Parking Lane Width and Bicycle Operating Space

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This study tests the hypothesis that marking narrower parking lanes can create additional operating space for bicyclists by inducing motorists to park closer to the curb. Parking offset (i.e., distance between the curb and a parallel parked car) was measured along two multilane urban arterials just outside Boston, Massachusetts, with parking lanes ranging from 6 to 9 ft wide. As parking lane width grew in progression from 6 to 7 to 8 to 9 ft, the fraction of cars parked more than 12 in. from the curb, the legal limit, increased in a corresponding progression from 1% to 13% to 44% to 60%. The authors argue that 95 percentile parking offset is a better measure of impact on bicyclist operating space than is mean parking offset, because when riding next to a parking lane, cyclists tend to choose a path that envelopes most parked cars, such that they need to deliberately maneuver around only about one parked car out of 20. With each additional foot of parking lane width, 95 percentile offset increased by about 5 in., for a response of 0.44 ft/ft or m/m. Multivariate regression indicates that wide vehicles (e.g., vans, large sport–utility vehicles) partially compensate by parking about 1 in. closer to the curb. Effects of adjacent lane width, whether there is an adjacent bike lane, and parking regulation type (meter or not) were found to have no significant impact on parking offset. These results imply that in cities that display this level of response to parking lane width, additional operating space for bicycling can be gained by marking narrower parking lanes.

When streets are designed, finding adequate operating space for bicyclists is often difficult because of limited right of way and the competing demands of other road users. On streets with parallel parking, one possible way to create additional space is to make parking lanes narrower. If the parking offset, the distance from the curb that cars park, is not affected by parking lane width, then marking a narrower parking lane may appear (especially in plans) to make more space available; however, it will not really create any additional space, because it is the position of the parked cars and not the parking lane line that determines the limit of the bicycling zone. If a narrower parking lane induces motorists to park closer to the curb, however, then it will genuinely create additional space available for bicycling or other roadway uses.

Applicable law usually requires that motorists park within 12 or 18 in. from the curb; however, compliance can be highly variable. In hilly cities, it is sometimes customary for motorists to almost always park with one wheel turned against the curb. Where this is not the custom, as in the Boston, Massachusetts, area, it has often been speculated that the width of a marked parking lane can affect the parking offset. This study addresses this question by examining the relationship of parking offset to parking lane width and other factors on two multilane arterials displaying a range of parking lane widths.

A previous study done in Cambridge, Massachusetts, found that markings substantially affect parking offset (*1*). When a previously undivided 22-ft area between curb and centerline was divided by a solid white lane line into a 10-ft travel lane and a 12-ft area for bicycling and parking, average parking offset increased from 7.25 to 10.75 in. Apparently, marking a right edge for the travel lane gave parkers greater assurance that their car would not be hit by a moving motor vehicle, resulting in a relaxed parking discipline. This is an interesting result, because while marking the right edge of the travel lane was meant to give bicyclists more operating space on the left by better confining through traffic, it also had the unintended effect of giving cyclists less space on the right by inducing parked cars to move away from the curb. When a second solid white lane line was added, dividing the bicycling-cum-parking area into a 5-ft bike lane and a 7-ft parking lane, mean parking offset fell by almost 3 in. The narrow parking lane improved parking discipline, giving cyclists more operating space. Many people have observed this effect anecdotally, and it has motivated Amherst, Massachusetts, and other cities to reduce parking lane widths from 8 ft to 7 ft to improve bicycle accommodation.

An unpublished study by Dustin White of the Municipal Transportation Agency in San Francisco, California, presented at the Pro-Walk Pro-Bike conference in 2007, found that although both the mean and variance of parking offset increased with parking lane width, sensitivity was far smaller than what was found in Cambridge, as shown in Table 1. According to a least-squares fit, a 1-ft increase in parking lane width increased average parking offset by only 1.2 in. White speculates that San Francisco's many hills (on which law requires one to park with a wheel against the curb) and narrow streets have fostered good parking skills and discipline among the city's drivers, even though the study sites were on level ground.

The AASHTO Green Book states that most vehicles park 6 to 12 in. from the curb, and that they therefore occupy 7 ft of space, a statement that is consistent with the common passenger vehicle width of 6.0 ft (*2*). Although the Green Book recommends a minimum width of 7 ft on urban local streets, and admits that 7-ft-wide parking lanes have been successfully used on urban collector streets in residential neighborhoods, it nevertheless gives 8 ft as the "desirable minimum" for parking lane width on all except local streets, and suggests that parking lanes be made still wider (10 to 12 ft) to provide additional clearance and to reserve the option of peak period travel in the parking lane. No suggestion is given that parking lane

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TABLE 1 Parking Offset by Parking Lane Width Category in San Francisco

Parking Lane Width (ft)	Observations	Mean Offset (in.)	Median Offset (in.)	Standard Deviation	Percentage of Observations with Offset > 18 in.
7	120	6.38	5.5	3.79	0.8
8	329	7.84	7.5	4.49	2.4
9	129	8.76	9.0	4.64	3.9

SOURCE: Dustin White, San Francisco Municipal Transportation Agency.

width might influence the amount of space that parked cars actually occupy.

SITE DESCRIPTION

The arterials studied were Beacon Street and Boylston Street, four-lane, median-separated arterials in an urban part of Brookline, Massachusetts, about 3 mi from downtown Boston. Beacon Street was observed between St. Mary's Street and Tappan Street; Boylston, from High Street to Cypress Street. In the study area, both streets have 30 mph speed limits and level or mild grades. Both streets carry more than 20,000 vehicles per day.

Beacon Street has an asymmetric layout, with a narrow carriageway on one side of the median and a wide carriageway on the other. The narrow side typically has two 11-ft travel lanes and a 7-ft parking lane; the wide side, two 12-ft travel lanes, a 5-ft bike lane, and an 8-ft parking lane. Parking lane widths vary from these typical dimensions, however, ranging from as little as 6.5 ft to just over 9 ft. Within the study area, Beacon Street passes through three commercial districts, where there is 2-h metered parking. Between commercial districts there is either 3-h metered parking or no parking meters, in which case the townwide 2-h parking limit (often violated) applies. Overnight parking is prohibited.

Boylston Street is a state highway over which the Massachusetts Highway Department maintains a degree of control. The section studied has two 12-ft travel lanes in each direction and 6-ft shoulders on which parking is permitted as an exception to the state law prohibiting parking on state highways. There are no meters, but the 2-h parking limit applies, as does the overnight parking ban. The section of Boylston Street studied is mixed institutional (schools), residential, and low-intensity commercial.

State law requires that cars park no more than 12 in. from the curb, and within parking lane lines where parking lines are marked (*3,* p. 25). In 2008, Brookline police gave 119 citations townwide for parking more than 12 in. from the curb, indicating at least a modest level of enforcement. It is not known, however, whether any of these citations were applied on streets with a marked parking lane.

DATA COLLECTION

Parking offset was measured from the adjacent curb to the rear curbside tire of a parked vehicle to avoid the complication of measuring to a sometimes sharply angled front tire. Because the vertical edge of the granite curbstones was sometimes beveled or rough, a measurement tool was devised: a strip of thin steel plate bent at 90 degrees to create two 4-in. arms. One arm was laid horizontally on the top of the curb (which was nearly always level and smooth), so that the vertical arm, pointed downward, touched the face of the curb 4 in. below the top of the curb. Parking offset was measured from the vertical arm to the tire's sidewall bulge in the front half of the rear tire where this bulge is at the same elevation as the top of the curb. Measuring to the sidewall bulge was unambiguous and direct, whereas measuring to the center of the wheel entailed complications of elevation differential and varying hubcap designs.

When vehicles are parked next to one another, they tend to line up with similar offsets, making observations of successive vehicles not strictly independent. To enhance the statistical value of the data, cars that were parked immediately between two other observed cars were skipped. Data were collected in early December 2008 (before there was any snow accumulation) and in April and May 2009 on six different days. Some sections were observed on two different days. To reliably estimate a 95-percentile offset, the target was to make at least 100 observations each for 6-ft, 7-ft, 8-ft, and 9-ft parking lanes.

Parking lane width (measured from curb to center of the parking lane line) and width of the adjacent lane were measured at least twice per block, more often if lane widths varied. Lane widths were measured to a precision of 1 in.; offsets, to a precision of 0.5 in. Other items observed were whether the adjacent lane was a bike lane, the parking regulation (meter, time limit), and whether each sampled vehicle was wide. Vans, pickups, minivans, and sport–utility vehicles were considered wide vehicles, excluding compact versions that are no wider than a typical passenger car.

FINDINGS

A plot of offset versus parking lane width, shown in Figure 1, shows a clear trend of increasing offset with lane width. In the scatterplot (but not the analysis), a random disturbance in the range ±0.1 ft was added to parking lane width to limit the overlap of plotted points. Six outliers, present in the graph, were excluded from analysis results. A least-squares fit indicates that each additional foot of parking lane width increases average offset by 3.7 in.; in dimensionless form, the response is 0.30 ft/ft or m/m. The scatterplot also shows that that range and variability in parking offset increase with parking lane width.

Data were grouped by nominal parking lane width (6, 7, 8, or 9 ft), with each category covering its nominal width ±0.5 ft. Because design widths tend to be in whole feet, observed parking lane widths tend to be concentrated near those nominal values. Analysis by lane width category is given in Table 2. There is a strong trend of mean offset increasing with lane width, with mean offset growing from only 3.5 in. with a 6-ft parking lane to 14.2 in. with a 9-ft parking lane.

The mean offset measured for the 7-ft parking lane, 6.6 in., is very close to what San Francisco found, and within 1.5 in. of the Cambridge study's result. (Small differences are to be expected because of different measurement methods.) With wide, 9-ft parking lanes, however, Brookline parkers (mean offset = 14.2 in.) showed far worse discipline than San Francisco's (mean offset = 8.8 in.).

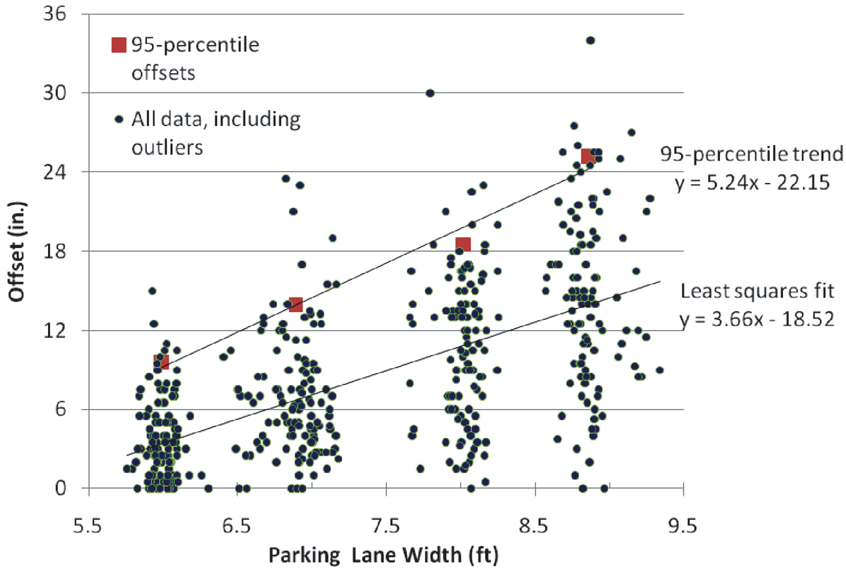

FIGURE 1 Parking offset versus lane width.

Although mean values may be convenient for analysis, safe operating space for bicycling is affected more by extreme values of offset than by the mean value. Using a high percentile value of parking offset to determine available operating space reflects both recommended and actual bicyclist behavior—not shifting one's lateral position in and out with each parked car, but following a smooth line that envelopes the door zone around most parked cars. The authors chose 95 percentile offset as the relevant measure, reasoning that cyclists follow a line that will require them to deliberately maneuver around only about one car in 20.

Extreme offsets are more sensitive to lane width than mean offset. As indicated in Table 2, the 95 percentile offset grew from about 10 in. with a 6-ft parking lane to 25 in. when the parking lane was 9 ft wide. The least-squares fit for 95 percentile values, shown in Figure 1, has a slope of 5.24 in./ft (0.44 ft/ft or m/m), indicating that making the parking lane 1 ft narrower will afford bicyclists about 5 in. more operating space.

Cumulative distributions of offset for different parking lane widths are shown in Figure 2, formatted to allow one to pick off any percentile value, and in Figure 3, which uses discrete categories of offset. In Figure 3 one can see how, as parking lane width grows in progression from 6 to 7 to 8 to 9 ft, the proportion of cars parked more than 12 in. from the curb (the legal limit) grows in a corresponding progression of 1% to 13% to 44% to 60%. The proportion parked more than 18 in. from the curb is near 0% when the parking lane is 6 or 7 ft wide; but with an 8- or 9-ft parking lane, that percentage grows to 6% and 29%, respectively, in marked contrast to the results reported earlier for San Francisco.

Other Factors Affecting Parking Offset

Linear multiple regression was applied to test for other factors besides parking lane width (Table 3). The mean response to parking lane width, after other factors were accounted for, was 3.5 in. of offset per foot of parking lane width (0.29 ft/ft or m/m).

Only one other independent variable proved significant. Wide vehicles parked, on average, 1.2 in. closer to the curb than cars, a compensating effect that dampens their otherwise negative effect on bicyclist operating space.

Where there is a bike lane, the results offer weak evidence that motorists relax their discipline and park about 2 in. farther from the curb. Because of variability and colinearity, however (most of the time, the presence of a bike lane was associated with 8-ft parking lanes and 12-ft travel lanes), the hypothesis that the presence of a bike lane has no effect on parking offset cannot be rejected at any reasonable level of significance.

The authors had speculated that parking offset might be greater where parking turnover is higher, reasoning that people parking for a few minutes might show less discipline than those leaving their vehicles for a longer period. The surrogate variable for high turnover was the presence of 2-h parking meters, which are located in the

TABLE 2 Parking Offset by Nominal Parking Lane Width Category

Nominal Parking Lane Width (ft)	Mean Lane Width (ft)	Sample Size	Mean Offset (in.)	Standard Deviation of Offset (in.)	95 Percentile Offset (in.)
6	5.99	117	3.5	3.0	9.6
7	6.89	122	6.6	4.1	14.0
8	8.01	115	10.6	5.4	18.5
9	8.86	113	14.2	6.5	25.2

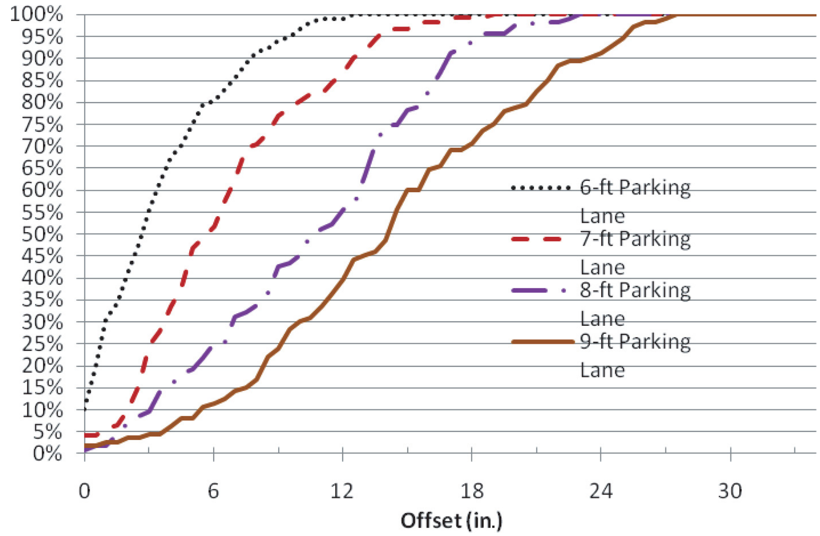

FIGURE 2 Cumulative distribution of parking offset by parking lane width.

commercial districts and charge a higher rate ($0.75/h) than the 3-h meters that lie outside the commercial areas. The 2-h metered parking dummy had no significant effect, however.

The authors also found that where there is no bike lane, the width of the adjacent lane had no effect on offset. Next to the 6-ft parking lanes on Boylston Street there is a generous 12-ft travel lane, but the authors' analysis shows that this wide adjacent lane did not encourage drivers to park farther from the curb. This result indicates that if space is reallocated from a parking lane to an adjacent travel lane—for example, if an 8-ft parking lane and 11-ft right travel lane were restriped to make a 7-ft parking lane and 12-ft travel lane—drivers would park closer to the curb in response to the narrower parking lane, without an opposite secondary effect in response to a wider adjacent travel lane.

Human Factors Explanation

Two reasons may be suggested for why drivers park farther from the curb in a wider parking lane. One is that the parking lane line, regardless of how far it is marked from the curb, may lead drivers to believe that they are entitled to park anywhere in the zone delineated by that lane line. Casual observation suggests that there is some confusion among drivers as to whether the law for parking within marked parking lines takes precedence over the law that one must park within 12 in. of a curb. For example, the car with the greatest observed offset, parked 34 in. from the curb, was still within its (9-ft-wide) parking lane. It is unlikely that this car would have been parked that far from the curb had the parking lane been 7 ft or even 8 ft wide.

A second reason is that when parking, most cars' mirrors are set such that the driver cannot see the curb, but can see the parking lane line or tee. This may lead motorists to use the parking lane line as a guide when parking, putting them farther from the curb when the line they are using as a guide is farther from the curb.

DISCUSSION OF RESULTS

The results showed a much stronger response to parking lane width than what has been reported for San Francisco, suggesting that parking discipline varies from city to city. Therefore, it is not possible to generalize the study results to every U.S. city. The conclusions apply

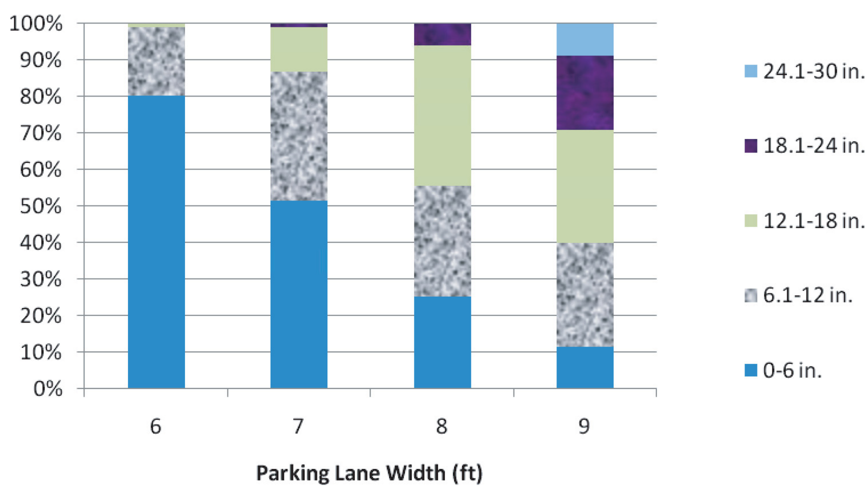

FIGURE 3 Relative frequency distribution of parking offset by parking lane width.

TABLE 3 Multivariate Regression Results

	Coefficient	SE	*t*-Statistic	*P*-value
Intercept	−18.22	5.79	−3.15	.002
Parking lane width (ft)	3.52	0.38	9.40	.000
Wide vehicle dummy	−1.21	0.51	−2.39	.017
Bike lane dummy	1.76	4.95	0.35	.723
2-h parking meter dummy	−0.07	0.56	−0.12	.902
Adjacent travel lane width (ft)—if no bike lane	0.07	0.41	0.16	.872

NOTE: Units of dependent variable (offset) = inches; observations = 469; standard error = 4.99; R-square = 0.42.

to cities that display a similar sensitivity to parking lane width as that observed in Massachusetts.

In studies concerned with operating space for bicycling, the authors believe that it is important to focus on an extreme value of parking offset, such as the 95 percentile value, rather than mean offset. Because offset is left censored [it cannot (easily) be less than zero], 95 percentile offset is more sensitive to parking lane width than is mean offset.

Minimum and Maximum Parking Lane Width

The strong discipline exacted by 6-ft and 7-ft parking lanes calls into question the wisdom of U.S. guidelines that recommend 8 ft as a "desirable minimum" parking lane width for all but residential local streets, often with no maximum. This guidance can be contrasted with Dutch street design guidelines (*4*), representative of neighboring European countries in which roadway space tends to be more limited than in the United States, which call for parallel parking lane widths to be between 6 and 6.6 ft (1.8 to 2 m) except when parking lanes are intended for buses or trucks. The Dutch guideline is supported by the finding that the 95-percentile car width is 5.75 ft (1.75 m), and therefore can be interpreted as providing little beyond the minimum needed to fit a car. The AASHTO guideline, with its generous minimum and no maximum, does not appear to be motivated by a similar sense of economy. That may be appropriate where roads are so wide that there is no need to convert parking space into operating space. Where roads are narrow and drivers respond to parking lane width, however, recommending narrower parking lanes may be appropriate.

Translating European guidelines requires some adjustment for the wider American personal vehicle fleet. Based on 1998 sales, the 85 percentile width of passenger cars is 6.1 ft, and for personal transportation vehicles (cars and light trucks combined), it is 6.6 ft (*5*). According to 2008 sales, the average width of the top 10 personal transportation vehicles (of which three are pickups) is 6.3 ft (*6*). Therefore, applying the reasoning behind the Dutch guideline cited earlier would probably result in recommended parking lane widths of 7.0 to 8.0 ft, and perhaps 6.75 ft in cities in which light trucks are less popular.

Safe Bicycle Operating Space

According to both Dutch (*7*) and American (*8*) guidelines, a bicyclist's operating space, not including shy distance, is 1 m, or about 3.25 ft, including 2.5 ft for the bicyclist, plus 0.75 ft of tracking or wobble width needed to maintain stability. When riding between a parking lane and a travel lane, cyclists also need some shy distance on both sides. Needed shy distance to the travel lane depends on car speeds; for 30-mph traffic in a commercial zone, 1 ft or more seems reasonable. On the parked car side, 2.75 ft or more is desirable to clear the door zone.

A common layout for the United States, and typical for Beacon Street in Brookline, is an 8-ft parking lane and a 5-ft bike lane. Taking car width as 6.0 ft, and adding the 95-percentile parking offset to find the effective left edge of parked cars, it can be determined that with this 8 + 5 layout, parked cars consume 7.5 ft of space. Accounting for shy distances, that leaves bicyclists with only 1.75 ft of clear operating space, creating a deficit of 1.5 ft in needed operating space for bicycling. Casual observation on Beacon Street will show that cyclists' arms and even tires routinely encroach in the neighboring travel lane, evidence that the existing layout does not provide them sufficient safe operating space.

Opportunities for finding additional operating space for bicycling by narrowing or eliminating travel lanes are often limited, and widening roads is often impractical and always costly. The analysis shows that it may be possible to gain additional operating space for bicycling at virtually no cost simply by marking a narrower parking lane. If the sensitivity to parking lane width that this research found holds, narrowing an 8-ft parking lane to 7 ft, without shifting the left edge of the bike lane, will add a much-needed 0.44 ft to the safe bicycling zone, with no impact on other street users.

On streets with bike lanes, it is important that the recommendation for narrower parking lanes be understood as a reallocation of space from the parking lane to the bike lane; that is, if the parking lane is made 1 ft narrower, the bike lane should be made 1 ft wider. If a parking lane is narrowed and the bike lane width is left unchanged, with the bike lane thus shifting toward the curb, bicyclists will suffer a loss of operating space.

Buffers

In practice, the space immediately next to parked cars functions as a buffer zone that is not used by adjacent traffic. Depending on parking offset and the parking lane width, the buffer zone may lie partly within the parking lane, the adjacent lane (whether bike lane or travel lane), or in a deliberately marked buffer. Some designers propose wide parking lanes, intending the outer part of the parking lane to function as buffer zone. This was one of the conclusions of the San Francisco study—make a wide parking lane, functioning as parking zone plus buffer zone, in order to guide cyclists away from the door zone. This conclusion was based on finding a small driver response to the wider parking lane. If the driver response to a wider parking lane is as observed in Massachusetts, however, much of the intended buffer becomes instead an extension of the parking zone, with an appreciable loss in overall operating space.

With a narrow parking lane, the function of the parking lane is simplified—it becomes just a parking zone, not a parking zone-cum-buffer. Therefore, if a bike lane lies next to a narrow parking lane, the buffer zone will lie (almost) entirely in the bike lane, and therefore the bike lane should be wider. An alternative layout recommended in Dutch guidelines (*7*) and applied in several American cities is to deliberately mark a buffer between the parking lane and bike lane. A buffer may be indicated by marking hatched lines or skip lines, or by inverting or extending parking tees (making their shape a +) with their stem extending outside the parking lane.

An important principle of road safety is to harmonize intended use, design, and actual use (*9*). Where a bike lane runs along a parking lane, road space serves three clear functions: parking zone, buffer, and cycling zone. A design that does not make the buffer zone explicit can lead to actual use being inconsistent with intended use. If a wide parking lane is marked with the intent of it serving as both a parking lane and a buffer, drivers may park farther from the curb (not the intended use), lowering safety. Likewise, if a wide bike lane, intended to function as bike lane-cum-buffer, is marked next to a narrow parking lane, cyclists may ride in the part of the lane intended to be buffer. By explicitly marking zones for parking, buffer, and bicycling, design comes into harmony with intended use, and actual use becomes more likely to match intended use as well.

Legal Protection and Enforcement

The authors observed several parked cars that encroached on the bike lane, even when given a generously sized parking lane. This lack of respect for bike lanes (also manifested by double parking in a bike lane) suggests a need for both stronger legal protection of the bike lane and more vigorous enforcement. The largely effective protections used for handicapped parking spaces and ramps may be an appropriate model for protecting bike lanes, when one considers that the blockage of a bike lane, like that of a handicap ramp, puts vulnerable people at risk by forcing them into traffic.

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