Lane Markings

The standards for shared lane markings are governed by the *Manual of Uniform Traffic Control Devices*. (*26*) The current (2012) edition provides guidance that SLMs should not be placed on roadways that have a speed limit above 35 mph, and if used in a shared lane with on-street parallel parking, SLMs should be placed so that the centers of the markings are at least 11 feet from the face of the curb, or from the edge of the pavement where there is no curb. There are two problems with this guidance where there is on-street parking:

1. Centering the SLM 11 feet from the curb provides inadequate clearance from doors, since, as discussed above, bicyclists should center their tire track at least 12 feet from the curb to be clear of parked cars. Moreover, the marking is 3.5 ft wide, and it is not clear that bicyclists understand that the only safe place to ride is the left half of the marking when it is placed adjacent to parked cars.
2. Centering the SLM 11 feet from the curb may leave a portion of the travel lane which appears wide enough for motorists to use to pass bicyclists without changing lanes, but is not wide enough for this movement to be made with sufficient clearance to be safe.

The Bicycle Technical Committee of the National Committee on Uniform Traffic Control Devices drafted a change to the SLM guidance that partly addresses these concerns. (*36*) The proposed revision would increase the minimum spacing from the curb from 11 to 12 feet where there is on-street parallel parking. The proposal also advises that when SLMs are used along with a Bicycles May Use Full Lane sign they should be centered in the travel lane. However it would be better to require that SLMs *always* be centered within the travel lane. The SLM installations summarized above were centered in the right-hand travel lane, 13.5 to 14 feet from the curb, a location that provides room for all of the marking to be out of the door zone, and that encourages bicyclists to ride so that motorists must make a full lane change rather than squeeze by within the same lane.

DISCUSSION

Despite revisions in recent years, standard design guidelines used in North America still permit a 5 ft bike lane next to a 7 ft parking lane. The studies summarized for this review show consistently that virtually all bicyclists will ride in the door zone in this configuration. The 2014 NCHRP report on bike lane widths states clearly that "the design of the bike lane should encourage bicyclists to ride outside of this door zone area and should account for the width of the bicyclist." Given the findings about the extent of the door zone in the report, a 4 foot buffer adjacent to a minimum 7-foot parking lane is needed to insure that bike lane users are outside the door zone. Yet the report's detailed design guidance does not recommend this, since it provides guidance for bike lanes with on-street parking where the total width available is less than 25 feet, which is the minimum total space needed to meet the minimums for parking lane, travel lane, and bike lane while including a 4-foot buffer. Further, even where there is at least 25 feet available, the report recommends allocating some of the space to provide a buffer to the travel lane. By its own admission, the report includes recommended designs that do not keep bicyclists out of the door zone: "Where bicycle lanes are designed according to the guidance [in this report], it should be recognized that bicyclists will still likely position themselves within the door zone of parked vehicles." The report authors acknowledge the discrepancy between their findings and their guidance:

> The basic question that has to be posed is, "Particularly for constrained or fixed roadway widths, which facility type is most desirable from a bicyclist perspective: a shared lane, a marked shared lane, or a bicycle lane?" This research did not answer this basic question, but rather focused on providing design guidance for a bicycle lane given the decision that a bicycle lane will be installed. (*21*)

This willingness to provide designs that are known to cause people to operate within the door zone might be re-examined in light of the findings in the first part of this review that dooring collisions may be the single most common cause of car-bike collisions in urban areas with on-street parking, and that their prevalence has gone unnoticed because they are systematically excluded from crash reports.

The new standards for separated bike lanes adjacent to on-street parking all include a requirement for a buffer zone between parked cars and the bike lane. However, the guidelines for standard bike lanes do not include this requirement, with the notable exception of the *Ontario Traffic Manual*. Proponents of separated bike lanes claim that they help prevent dooring: "Rather than having a bike lane between parked cars and moving cars, a parking-protected bike lane is between parked cars and the curb, reducing the risk of crashes due to opening car doors and double-parking. . . Parking-protected bike lanes include a buffer, where vehicle doors can swing open without overhanging the bike lane." (*37*) But it is the buffer zone between the parked cars and the bike lane that reduces the risk of dooring—and which could equally do so if it were employed with a standard bike lane.

Requiring a buffer for standard bike lanes will require cities to acknowledge the reality that bike lanes do not fit next to on-street parking without at least 3 feet more of width than is currently provided in the minimum guidance, thereby necessitating at least 25 feet between the left edge of the travel lane and the curb, rather than the 22 feet that is possibly under current standards. Under such constrained conditions, if it is not deemed possible to remove parking, bicyclists should be encouraged to ride in the travel lane. This can be accomplished by the use of shared lane markings and Bicycles May Use Full Lane signs. Such treatments have now become common and are permitted on roads with speed limits of 35 mph or less. Most areas with on-street parking have lower speed limits, since on street parkers must stop and reverse in the travel lane.

CONCLUSIONS AND RECOMMENDATIONS

This paper has reviewed the available evidence and found that:

1. Motor vehicle crash reports exclude crashes between bicyclists and parked cars by definition. Thus the full extent of the dooring problem is not known.
2. The studies that do include door-opening incidents reveal that they are one of the most common causes of urban bicycle-motor vehicle collisions, accounting for 12% to 27% of the total.
3. Current guidelines for ordinary bike lanes insufficiently account for the door zone, as demonstrated by several studies that show most bicyclists using bike lanes adjacent to parking are not far enough away from parked cars to avoid a suddenly opened door.
4. A 3 ft buffer zone is described in the design guides as an essential component of separated bike lanes. Ordinary bike lanes have an equal need for a buffer.
5. Shared lane markings centered in the travel lane can help to move bicyclists away from the door zone.

Based on the findings, the following recommendations are offered:

1. Revise bike lane guidelines to include a marked buffer whenever a bike lane is installed adjacent to parked vehicles.
2. Revise the shared lane marking standard to require that it be centered in the shared lane.

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