

Rethinking Bike Lane Design Standards: The Importance of an Operating Concept

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Abstract

Although one of the purposes of bike lanes is to improve bicyclist safety, designs based on AASHTO and MUTCD standards and guidance do not minimize common types of bike lane crashes. They expose bicyclists in bike lanes to preventable crash risks and close passing by motorists. They may not induce motorists to merge into bike lanes before turning. This is because bike lane design guidance lacks a coherent concept of how bike lanes operate and how road users are expected to respond to them. The lack of an operating concept for bike lanes has resulted in road infrastructure that is less safe and efficient than if a more systematic approach was used in the development of standards and guidance.

An operating concept for bike lanes focuses on understanding the bike lane design user, encouraging compliance with traffic laws, and assessing whether bike lanes achieve the goal of reducing bicycle/motor vehicle crashes. It applies roadway design principles that minimize crashes between bicyclists using bike lanes and motorists. Because state and local agencies take their lead from AASHTO and MUTCD standards and guidance, it’s essential to base them on a coherent operating concept.

WHY AN OPERATING CONCEPT FOR BIKE LANES IS IMPORTANT FOR SAFETY

Standards and guidance for bike lanes lack a coherent concept of how they operate, including how road users are expected to interact with them and whether they achieve their goal of reducing bicycle/motor vehicle crashes. The absence of a sound operating concept has resulted in highway infrastructure that is less safe and efficient than if a more systematic approach had been used in the development of bike lane (BL) standards and guidance.

A coherent operating concept is that bike lanes:

- are intended for bicyclists who do not have high traffic and crash avoidance skill levels
- provide shy clearance from the bicyclist to fixed and moving objects
- provide a clear, consistent and continuous path of travel
- enable bicyclists approximately centered in a BL to avoid edge debris and other edge hazards
- position bicyclists approximately centered in a BL within scanning range of conflicting road users
- enable bicyclists approximately centered in a BL to operate clear of parked vehicle doors suddenly opened into traffic
- encourage turning motorists to merge into the BL before intersections as required by traffic laws (except in Oregon) by providing enough width to drive completely within the lane
- clarify and encourage appropriate yielding behavior by bicyclists and motorists
- allow bicyclists to make lawful movements to/from a BL, e.g., to pass slower right turning traffic, turn left
- deter unlawful encroachment by motorists between intersections
- have initiation/termination signs and markings similar to those for other preferential lanes

COMMON BIKE LANE CRASH TYPES BETWEEN MOTOR VEHICLES AND BICYCLES

Almost three quarters of urban motor vehicle/bicycle crashes occur at intersections, interchanges, alleys, and driveways. The three types of crash types at intersections are the “right hook”, “left cross”, and “drive out”. Of crashes that involve motorists failing to yield to bicyclists at intersections, the left cross is the most common, followed by the right hook. Left cross and right hook crashes also include bicyclists hit by motorists turning into and out of driveways and alleys, and entering/exiting on-street parking spaces. The risk of overtaking crashes is small compared to right hooks, left crosses and drive outs, so we must understand why so many crashes are of those types in order to reduce bike crashes overall. [Hunter 1997]

Intersection crash types

A left cross is a collision between an oncoming, left turning motorist and a through bicyclist (Fig 1). One of the primary crash factors is a left-turning motorist being focused on finding a gap in oncoming traffic at an intersection, driveway or alley and failing to detect a bicyclist. The motorist doesn't notice oncoming users on the periphery (road edge or BL), especially if the motorist is turning across multiple lanes. In addition,

vehicles in traffic lanes adjacent to a BL can block the left turning motorist's view of approaching bicyclists (i.e., the multiple threat). Although the most visible bicyclist position is near the center of a traffic lane, BL design that encourages bicyclists to position themselves further left, closer to where left turning motorist are looking for conflicts, can reduce left cross crashes.

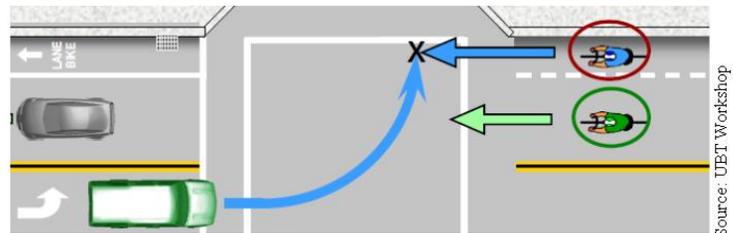


Figure 1: Left cross crash

A right hook is a collision between a right turning driver and a through bicyclist on the driver's right (Fig 2). It can be largely prevented if motorists approach and make the turn from as close as practicable to the right-hand curb or edge of the roadway, as required by law [UVC 2000]. A BL is considered part of the roadway [MUTCD 2009], so when a BL is present, a motorist is required to merge into the BL before turning (except in Oregon).

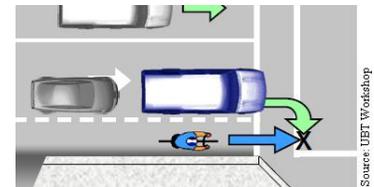


Figure 2: Right hook crash

Right turns and bike lanes

When bike lanes are too narrow to drive a motor vehicle completely within them, they deter right turning motorists from merging into the BL before turning because motorists don't recognize them as allowing motor vehicles. When a motorist instead turns from the rightmost traffic lane across a BL, conflicts occur with through bicyclists who approach on the right. In the U.S., right turning motorists tend not to think about or look for narrow bicycles approaching from their right and behind. Even when the bicyclist and motorist do not collide, it causes traffic delay while the bicyclist and motorist negotiate who will go first. The reason the right hook is so common is that bicyclists tend to drive too far to the right (although it's common practice and usually legal to do so) and right turning motorists are reluctant to merge into bike lanes before turning when the BL is narrow.

Bicyclists can avoid being right hooked by not operating far to the right (FTR) and passing potentially right-turning traffic on the right. However, laws that require bicyclists to operate FTR induce bicyclists to stay at the right edge even when those laws explicitly allow bicyclists to leave a BL where right turns are permitted. [UVC 2000]

Motorists, bicyclists and even police don't understand the exceptions in the FTR laws. High road speeds further deter bicyclists from moving out of bike lanes to avoid crash risks and reinforce the belief that bicyclists should stay FTR because they're much slower than motorized traffic.

A BL next to parking can be wide enough at intersections, alleys and driveways for motorists to recognize as a de facto right turn (RT) lane. This is only possible if parking is prohibited far enough from the intersection and the parking stripe (i.e., edge line) is dropped. Nevertheless, parking is too often allowed too close to the intersection (Fig 3). This prevents motorists from merging into the BL before turning.



Figure 3: Parking allowed too close to corner

Dropping a bike lane for a right turn lane

When a BL drops for a RT lane and there's no through BL, it can encourage bicyclist behavior that is unsafe and violates traffic laws. It can increase right hook and left cross risks, as well as sideswipes. Bicyclists, depending on traffic speeds, may stay to the far right of a RT lane, where right turning motorists (especially truck drivers) don't see them or expect them to go straight. Some bicyclists split the lane, or stay to the far right side of an unsharable through lane. A RT lane that lines up with a BL on the far side of an intersection induces bicyclists to make a through movement from it. By staying in the RT lane, the bicyclist avoids merging left into the through traffic lane on the near side, only to merge right again into the BL on the far side. Oncoming left turning drivers don't scan for a through bicyclist FTR in a RT lane, or assume the bicyclist is turning right as required, and aren't prepared to yield to the through movement.

Mid-block crash types

A "rear end" is a collision between a motorist and a bicyclist going the same direction when neither is turning. [Hunter 1997] Many rear end crashes occur when the motorist does not notice a bicyclist riding at the right edge or misjudges the space needed to overtake the bicyclist. It is not known whether a bicyclist using a full lane by riding near the center of a traffic lane is more or less likely to be involved in a rear end crash, but such a bicyclist is in direct view of a motorist so it makes sense that the motorist is more likely to notice him/her.

A "drive out" is a collision between a driver exiting a street, alley or driveway and a passing bicyclist. [Hunter 1997] The potential for a drive out crash increases when driveways are frequent or closely spaced or on-street parking is permitted too close to the intersection, alley or driveway. Drivers entering a roadway are scanning the traffic lane for conflicts with vehicles, and perhaps scanning the sidewalk on each side. Drivers who have yielded to pedestrians on the sidewalk may pull into a curbside BL without seeing a bicyclist because the driver's line of sight is focused on the traffic lane. In other cases, drivers may pull into a BL next to parking before stopping because of parking that's too close to the driveway or alley that blocks their view of approaching conflicts in the traffic lane. Designs that position bicyclists further from the curb, closer to where exiting drivers are looking for conflicts, and prohibiting parking that obstructs corner sight distance can reduce BL drive out crashes.

A "dooring" occurs when an occupant of a parked vehicle opens a door into the path of a bicyclist without yielding. [Hunter 1997] The "door zone" is the distance from side of a parked vehicle to the edge of an opened door, plus shy distance from the door edge and the edge of the bicycle. In some cities, doorings are a high percentage of injury and fatal bike crashes. The AASHTO *Guide for the Development of Bicycle Facilities*, commonly known as the *Bike Guide*, estimates that between 3 and 6 percent of urban bike crashes are doorings, and the percentage can be higher in cities with a high amount of on-street parking. [Bike Guide 2012]

Bicyclists are often advised to scan inside parked cars and to watch out for opening car doors. This isn't a realistic strategy. It diverts bicyclists' attention from the road and other conflicts, e.g., pedestrians stepping into the road, and motorists merging into and out of parking spaces. The *Bike Guide* notes that headrests, tinted windows,

and vehicle designs prevent bicyclists from seeing occupants. Even if an occupant is detected, merging safely to the left before reaching a door isn't feasible at typical bicycle speeds. A bicyclist who swerves to avoid a suddenly-opened door doesn't have enough time to check for conflicting traffic. A bicyclist who collides with a door loses all control. Doorings that involve a door striking the end of a handlebar can be severe, since the bicyclist is usually thrown into the traffic lane. Doorings crashes in bike lanes can be reduced with designs that enable a bicyclist centered in a BL to be outside the door zone. Bicyclist side on-street parking is present in nearly 12 percent of bicycle/motor vehicle crashes. [Hunter 1997]

AASHTO AND MUTCD GUIDANCE DOESN'T MINIMIZE BIKE LANE CRASHES

Bike lanes may attract people who wish separation from motor vehicle traffic, but these users may be least able to recognize the most common BL crash risks and avoid them.

The ITE Traffic Control Devices Handbook notes that poorly designed facilities can be counterproductive to bicyclist safety. [ITE 2012]. Poorly designed facilities place bicyclists where they don't expect traffic conflicts and fail to address that bicycles are vehicles and bicyclists have the same rights and duties as drivers of vehicles, at least as far as the rules of the road are concerned [UVC 2000]. Bike lanes designed to current minimum *Bike Guide* and MUTCD guidance, instead of improving bicyclist safety, may route bicyclists into unexpected conflicts and induce motorists and bicyclists to violate the rules of the road for traffic lanes, rules that motorists take for granted, because such bike lanes don't reflect an operating concept that reflects that bicycles are vehicles and bicyclists are drivers.

AASHTO *Bike Guide* guidance issues - bicyclist operating width and shy distance

The "Design Vehicle" section (3.2) of the *Bike Guide* states that a minimum operating width of 48" (50" preferred) for a 30" bicyclist/bicycle includes normal side to side variation during forward movement, which doesn't include shy distance (which this paper will refer to as "clearance" from fixed objects (*Bike Guide* Fig 3-1). It notes that bicyclists may accept smaller clearances from other users, but never states whether the shy distance from users is also in addition to the operating width. One would think that a bicyclist needs more clearance from moving traffic than from a fixed object, since motorists or bicyclists might move laterally. That section doesn't specify what the minimum clearance should be from each type of user (e.g., bicyclists, passenger cars, buses and motor homes). The "Shared Lanes" section (4.3.1), however, says what the clearance should be to motor vehicles: "Lane widths of 13 ft (4.0m) or less make it likely that most motor vehicles will encroach at least part way into the next lane to pass a bicyclist with an adequate and comfortable clearance (usually 3 ft [0.9 m] or more depending on the speed of the passing vehicle)". But the Guide then fails to discuss this clearance in relation to BL width, and how much of that clearance should be within the control of the bicyclist (within the BL). Is it assumed that all of the 3' clearance should be provided by the motorist in the traffic lane? The entire passing clearance can't come from the bicyclist operating width, since the bicyclist only has 1.25' of operating width on each side in even a 5' BL. There's no discussion of clearance needed from motor vehicles moving at much higher speeds than the bicyclist, who is, after all, at least as vulnerable to injury as a motorcyclist. Close motor vehicle passing can discourage bicyclists from using bike lanes or using bikes for travel generally.

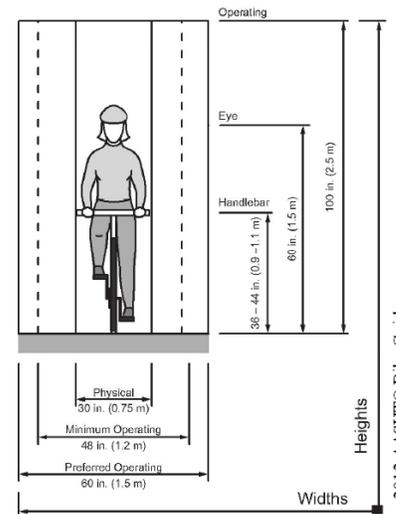


Figure 3-1. Bicyclist Operating Space

Source: 2012 AASHTO Bike Guide

In the same section, the *Bike Guide* measures the usable lane width from the center of the edge line to the center of the traffic lane line, or from the longitudinal joint of the gutter pan to the center of the lane line: "The gutter should not be included in the measurement as usable width, as bicyclists will typically ride well to the left: of the

joint". It acknowledges bicyclists will ride well left of the gutter joint and it shouldn't be included in the usable lane width for a traffic lane when considering if bicyclists can share side by side with a MV, yet they include the gutter in the width of a 5' BL, without really discussing the operating ramifications of only 3' being available with a 2' gutter. So if a bicyclist is riding 1' from the gutter joint in a lane with only 3' left of the gutter joint, there's exactly 2' from the center of the bicyclist to the BL line – the minimum operating width. There's no clearance in the BL to a car, bus, truck or motor home whose driver may be within a foot of the BL line. For people using adult tricycles, trailers, or cargo bikes, the situation is worse: if the right wheel is 1' off the gutter joint, and the non-gutter width is 3', the left wheel of a 30" wheelbase bike is outside the BL. That is not a coherent operating concept for a curbside BL.

Buses and other wide vehicles, and even automobiles are often driven close to the BL stripe. It's worse when traffic lanes are narrowed to 10' or 11' to provide room for a BL, leaving motorists in the adjacent lane little ability to provide the 3' minimum clearance next to bikes recommended in the Guide. At least some of the clearance should be provided in the BL itself.

***Bike Guide*/MUTCD guidance issues – bike lane with parking**

Narrow bike lanes next to parking and curbs reinforce the belief that bicyclists should always stay far to the right, even in lateral positions that a motorist would recognize as high risk (door zones, close to the curb at driveways). Yet bike lanes designed to *Bike Guide* widths entice bicyclists into them (and FTR laws require bicyclists to use them).

The ITE TCD Handbook's estimate of the door zone and where a bicyclist should be centered where parallel parking's permitted is realistic. In its discussion of Shared Lane Markings (commonly known as sharrows), the TCD notes that MUTCD's minimum sharrow distance of 11' from curb when there's parallel parking is based on a study in San Francisco that found an 85th percentile distance of 11' from the edge of opened car doors to the curb. Six inches shy distance was assumed to the handlebar end, and half the width of a 24" handlebar was added to arrive at 11'. But the ITE TCDH concludes this width is inadequate, based on the consequences of striking a door that protrudes more than the 85th percentile, vs a driver modestly exceeding a speed limit set by the 85th percentile, and states that a higher percentile value should be used. It states that the vehicle width and opened door width of common SUVs and two door vehicles parked 1' from the curb can be 9.6'; and assumes that motorists will park 1' from the curb. ITE considers the first 11' from the curb to be an unsafe bicycling area when there's on street parking and notes that a 6" shy distance may be too narrow. It recommends centering a 40" sharrow at 13' for adequate door zone clearance, which reflects a shy distance to the door edge of about a foot.

Since a bicyclist is expected to be centered on a sharrow, this minimum lateral bicyclist position of 13' from the curb should be the beginning of the process to design bike lanes next to on-street parking.

The *Bike Guide* says since 5' is the preferred bicyclist operating width, "...therefore, under most circumstances the recommended width for bike lanes is 5 ft (1.5m)." The *Bike Guide*'s BL stripe minimum distance from curb is 12', positioning the bicyclist who is in the middle of the BL at 9.5'. All but about 6" of the BL is in the door zone (Fig 4).



Figure 4: 5' Bike lane next to 7' parking

The *Bike Guide* recommends a BL width of 6'-7' next to 7' (13'-14'/7') parking only where there's high parking turnover.

While this may provide shy distance from vehicle sides, it doesn't, as the *Bike Guide* claims, "provide more operating space for bicyclists to ride out of the area of opening vehicle doors." A 13'-14' BL is still in the door zone (Figs 5 and 6). In areas without "high turnover", there's no position in the BL that isn't in the door zone. Is it

acceptable to induce bicyclists into a high risk position based on a subjective metric such as “high parking turnover”?

Following the process for arriving at 13' for a bike to be centered over a sharrow, with the door zone extending to 11.6', only 0.4' of a 12'/7' BL is available for use. A bicyclist would be centered 1' into the adjacent traffic lane of a minimum 12'/7' BL, or on the stripe of a 13'/7' BL, and only 1' inside the stripe of a 14'/7' BL. In other words, the recommended-width for a BL is insufficient for a bicyclist to avoid the door zone. In the section entitled “Bicycle Lanes and On-Street Parking” (4.6.5) the *Bike Guide* recommends a width of 6' next to 7' parking without mentioning parking turnover, but two sentences later reverts to a condition of high parking turnover.

Where parallel parking is permitted but the parking lane is not marked the recommended total width of 13' – not 13' to 14', as when parking is marked, then, when parking usage is “low” and turnover’s “infrequent”, 12' may be satisfactory. Why should the absence of a marked parking lane reduce the width recommended for a BL? It seems to imply that the risk of the occurrence is low even though it says up to 6% of urban bike crashes are doorings and they're a high percent of injury/fatal bike crashes. This guidance ignores the injury risk and fails to explain why a bicyclist should ever be subjected to a dooring in a lane that's purported to increase bicyclist safety. Is it ever permissible to route unsuspecting bicyclists into the door zone? That is not a consistent operating concept.

The *Bike Guide* briefly discusses dooring but says bicyclists can avoid it by riding on left side of BL, outside the door zone. But to what BL width does the *Bike Guide* mean this to apply? It's not explained. Even the left side of the *Bike Guide*'s 12'-13'/7' BL is in the door zone.

But even ITE's BL recommendation still locates the parking stripe at 9' and BL line at 14'. The opened door protrudes 1.6' into BL, and a 1' shy distance extends the unusable space to 11.6', taking up 2.6' of a 5' BL. This leaves a bicyclist only 2.4' (1.6' less than the recommended operating space for a bicyclist and less than the width of a bicycle trailer or some cargo bikes) in which to operate and no clearance to the lane stripe. The left wheel of a trailer, or handlebar end of many conventional bikes, is on or into the traffic lane. Therefore, even cycling in the leftmost part of a 14'/9' BL with the right edge of a bicycle 11.6' from the curb doesn't provide enough bicycle operating space or clearance to traffic. This is an unrealistic way to expect bicyclists to position themselves and contrary to a bike lane's (or any traffic lane's) operating concept.

In the section of the *Bike Guide* entitled “Contributing Causes of Bicyclist-Motor Vehicle Crashes and Recommended Countermeasures” (section 3.4.3), one of the remedies to dooring is training bicyclists not to ride too close to parked cars. It cites a design treatment to reduce the likelihood of a dooring crash: “If a bike lane is marked next to a parking lane, using a second stripe between the bike lane and parking lane helps place bicyclists further from parked cars”. But it doesn't say how far out that second stripe should be, since it doesn't give dimensions for the door zone. It also notes that some communities have used sharrows to encourage bicyclists to operate away from parked cars. Even using the MUTCD-recommended location of a sharrow 11' from the curb, the wheels of a bicyclist who is centered 11' from the curb in a 12' BL are only 1' from the lane line and still in the “door zone”. The rear wheel (for an adult tricycle or trailer) or left handlebar end (for a conventional bike) is either directly above or left of the BL line. How could this possibly be a valid BL operating concept?



Figure 5: 13'/7' door zone bike lane



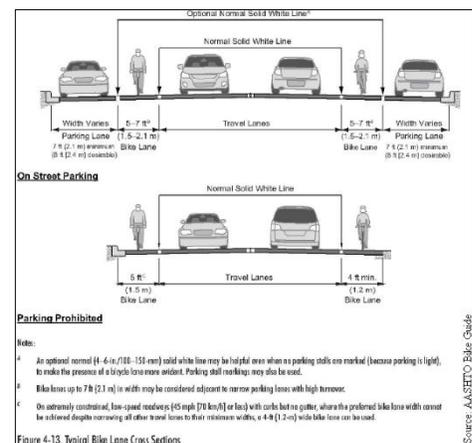
Figure 6: 14' door zone bike lane

Bike lanes next to parking need to be wide enough to allow bicyclists to operate outside the door zone. They need to provide clearance in addition to a bicyclist's operating space for side to side variation between bicyclists and the adjacent traffic lane. Not all of the clearance between a bicyclist and adjacent traffic should be provided by the driver in the traffic lane. When drivers don't provide enough clearance for various reasons, it can cause bicyclists to shy to the right, towards parked vehicles as they try to create clearance from moving vehicles. Yet a minimum width, or recommended width BL next to parked vehicles doesn't allow a bicyclist to operate clear of the door zone unless the bicyclist is positioned on or to the traffic lane side of the BL stripe.

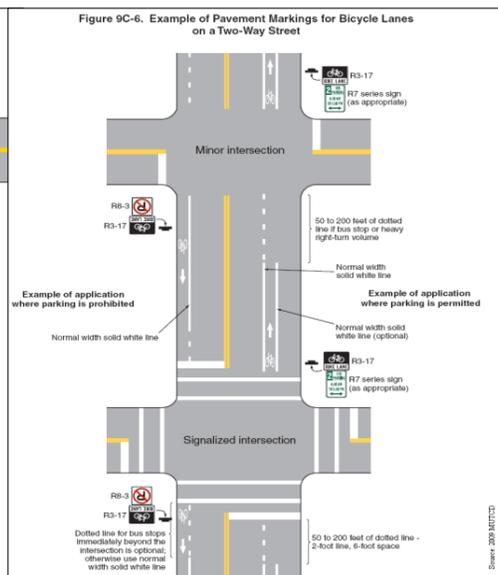
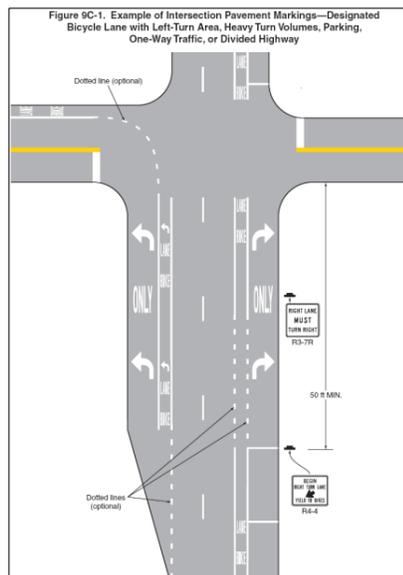
Bike lane standards and open car doors

The BL standards that the second author helped develop in the 1970s didn't account for opened vehicle doors. It was thought that people in cars would not unlawfully open their car doors without yielding to traffic, including bicyclists. Almost 40 years of experience has shown this as a flawed assumption. Since the guidance for BLs next to parking was established, awareness of dooring crash risks has grown. This crash risk, and how to minimize it through better BL design, is thoroughly discussed and illustrated, often with dooring videos, seemingly everywhere – except in the *Bike Guide* BL standards. While the *Bike Guide* acknowledges that dooring crashes are a significant cause of urban bike crashes, and that bicyclists should ride out of reach of doors, the Guide and the MUTCD seem unable or unwilling to estimate how far away from the sides of parked vehicles bicyclists should operate to avoid this risk, or estimate the width of the door zone for various vehicles. Thus BL width minimums next to parking remain the same – in the door zone – in spite of the evidence of the danger. In addition to the dooring risk, bicyclists in the *Bike Guide*'s minimum and recommended bike lanes are at risk of being hit by motorists leaving the parking lane, since there's so little clearance between the bicyclist and the parked vehicle.

This unrealistic guidance is reinforced by the *Bike Guide*'s equally unrealistic illustrations. Consider the 5' BL next to parking. The *Bike Guide*'s Fig 4-13 show bicyclists centered in the BL. The BL is supposed to give the bicyclist 60" of operating space. A bicyclist may need more space because of cargo bike widths up to 33" or trailer sway. In either case, no shy clearance is provided to parked vehicles or to the traffic lane.



When a 5 or 6' BL is adjacent to parking and parking is allowed too close to an intersection the conflict isn't just in the mind of the driver; the driver is unable to enter the BL prior to turning. At the intersection the driver is forced to turn across, instead of from, the bike lane (Fig 3). Yet the MUTCD has no standard or guidance on the distance a "no parking" zone should extend from the corner when a BL is present. The MUTCD should include this in figs 9C-1 and 9C-6.



***Bike Guide*/MUTCD guidance issues - bike lanes parking prohibited**

The *Bike Guide*'s recommended width for BLs next to curb and gutter is 5' to face of curb, leaving only 3' to 4' of operating space outside of, respectively, a 2' or 1' gutter (p 4-14). The only exception is for higher motor vehicle speeds (over 45 mph) and 2' gutter, in which case the preferred width is 6' including gutter. But the usable BL width is still only 4', with no passing clearance. Why does the *Bike Guide* exclude the gutter from the traffic lane width in the shared lane discussion (Sec 4.3.1) but include it as part of BL width? It leaves the reader the impression the BL is wider than it is.

Bicyclists with trailers, adult tricyclists, recumbent, and cargo bike riders with one 2-wheeled axle will need to keep the rightmost wheel 1' from gutter. For a 5' BL with a 2' gutter, the left wheel of the 2-wheel axle will be 6" outside the BL, and for a 5' BL with a 1' gutter the left wheel will be only 6" inside the BL. This design bicyclist has only 3' of operating space within the BL – barely more than their physical width and a full 1' less than the 4' minimum operating space for the *Bike Guide*'s design bicyclist. That is not a sound operating concept for a BL next to high speed traffic.

The *Bike Guide* recommends a 6' to 8' BL width in areas of "high bicycle use" (another subjective metric), because it "...makes it possible for bicyclists to ride side by side". Yet 4' is the minimum operating width of a bicyclist, with no shy distance to objects, much less another bicyclist who may vary his/her position. Six feet is only 1' wider than the total width of two stationary bicycles! There's no connection to the essential operating space discussion in Chapter 3, nor are dimensions given for clearance to other moving bicyclists or motor vehicle traffic.

It continues, "On high speed (over 45 mph) and high (another subjective metric) volume roadways, or where there is a substantial volume (still another subjective metric) of heavy vehicles, a wide (no numerical value is given) bicycle lane provides additional lateral separation between motor vehicles and bicycles to minimize wind blast..." This guidance seems to sanction 5' BLs on 45 mph roads that don't provide lateral separation. This does not seem like an operating concept that values the safety of the novice bicyclist. A little cycling experience will tell you that 45 mph is not "low speed". The *Bike Guide* should not use 45 mph to describe "low speed" for the purpose of BL design.

Furthermore, debris swept from traffic lanes often collects in bike lanes. Often only the left 1' of a BL is relatively free from debris, forcing bicyclists to ride with the left side of their handlebars on the BL stripe. Street sweeping schedules for bike lanes need to be accelerated in order to keep them free from debris, but public agencies don't seem to have the resources. Keeping the BL away from the gutter is a more realistic strategy.

***BIKE GUIDE*/MUTCD guidance issues - bike lane width at intersections without a designated RT lane**

As noted above, a motorist's failure to merge into a BL before turning right creates the risk of a right hook crash. Bike lanes designed using *Bike Guide* and MUTCD guidance where turns are permitted creates conflict in the minds of drivers due to expectations they've learned from other drivers, widespread cultural beliefs, and/or their interpretation of VC sections or the drivers' manual:

- Drive entirely within a single lane(no straddling)
- Must enter BL before turning (except in Oregon)
- Don't drive in bike lanes; they're for exclusive use of bicyclists

The conflict arises when the BL is so narrow that only part of the vehicle can occupy it and the vehicle straddles the BL and the traffic lane. Motorists expect to use traffic lanes 9 to 12' wide or wider. This mental conflict sets the

stage for the right hook crash where turns are permitted. The requirement to enter a BL before turning also conflicts with an incorrect but widespread cultural belief that bicyclists should always be at the right edge.

Bike lines of 5' or 6' at intersections don't induce motorists to merge before turning because of this mental conflict. They don't recognize bike lanes as available for turning.

The *Bike Guide* states (p 4-11), "Properly designed bike lanes encourage bicyclists to operate in a manner consistent with the legal and effective operation of all vehicles." That statement should also apply to bicyclists. Yet "properly" striping a narrow curbside BL to the intersection deters turning motorists from merging into the BL - hardly "legal and effective."

The *Bike Guide* so lacks the BL operating concept that it's statement about when bicyclists can leave a BL doesn't include "where right turns (or left turns on a one way street) are permitted." (p. 4-11) This is a key exception in many vehicle codes that protects bicyclists from being trapped in a right hook position in a BL.

Driver training (DMV manuals) and most importantly driver license testing does not address this problem by ensuring motorists understand that straddling a traffic lane is required. Training and testing would have to be intensive to overcome the intuitive understanding that you should drive entirely within a lane. It takes far less effort to make BLs at intersections look like traffic lanes, with enough length to enable motorist to merge into it before turning. In the case of BLs next to parking, this requires prohibiting parking further from the corner. We can't rely solely on educating motorists and bicyclists to resolve the mental conflict and undo widespread cultural beliefs. Both engineering and education are needed.

Current MUTCD BL striping standards (or lack thereof) for curbside BLs encourage bicyclists to stay at the right edge and motorists to start their turns from the traffic lane. To be consistent with its advice for bike lanes with right turn lanes, the *Bike Guide* should recommend that a bicyclist continuing straight through an intersection from the right of a traffic lane from which right turns are allowed would be inconsistent with normal traffic behavior and would violate the expectations of turning motorists.

Solid and dashed stripes that define a narrow BL contribute to the mental conflict described above. It should be clear from the frequency of right hooks that any design that requires a motorist to enter a BL that requires a lane straddle is undesirable. To discourage right hooks, MUTCD Figure 9C-6, which shows a narrow BL striped to the corner, should instead reflect a standard for BL striping that allows motorists to avoid straddling at intersections without RT lanes. The stripe of a narrow (5'-6") BL should be dropped entirely to provide a "drivable" space and a sharrow at least 8' from the curb should be included to signal bicyclists to move away from right hook position and inform motorists where to expect through bicyclists.

As discussed below, a more desirable option is to position a BL (parking prohibited) further away from the curb, so it can be a wide BL that motorists recognize as a lane.

***Bike Guide* /MUTCD guidance issues – bike lane to left of RT lane at intersection**

When both a through BL and a RT lane is provided at an intersection, and a BL is adjacent to the curb, the curb line can be offset to the right to accommodate the RT lane width. If the curb isn't offset, the *Bike Guide* recommends that the BL terminate and then after an undefined break, resumes further to the left to delineate the intersection BL. The *Bike Guide*'s Fig 4-21 illustrates this situation, which it says "...should be avoided when practicable"

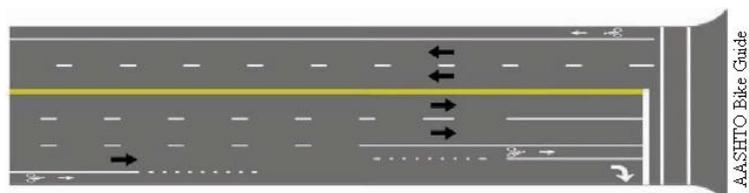


Figure 4-21. Example of Bike Lane with Through Lane Transitioning to Right-Turn-Only Lane

Source: AASHTO Bike Guide

The *Bike Guide* points out that although the travel lane adjacent to the bike lane becomes a RT lane the BL shouldn't be striped diagonally to connect the two BL segments nor should a "RT yield to bikes" sign be used because bicyclists "...are the users who need to yield as they are weaving across the path of motor vehicle traffic". The ITE TCDH's description of the same figure (ITE Fig 14-24) is similar: "...in this case the bicyclists are the road users needing to yield to traffic continuing in the lane"

Both publications, however, are in error. That's not what this figure depicts. It depicts the through traffic lane and the BL crossing each other with neither movement having priority. Motorists in the through traffic lane can't continue into the BL and through bicyclists cannot continue into the RT lane. In the "no man's land" where the BL marking is dropped completely, the obligation to yield is ambiguous. It's a simultaneous left merge of through bikes and right merge of turning drivers, with neither having ownership of the wide traffic lane. AASHTO doesn't merely need to revise the title and description of the figure. The *Bike Guide* needs to explain the yielding uncertainty and heightened risk of conflict this design creates compared to a design that clearly establishes which line of traffic has control of a lane, whether it's a traffic lane or BL.

The *Bike Guide's* BL width next to a RT lane is 4' minimum and 5' recommended. But, as described above, this does not provide any shy distance from motor vehicles in either the RT lane or the adjacent through traffic lane. Assuming that half of the shy distance of 2' needs to be provided on each side, the recommended width of a BL next to a RT lane needs to be increased by 2' to 6' or 7'. If more shy distance is desired because of high speed differentials between bicycle and motor vehicle traffic, then the BL should be even wider.

Bike lane dropped for rt lane – bicyclist must merge into shared travel lane

Of all the solutions in the *Bike Guide* to address the right hook conflict, none includes wide bike lanes that encourage motorists to enter the BL. The City of Cupertino, CA, which widened bike lanes to a full lane width at intersections, found that motorists routinely merge into the BL before turning, preventing the right hook crash. Most likely that is because the BL looks like a normal traffic lane.

Actually, dropping a BL to make room for a right turn lane does not serve the target BL customer and therefore violates the BL operating concept.

AN OPERATING CONCEPT CAN REDUCE BIKE LANE CRASHES THROUGH IMPROVED GUIDANCE

Designing bike lanes with an operating concept would serve bicyclists with a lower degree of operating and crash avoidance skills, and serve bicyclists at higher levels of service. It would serve bicyclists using tricycles, bikes with trailers, recumbent bikes, and cargo bikes. Such bike lanes would:

- provide adequate clearance from motor vehicle traffic;
- provide a consistent/continuous path of travel;
- enable bicyclists to avoid edge hazards and the door zone;
- position bicyclists within scanning range of potentially conflicting traffic;
- encourage motorists to merge into the BL before turning;
- deter unlawful use of the BL;
- encourage proper positioning in the road
- encourage safe yielding behavior where the lane ends and other locations;
- allow bicyclists to make necessary movements to/from a BL; and

- have signs and markings similar to other preferential lanes so bicyclists and motorists recognize how to respond to them.

These are all concepts intrinsic to traffic lane design. Designing bike lanes with the principles applied to other traffic lanes meets driver expectations and minimizes conflicts.

Guidance based on an operating concept might recommend that if providing a RT lane causes a BL to be discontinuous or the obligation to yield to be ambiguous, or creates difficult merges or lane changes, a wide BL instead of a RT lane should be provided. The focus of BL design should be on simplicity and safety.

Providing operating space and some clearance to adjacent or opposing traffic is fundamental traffic lane design concept. Traffic lanes provide shy clearance to vehicles in adjacent lanes. So should bike lanes.

Bike lanes need to provide clearance to adjacent traffic lanes so the bicyclist isn't dependent on motorists to provide all of the clearance. A 12' traffic lane provides 1.75' for the maximum legal width vehicles. They get additional clearance from the adjoining lane as long as those drivers don't hug the line. Yet bicyclists are dependent on adjacent vehicles for almost all of the shy clearance. Instead, the shy clearance should be provided by the BL itself. That means for the *Bike Guide* design bicyclist operating space of 4' and a shy clearance of 3' to the adjacent travel lane and 2' to fixed objects, the minimum BL width needs to be 9' (or for a BL between two traffic lanes, 10'). In the past, it was feared that motorists would confuse such wide bike lanes for traffic lanes, but by providing such things as right side buffers or frequent BL markings would clarify the situation. At the same time, such wide bike lanes would make it clear to motorists that they are not prohibited from merging into them to park or to make right turns.

The *Bike Guide* needs to show and describe realistic figures instead of deceptive ones. The *Bike Guide's* Fig 4-13 showing bike lanes with and without parking is not to scale (the bicyclist appears to be less than 2' wide instead of 2.5') and it doesn't show opened vehicle doors, making it appear that the bike lanes provide more operating space than they really do. They don't show maximum legal width vehicles such as buses and motor homes. All figures should be drawn to scale, with maximum legal width vehicles. Using the 85th percentile for the extension of an opened car door is insufficient. Instead they should use the 95th percentile value. The "design bicyclist" should be a bicyclist with a trailer or operating an adult tricycle or recumbent or cargo bicycle. By providing realistic figures designing for the design bicyclist, and being consistent with the way it expresses the width of a BL (excluding the gutter, as it does with a shared use lane), the *Bike Guide* will provide a true picture of where a bicyclist is positioned in a lane, and it will be clearer whether the minimum BL widths support the BL's operating concept.

Bike lanes next to parking

A BL operating concept takes a consistent approach to safety. If bicyclists can operate clear of the door zone in shared lanes then BL designs should do the same by providing appropriate lane width, placement and pavement markings. Recommendations found on bicycling websites and in the Caltrans "Understanding Bicycle Transportation" workshop vary in terms of how to alert bicyclists to and provide clearance from the door zone, where the BL and parking stripes should be located and whether additional pavement markings should be used to mark the door zone. The common element is a BL operating concept, which in turn is consistent with the TCD Handbook's conclusion of the distance that a bicyclist should be from the curb. Designs for bike lanes next to parking that are consistent with the BL operating concept have the following characteristics:

1. BL stripe at 16' minimum from curb (Fig 7). It assumes a vehicle is parked 1' from curb and provides 1' shy distance from the edge of bicycle to the door edge. Parking stripe or Ts are 11' from the curb. Some of the shy clearance from the door is in the BL, but if



Figure 7: 16/11' bike lane

the bike symbol is centered no closer than 22” from the parking stripe, and the bicyclist is centered on the bike symbol, the handlebar end or the right wheel of a trailer is clear of the door zone. This design gives a stationary bicyclist 23” of clearance to the BL stripe.

2. BL stripe at 17’ preferred, and parking lane stripe at 12’ (Fig 8). This allows the bicycle’s handlebar end or right wheel to be 6” outside the parking lane stripe and still have 1’ shy clearance from door edge.
3. BL stripe at 16’ (17’ preferred); no parking lane stripe; pavement markings for the door zone begin at 8’ from curb and extend to 11’ (12’ preferred).



Source: UBT workshop

Figure 8: 17/12’ Bike Lane

Regardless of laws that require vehicle occupants to yield before opening doors into traffic, too many people don’t comply. A door zone BL serves as little more than a buffer that deters motorists from driving in the door zone. It’s worse than no BL at all, because it undermines the operating concept of a BL – it should improve bicyclist safety. Cities often shoehorn in bike lanes at the behest of the public, but the perceived comfort of a too-narrow BL is at odds with preventing crashes. It undermines the training of bicyclists not to ride in the door zone and subjects bicyclists to harassment by police and the public for not using it.

We need to focus on the BL user, encouraging appropriate yielding behavior and preventing the most likely crashes by providing detailed guidance on sight lines for bike lanes next to parking. The *Bike Guide* should adopt operating concept based guidance for bike lanes next to parking to reduce dooring risk and provide lateral clearance to adjacent lanes and clear sight triangles. The MUTCD needs to include guidance for pavement markings that can be used to buffer a BL from the parking lane to warn bicyclists of the door zone hazard.

Bike lanes parking prohibited

As discussed earlier, where parking is prohibited, minimum width bike lanes not only position bicyclists out of the central vision of motorists, they provide as little as 3’ of operating space and position bicyclists close to where debris accumulates. They deter motorists from entering them before turning right into driveways and alleys, setting up “right hook” crashes. In a curbside BL, the rightmost foot or two is unusable gutter.

Designs that position bicyclists further from the curb and give bicyclists more time to react to a motorist who exits a driveway and prohibiting parking that obstructs corner sight distance can reduce BL drive out, right hook and left cross crashes. Such designs also help bicyclists avoid debris that can cause a bicyclist to crash or swerve suddenly into traffic, and help position the BL for the intersection. Although the first foot or two of the BL may still accumulate debris from the sweeping effect of motor vehicles, the bicyclist can use the right half of the BL, and part of the buffer if necessary.

A BL can be moved further from the curb by striping both sides of the BL, providing at least 2’ of clearance between the right stripe and gutter joint. Buffers wider than 5’ can be mistaken by motorists for parking lanes; they should include pavement markings to prohibit motor vehicles. (Fig 9)

In addition to increasing bicyclist visibility, a right side buffer can become a RT lane at an intersection or driveway by dropping the buffer for the RT lane. The BL maintains continuity and the



Source: UBT workshop

Figure 9: Right bike lane buffer midblock

bicyclist doesn't have to shift significantly to the left. Motorists easily understand how to yield and merge across the BL to enter the RT lane just as they would merge across another traffic lane.

When a RT lane is not provided, the buffer can be dropped on the intersection approach to create a BL that's wide enough to induce right turning motorists to enter before turning (Fig 10). Where the curb line varies, a right buffer can help the BL (and bicyclist) maintain a consistent position in the road, preventing "curb diving" (Fig 11).

While some cities already use buffers to move bike lanes away from the curb, the MUTCD needs to include explicit guidance for right side BL buffers.

Bike lanes at intersections, driveways and alleys

Since such a high percentage of bike/motor vehicle crashes happen at intersections, driveways and alleys, locations where turning movements occur need to induce proper yielding and merging behavior.

Since laws in all states except Oregon require drivers to drive as close as practicable to the right hand curb or edge of the roadway before turning, the BL becomes a de facto RTL for motorists but remains an optional lane for bicyclists (bicyclists can both go straight and turn right). Such wide bike lanes also allow for motorists to use them without straddling. We should not expect motorists to turn right from a lane that they must straddle

When a BL isn't provided next to a RT lane at an intersection, providing a BL that is the normal width of a RT lane will reduce right hooks because it resolves the mental conflict between driving completely within a lane and entering a BL before turning. This allows through bicyclists to position themselves within the central field of vision of oncoming left-turning motorists, reducing left cross crashes. It should be the preferred treatment even when the approach doesn't have a BL, because the objective is allow the bicyclist to maintain a consistent lateral position from the near side to the far side of the intersection, without having to change lanes to the left to avoid the RT, only to merge right again on the far side of the intersection

When a BL is next to parking and there's no RT lane at the intersection, extending the "no parking" zone back from the corner will ensure that the BL is at least as wide as a normal turn lane and will induce drivers to enter the BL before turning. The length of the no parking zone should be determined the same way the length needed for a RT lane is determined. It needs to give drivers enough time to yield to bikes before entering.

Instead of a wide BL from which motorists make right turns (Fig 12), Fig. 14-12 of the ITE TCDH recommends an intersection treatment that uses sharrows (Shared Lane Markings) in the left side of a RT lane, when the bicyclist approaches a RT lane from a shoulder or when motor vehicle speeds deters through bicyclists from merging into a through lane. This conflicts with bicyclists having the same duties as drivers of vehicles, so the TCDH points out that some states might have to change their laws. The FHWA's MUTCD adoption status webpage for bicycle traffic control devices even states that "... facilitating the bicycle lane through the exclusive turn lane can be done at the present time if Shared Lane Markings are used instead of bike lane markings."



Figure 10: Right buffer dropped at intersection



Figure 11: R buffer prevents "curb diving"

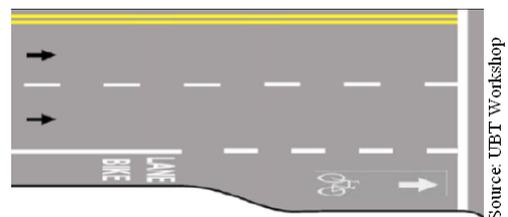
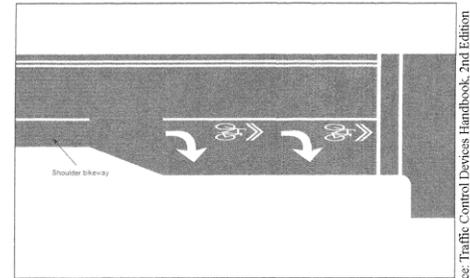


Figure 12: Wide bike lane in advance of intersection

While this treatment is more consistent with a BL operating concept, because it allows a bicyclist who approaches an intersection in a BL or shoulder to proceed straight and not have to merge into through motor vehicle traffic, a wide BL that functions as an option lane for bicyclists and a RT lane for motorists has advantages. In every state, right turns are to be made from as far right on the roadway as practicable (except in OR when there's a BL).

- UVC 11-601 - Required position and method of turning*
The driver of a vehicle intending to turn shall do so as follows:
(a) Right turns - Both the approach for a right turn and a right turn shall be made as close as practicable to the right-hand curb or edge of the roadway.

FIGURE 14-12. Example of Shared Lane Markings in a Right Turn Only Lane



SOURCE: John Ciccarelli.

Source: Traffic Control Devices Handbook, 2nd Edition

Because a BL is considered to be part of the roadway and thus right turning motorists are required to merge into the BL before their turn (except in Oregon), a wide BL requires no special treatment (doesn't require a sign to allow through bike travel), doesn't require understanding that the sharrow means "OK to go straight"; it doesn't require a break in the BL striping, so the bicycle lane is continuous, and it doesn't require understanding an "exception" sign (because no sign is necessary).

The MUTCD already includes guidance on the marking of a motor vehicle preferential lane at intersections. Unfortunately, it has no sign advising drivers of non-preferential vehicles that they are required to merge into the preferential lane before turning right. The lack of such a sign in the MUTCD is a serious omission and should be rectified. However, even this omission is not a deterrent to wide bike lanes at intersections, since no sign is needed to allow motorists to enter the BL to turn right. Indeed, they're required to.

While the sharrow may help with destination positioning, the sharrow alone may only add complexity by creating more differences for the meaning of RT lanes to bicyclists and motorists and adding a new meaning for the sharrow. A sign may be needed as well as change in law to exempt bicyclists from the RT requirement. The MUTCD's permitted use for a sharrow is for bicyclist lateral positioning, not to convey that it allows through travel from a mandatory turn lane. A change in law without the sign would make it even more complicated than it already is to understand differences between motorists' and bicyclists' rights and duties.

Ending the midblock BL in order to install a right turn lane along with a RIGHT LANE MUST TURN RIGHT sign with an EXCEPT BIKES plaque is not desirable. It makes the BL discontinuous, which is a disadvantage for the target consumer of bike lanes. Even the addition of a RT sign with an "EXCEPT BIKES" plaque perpetuates the mindset that normal traffic rules don't apply to bikes. There is already enough public misinterpretation of special traffic rules for bicyclists without adding another.

Fig 14 illustrates how an 8' BL in Cupertino induces motorists to make their turn from the BL. Before and after counts revealed a dramatic improvement in motorist using the BL to turn right. It's used at other intersections as well. Cupertino's standard detail 2-27 doesn't show a specific width but when there's room for a wide BL, it varies from 7' to 9' [Cupertino 1989]. Ft Collins, Colorado's standard BL width on arterials is 8', which it adopted from the Larimer County (CO) Urban Area Street Standards [Larimer County 2014]. Ft Collins is now dotting all BL stripes to help convey that motorist should merge right.



Source: Google Earth

Figure 13: Motorists make right turns from wide bike lane

Adding a new sign to the MUTCD to convey that right turns must be

made from BL might be useful, at least initially, until wide bike lanes at intersections are as familiar to drivers as RT lanes. However, the City of Cupertino did not need to use signs to see results. In both Cupertino and Fort Collins, the BL effectively acts as an option lane for bikes and RT lane for motorists, without any unusual signs or pavement markings to exempt anyone from the normal rules of the road.

Before incorporating guidance into the MUTCD on either the sharrow in a RT lane or wide BL in lieu of RT lane concepts, the advantages and disadvantages of the two treatments should be studied. Such a study should address how to deter through and turning bicyclists from staying FTR; otherwise the same right hook risk will occur when a through bicyclist tries to share the BL with a narrower right-turning vehicle, or a turning bicyclist is to the right of a turning truck or bus.

Bike lane next to RT lane at intersection

When a BL is between a RT lane and a through traffic lane approaching an intersection it's important to provide ample shy clearance between the bicyclist and motor vehicle traffic on each side. The BL and RT lanes can be quite long and traffic speeds in both adjacent lanes can be high. In addition, trucks and other large vehicles will begin their turn further to the left than passenger vehicles due to off-tracking. If 4' of operating space and 3' of shy clearance on each side of a bicyclist is to be provided, the BL should be a minimum of 10' wide.

The transition between midblock BLs, and BLs next to RT lanes at intersections should be continuous and require at most a small shift to the left of the BL from the midblock to the intersection storage position. This eliminates the ambiguity of simultaneous left merging of through bicyclists and right merging of turning motorists required by a significant BL shift. Designs that are consistent with a BL operating concept in both parking permitted and no parking contexts makes it unnecessary to end the approach BL and shift the intersection BL significantly (Fig of R buffered BL on approach to intersection with RT and BL).

CONCLUSION

Applying the operating concept approach to BL standards can greatly reduce crash risks and delays and add coherence to *Bike Guide* and MUTCD guidance. It can increase the safety of existing bike. State and local agencies (except Oregon) can act now under existing laws and BL design guidance. However, we need to change the *Bike Guide* and MUTCD's approach to BL design because state and local agencies look to those publications for authoritative guidance.

There is a need to study traffic lane-width bike lanes vs RT-lanes-with-sharrow designs at intersections. Research may be needed to see if through bicyclists will tend to center themselves over a BL symbol in a traffic lane-width BL.

For bike lanes next to parking, research is needed to study the best treatment to keep bicyclists out of door zone - whether it's better to move parking lane stripe out to 11 or 12', or place the parking stripe at 7' or 8' and buffer the door zone within a wide BL with pavement markings. A 16'/7' or 17'/8' design might be problematic unless some of it is marked off for the door zone; untrained bicyclists might operate within the door zone and drivers might feel welcome to park or drive in a 9' BL.

This is an engineering response to complex laws that sometimes require bicyclists to stay far to the right and sometimes not. Exceptions that allow bicyclists to leave BLs to mitigate right hook, dooring and other crash risks have not been effective in preventing crashes because only the "FTR" and "stay in bike" lane messages sink in. High vehicle speeds on some roads reinforce the belief that bicyclists need to stay out of the way. Nevertheless, basing BL design guidance on systematic approach – an operating concept for bike lanes – is a start.

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