On-Road Bicycle Facilities for Children and Other “Easy Riders”: Stress Mechanisms and Design Criteria

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ABSTRACT: Design criteria were developed for a bicycling network in which the design user is older children and other “easy riders” – cyclists who want to be separated from traffic stress. Stress mechanisms such as overtaking traffic, parking turbulence, and right turning traffic were analyzed to determine criteria for traffic volume, speed, parking, lane width, and other traffic and roadway factors at which a bicycle route becomes unacceptably stressful, and for design features that reduce traffic stress. Facilities examined were shared lanes, bike lanes, bicycle contraflow both with and without centerline marking, and no-passing-bikes zones. The latter is a proposed facility for narrow streets with low speeds but high traffic volumes. When applying these criteria to design of a town-wide bicycle network, contraflow and no-passing-bikes zones were found to provide critical links for creating direct, low-stress bike routes.

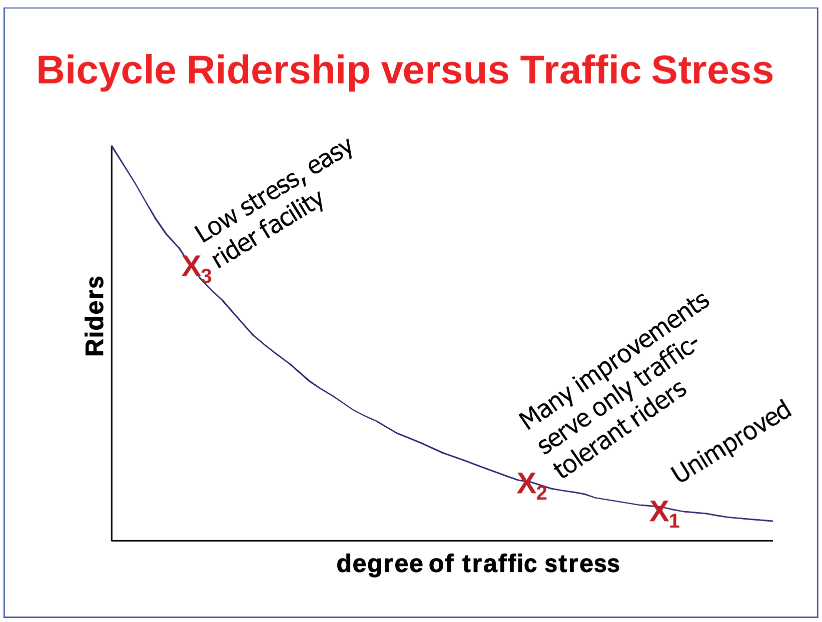
This paper describes research findings of general interest stemming from a study to design a bicycle network for Brookline, Massachusetts, a mostly urban town of 50,000 people bordering Boston. Because primary objectives of the network were to serve high school students and family recreation, the study involved developing facility and route design criteria for users uncomfortable dealing with the stress of traffic danger. Design criteria were developed based on analysis of fundamental stress mechanisms. Innovative facility types given some attention are no-passing-bicycle zones and bicycle contraflow.

Designing for Children and "Easy Riders"

Bicyclists vary in their tolerance for traffic stress. "Traffic tolerant" cyclists, those willing to mix into almost any traffic stream, have the entire street network as a bicycling network. However, most people want to be separated from the stress of fast, heavy, or turbulent traffic. Along with fellow researchers Anne Lusk, Petra Staats, John Pucher, and Michael King, I have come to call them "easy riders." Children, whose judgment and ability to deal with complex demands are still developing, are easy riders. Most adults, too, want the separation from traffic that characterizes easy riders. Surveys of American cyclists routinely show than less than 30% are women, contrasting with 50% in countries like the Netherlands and Denmark where separation from motor traffic is the norm (1), suggesting that women on the whole have less tolerance for traffic stress than men, and are ill served by facilities demanding stressful interaction with traffic.

Figure 1 illustrates conceptually how tolerance for traffic stress affects the number of people willing to use a bicycle facility. Many existing roads involve a high degree of traffic stress, represented by point X_1; at that level of traffic stress, they will attract a small number of riders. Many improvements made to accommodate bicyclists still leave them facing a lot of traffic stress, as represented by point X_2, and therefore do not attract many more cyclists. However, facilities that subject cyclists to little traffic stress, represented by point X_3, have the potential to attract many more riders.

Figure 1: Bicycle Ridership versus Traffic Stress



The distinction between traffic tolerant riders and easy riders is not simply a matter of skills, as suggested by terminology used by FHWA (2) to divide riders into classes A ("advanced cyclists"), B ("basic cyclists"), and C (children cyclists). We find the term “advanced cyclist” unacceptably normative, suggesting that “basic cyclist” is merely a transition state until one acquires sufficient experience and skills. Why build facilities for “basic” cyclists when, with a little education (which is far cheaper), they could use roads as they are? Intolerance for riding with the ever-present stress of traffic danger is something that surpasses skill. Some people – especially young, athletic men – don’t mind that sort of stress, and perhaps are even energized by it. However, most people, including many who are skilled at dealing with traffic, find that kind of stress a deterrent to cycling.

Two of the three main user groups the Brookline network aims to serve are easy riders: older children riding to high school and to athletic fields, and family recreation. The third group – adults riding to work and on errands – also includes a large number of easy riders. Therefore, easy riders were taken as the design user, knowing that traffic tolerant riders would enjoy the Easy Rider network as well as the full street network.

Review of Design Guides

With the design user thus defined, the next question is what design criteria are appropriate for easy riders. King (3) offers a helpful review of design guides from North America, Europe, and Australia, examining traffic speed and volume criteria for facilities aimed to serve “non-vehicular (casual, average and child) cyclists.” The variance among North American guides is striking. Maximum speed criteria for narrow shared lanes vary from 20 to 35 mph, and maximum volume criteria for shared lanes (at 25 mph) vary from 2,000 to 10,000 veh/day. Some guides permit shared wide curb lanes for speeds up to 35 mph and traffic volumes up to 10,000 veh/day; others do not recognize wide curb lanes as a suitable facility at all.

Design guides from northwestern Europe tend to benefit from the greatest amount of experience and research, and carry the weight of unquestioned success in attracting easy rider cyclists (1). However, they also show some significant differences; for example, for a given traffic speed, the Dutch guide (4) permits roughly double the volume as the Danish guide as the breakpoint at which shared lanes are no longer appropriate and bike lanes are warranted.

Design guides implicitly indicate a design user by virtue of the types of facilities they permit. Bicycle facilities built in Massachusetts in the last 15 years following prevailing federal and state guidelines show an implicit design user able to tolerate a lot of traffic stress. Examples include bike lanes that vanish on intersection approaches (in order to make room for added turning lanes) and 14-ft wide shared lanes on 35 mph, high volume arterials. Brookline has a designated shared lane facility, replete with “Share the Road” signs, on an arterial with more than 20,000 veh/day, 30 mph vehicle speeds, and narrow lanes next to metered parallel parking. While those facilities are an improvement over pre-existing conditions, and may represent the best that could be done in the face of competing demands for roadway space, they terrify the majority of would-be cyclists, and demonstrate the inadequacy of prevailing design guidelines if the goal is to serve easy riders.

Studies of Cyclist Stress and Comfort

Harkey, Reinfurt, and Knuiman (5), in developing the Bicycle Compatibility Index, review earlier efforts to use stress as a basis for facility design. They tried to model the relationship of stress to facility design based on observers’ rating of comfort for a variety of layouts shown in video clips. Their model, the Bicycle Compatibility Index, shows that for on-road facilities, comfort improves with lower traffic volumes and speeds, fewer trucks, a marked bike lane, and a wider bike lane or curb lane. They also found that stress increases when riding in a commercial area, and next to parallel parking with 30% or greater occupancy.

Researchers in Florida conducted a similar modeling effort based on ratings from observers who rode a prescribed route consisting of different segments (6). Their model, the Bicycle Level of Service (BLOS) index, shows similar relationships between stressors and comfort ratings. They found that traffic volume has a diminishing (logarithmic) effect. They also found that space in a bike lane has twice the value it would have if used to widen the curb lane.

This beneficial effect of marking a bike lane, found by both of the previously mentioned modeling efforts, was also found in two comparative studies of wide curb lanes versus bike lanes (7, 8), the latter being a before-after study of converting 14-ft curb lanes to 11 ft lanes plus a 3-foot “undesignated lane” serving as a *de facto* bike lane. Where a bike lane was striped, cyclists rode substantially further from the curb, showing that with a bike lane marked, cyclists are less fearful of cars approaching from behind. Measurements of cars’ lateral position showed that cyclists had good reason to relax – with the lane marking, cars drove further to the left. More significantly, the first study examined the difference between cars’ lateral position when passing a bicycle and further downstream, representing the shift a driver makes when passing a bicycle. The bike lane marking made the average shift fall from 2.7 ft to 1.4 ft. For a cyclist, seeing that cars have to shift a considerable amount to pass you is understandably worrying, and so a reduction in this shift gives cyclists reason to relax. (Because stress is more related to “worst likely” motorist behavior than to average motorist behavior, an comparison of 95-percentile lateral shift might have been still more instructive, and probably would have shown a still stronger benefit of a bike lane marking.) Bike lane lines also make it easier for motorists to judge their lateral offset from a cyclist they are about to pass, as evidenced by measurements showing that with a bike lane, motorists encroach on the neighboring lane less often when passing a cyclist.

Attempts to model stressors at intersections based on observers’ ratings have been less conclusive. One study (9) found the presence of right turn lanes to be a significant stressor where bike lanes were present. Steinman & Hines (10) developed a detailed comfort index for cyclist crossings based on their own expert judgment of what constitutes a low-stress crossing. It assigns points for favorable signal timing parameters, advanced stop bars, type of left turn conflict (none, protected, permitted), space devoted to bikes on approach and departure legs (bike lane, wide lane, neither), right turn conflicts, approach speed, right-turn-on-red, and crossing distance. To date, they have applied their model to more than 500 signalized intersections in Charlotte NC, and found that only about 10% meet their low-stress criterion (N. Steinman, personal communication, 6/11/2007). To support their goal of making low-stress crossings, they cite local survey results that show that while a huge fraction of the population owns a bike, most won’t ride it unless the streets are made safer.

Comfort or level of service indices, developed primarily as screening tools for route selection and prioritizing improvement needs, could conceivably be used as design criteria by specifying a threshold value of acceptability. However, their mathematical formulation makes them unsuitably complex for justifying actions to decision makers, and they don’t account for local details are often important. They also offer no behavioral basis for a breakpoint defining what level of combined stress is acceptable.

Analysis of Stress Mechanisms

Design criteria have to strike a balance, offering adequate protection from traffic stress without being overly stringent, lest it become impossible to find acceptable and continuous routes to form a town-wide network. Therefore, the driving issue became finding breakpoints in traffic speed, volume, and other road characteristics at which the level of stress for a given facility becomes unacceptable to easy riders, along with design guidance to mitigate that stress.

Easy rider facilities have to be safe both objectively and subjectively, protecting cyclists from both stress (perceived danger) and hazard (objective danger). Often, stress and hazard are well aligned – there is a real danger, and people perceive it. There are situations, however, in which cyclists may feel relatively safe when in fact there is a high statistical risk of an accident, such as riding on sidewalks on a street with frequent intersections. Likewise, there may be situations that are statistically safe but are perceived by most people as unacceptably stressful, such as riding on a freeway shoulder.

This section describes an effort to establish design criteria and design guidance for easy riders based on an analysis of stress mechanisms that cyclists face in on-road facilities. Roadside cycle tracks or separated lanes, which may also be suitable facilities for easy riders and are widely used to that effect in Europe, were beyond the scope of this study.

Stress Mechanisms for Shared Lanes

Stress of Overtaking Traffic: Volume and Speed Criteria

Traffic approaching from behind is probably the greatest source of stress to cyclists riding in the street. This stress depends on the confidence cyclists have that overtaking motorists will respect their space, passing with sufficient clearance or, if passing is not safe, slowing down and following the cyclist until it is safe to pass.

In a shared lane, regardless of width, at least some motorists will have to deviate from their course to avoid a cyclist when passing. It is vital to cyclists to know that motorists will be able to see them in plenty of time and change course if necessary. On urban streets, where a changing environment means that motorists don't look far ahead, the need for advance visibility calls for a maximum motor vehicle speed for shared lanes of about 30, regardless of volume. (All speed criteria in this paper apply to 85-percentile speed.) On low volume rural roads with good sight lines, good visibility and a non-complex environment can make somewhat higher speeds acceptable, as recognized by the Dutch design guide.

Being passed involves some stress as a cyclist's lateral position is constrained, usually between a fixed object (a curb or parked cars) and moving motor vehicle. When platoons form in the traffic stream, this stress continues unabated until the platoon passes, reaching a limit of acceptability for many cyclists, particularly children, who often tend to avoid such a situation by riding on the sidewalk. On a low volume street, the "worst likely" platoon size can be taken as the average number of cars passing in a single direction in 60 s. Using 4 as the limiting platoon size, and assuming the typical ratios of K_p=10 to 12 percent of daily traffic occurring in the peak hour, and D=60% of peak hour traffic going in the peak direction, preventing the peak hour, peak direction traffic volume from exceeding 4 cars per minute results in an average daily traffic (ADT) criterion of 3,333 to 4,000 veh/day. This value is consistent with criteria reported by King (2) for Portland OR, Cambridge MA, Denmark, the UK, and Australia.

On two-way streets with marked lanes less than 14 ft wide, or (lacking a centerline marking) less than 30 feet wide net of parking lanes, a "passing challenge" occurs when a bicycle, same-direction motor vehicle, and opposite-direction motor vehicle coincide. In such a situation, the same-direction motorist may be tempted to pass with insufficient clearance or to hurry the passing maneuver, stressing the cyclist. The frequency of passing challenges can be determined as a function of traffic volumes, speeds, and the time required to make the passing maneuver. Defining auto and bicycle speeds as u_a and u_b respectively, and auto volumes in the bicyclist's direction and opposite direction as v_1 and v_2 respectively, the frequency of a cyclist being overtaken, assuming auto speed is considerably greater than bicyclist speed, is

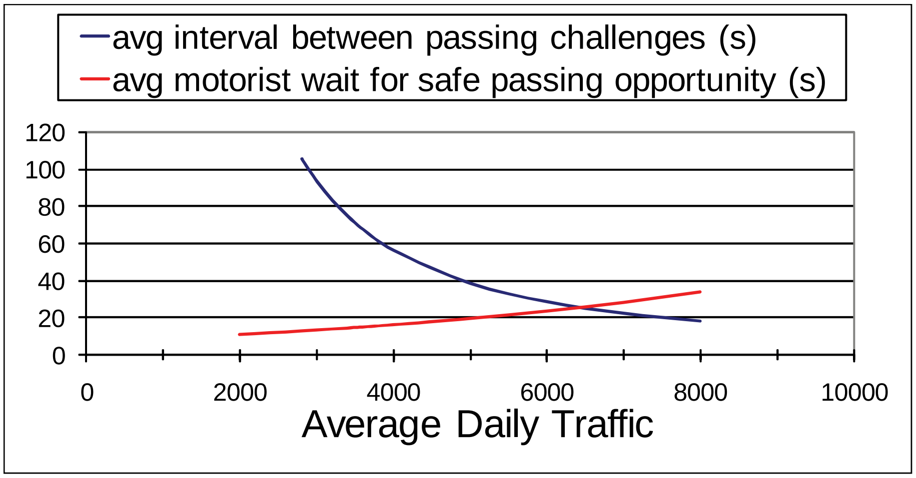
$$\text{overtaking frequency} = v_1 * (u_a - u_b) / u_a$$

If $t_{overtake}$ is the time that a car requires without encountering an opposite direction car in order to overtake a cyclist without being hurried, then the required length of gap in the opposing traffic stream for an unhindered overtaking is $2* t_{overtake}$. Assuming a Poisson model for car arrivals, a reasonable assumption on low volume local streets, the probability that a car approaching a bicycle from behind will be hindered by an opposing direction car is

$$P(\text{hindered}) = p = 1 - \exp(- 2 * t_{overtake} * v_2).$$

The frequency of passing challenges is the product of overtaking frequency and P(hindered); the average time between passing challenges is the inverse of this product. Figure 2 shows how the time between passing challenges (as experienced by a bicyclist) varies with traffic volume, with parameter values u_a = 26 mph, u_b = 11 mph, car speed 26 mph, K_p=10%, D=60%, and $t_{overtake}$ = 7 s. As ADT rises from 3,000 to 4,000 veh/day, average time between passing challenges falls from 93 seconds to 56 seconds. Having passing challenges occur no more than once per minute seems an appropriate limit for an easy rider, further supporting a volume criterion in the 3,000 to 4,000 veh/day range.

Figure 2: Stress parameters related to overtaking as a function of traffic volume



The stress involved in a passing challenge depends on the motorist's willingness to slow down to the cyclist's speed and wait for a large enough gap in opposing traffic. When the speed differential is more than about 15 mph, willingness to slow down falls rapidly, implying a speed criterion for shared lanes on narrow streets of about 26 mph.

When opposing traffic is heavy, the time that a motorist has to ride slowly behind a cyclist waiting for a gap in the opposing traffic stream becomes large, creating an unacceptably strong temptation for motorists to pass unsafely. Using the Poisson model for traffic, the expected time that a motorist has to wait for a gap of length 2* $t_{overtake}$ in the opposing traffic stream is

$$E(t_{wait}) = (1/v_2)^* (p/ (1-p)) - t_{overtake}$$

and 95-percentile waiting time is approximately 3 * $E(t_{wait})$. Figure 2 shows how this average waiting time for a peak hour car traveling in the non-peak direction varies with ADT for the parameters mentioned earlier. It shows that as ADT rises from 3,000 to 4,000, mean waiting time rises from 13 to 16 seconds, suggesting that 95-percentile waiting times will rise from about 39 to 48 s. Because safety and stress are based on "worst likely" scenarios rather than average, and because one would expect willingness to wait to fall sharply after 30 s, a volume criterion closer to 3,000 seems appropriate.

The criteria proposed for Brookline study, 27 mph and 3,000 veh/day, correspond well with what the general public and elected officials consider to be a "quiet local street" that is safe for cycling. Satisfying these criteria may require traffic calming, something usually consistent with neighborhood desires.

Stress of Queuing in a Shared Lane: Intersection Approach Criteria

At signalized intersections, bikes usually queue to the right at the head of the queue. When just getting started, bikes are the most wobbly, and the open intersection offers them plenty of space to reach a more stable speed while the traffic queue passes. If a lane is so narrow that cyclists can't reach the head of the queue, it becomes very stressful to start with cars either beside or behind a cyclist. In the latter case, motorists will see bikes as holding them up and wasting green time; this frustration plays out in aggressively following closely behind the cyclist, or passing with and uncomfortably tight clearance.

Therefore, shared lane approaches to signalized intersections should be wide enough for cyclists to advance past a standing queue to the stopline. A reasonable criterion is 11.5 ft from curb to lane line (half a foot more than the Dutch criterion to account for the wider American car fleet), and 19 ft where there is parallel parking. Meeting this criteria may involve merely shifting a centerline, or it may require eliminating parking places on the intersection approach.

No Passing Zones for Narrow, Higher Volume, Low Speed Streets

On narrow streets without a bike lane, cyclists force cars to queue behind them until there is a safe passing opportunity. As pointed out earlier, when ADT exceeds 3,000, the wait for a safe passing opportunity can be long, creating a stressful situation in which motorists tend to ride aggressively just behind the cyclist, sometimes passing when it isn't safe. Cyclists can often be seen responding to this stress by riding dangerously close to the curb or parked cars, or by riding on the sidewalk.

To eliminate this stress, motorists and cyclists have to be "educated" that the narrow street they are on is not the place to overtake a bicycle. A model is German "bicycle streets," for which regulations expressly prohibit passing bicycles. With this prohibition in place, cyclists can relax and ride in the middle of the lane, and motorists also relax, not looking for an opportunity to pass.

Much the same outcome can be achieved within the American legal framework by creating a "no passing bikes" zone by posting "No Passing Bicycles" and, at the end of the zone, "Pass Bicycles With Care." Such a regulation should be self-enforcing because it encourages cyclists to ride further from the curb, making it hard for a car to pass, and because it removes from the motorist immediately behind the cyclist the pressure to pass to avoid holding up the cars behind them.

Under Massachusetts law, all "no passing" signs are advisory (the only law about passing is that it must be done "safely"), so no legislation is needed to permit creating a "no passing bicycles" zone. For the same reason, police enforcement of such a zone may be difficult; however, the goal is to make it self-enforcing, because relying on routine police enforcement is impractical.

To prevent motorist frustration which would lead to non-compliance, the length of no-passing sections should be limited to about 1,000 ft, as proposed in the Dutch design guide for a "tight profile" in which passing bicycles is difficult. A car forced to go 12 mph instead of 25 mph over this entire distance will be delayed by 30 s.

In summary, criteria proposed for "no passing bicycles" zones are as follow: no more than one lane per direction, curb to centerline width no greater than 11 ft (19 ft if there is parallel parking), ADT > 3,000 veh/day, 85-percentile speed ≤ 27 mph, and segment length < 1000 ft. In developing a town-wide network, this facility type was recommended on three street sections, providing essential links.

No-passing-bicycles zones, based not on traffic volumes but on sight distance, are also needed on winding roads, where a common stressor for cyclists is cars trying to pass with inadequate sight distance, often leading to emergency maneuvers when an opposite direction car appears. Standard criteria for establishing no-passing-bikes zones are urgently needed, along with standard signage and centerline marking for such zones.

Stress Mechanisms for Bike Lanes

Stress from Overtaking Vehicles

Where a bike lane is marked, the stress of the passing challenge vanishes because motorists respect the lane line, which helps guide them clear of the cyclist's space. Still, a speed criterion arises from the stress of being passed at high speed without physical separation, considering the cyclist's vulnerability to unexpected hazards such as potholes, debris in the road, or an illegally parked car. A maximum speed of about 35 mph is therefore appropriate, consistent with many of the design guides reported by King (2). Greater speeds may be appropriate with wide bike lanes such as the 8 ft lanes commonly used in Davis CA, but only if the bike lane is never used for parking, a major challenge on urban streets.

Stress and Bike Lane Width

While most American guidelines give a minimum width of 4 ft, guidelines from the Netherlands and Germany give 1 m (3.3 ft) as sufficient next to a curb without a gutter seam. The Dutch guide cites extensive research showing that 1.0 m is sufficient operating space, considering a bike's normal wobble. It also allows the outer 0.25 m (10 in) of that space to come from unpaved buffer next to a bike lane. Two American studies (7, 8) found that 3-ft bike lanes, plus a gutter when next to a curb, provided sufficient separation between bikes and cars. The 4-ft minimum width commonly employed in the U.S. can have the undesired effect of making bike lanes infeasible where they would in fact be beneficial. In summary, lane width minima that seem appropriate are 3.0 ft next to a buffer offering no vertical obstacle, 3.5 ft when against a curb, and 3.25 ft otherwise. (Lane width next to parallel parking is discussed later.)

The possibility of converting a 14-ft wide curb lane into a travel lane and bike lane makes the "wide curb lane" an inferior and therefore inappropriate facility for easy riders. The state of Florida no longer recognizes wide curb lanes as a bicycle facility, and has converted many of its existing 14-ft lanes into 11-ft lanes and 3-ft "undesignated" lanes which usually run along a 1-ft gutter. The fact that these popular *de facto* bike lanes cannot be marked or signed as bike lanes shows that our bike lane width criteria are overly stringent.

Riding in a narrow lane imposes some stress on cyclists. Therefore, bike lanes narrower than 4 ft should only be applied when there could otherwise be no bike lane. This stipulation implies that narrow bike lanes should only be used when motor vehicle lanes have likewise been narrowed, slowing traffic and thereby mitigating the stress of a narrow bike lane.

Trucks passing at close distance present a special case of stress and danger. Apart from their blast effect at high speeds (> 45 mph), their large wheels and elevated bodies offer no forgiveness in case a cyclist falls (e.g., due to a pothole, being doored, or colliding with another cyclist) or gets trapped as a truck begins to turn right. Therefore, narrow bike lanes are not appropriate on streets with regular truck traffic.

The Dooring Hazard: Lane Width and Buffer Criteria next to Parallel Parking

To prevent cyclists from being doored where there is parallel parking, accepted U.S. design criteria call for a minimum of 13 ft between the curb and motor vehicle lane. Typically, there is an 8 ft parking lane and a 5 ft bike lane; however, a 7 ft parking lane with a 6 ft bike lane is preferred, because the narrower parking lane encourages motorists to park a few inches closer to the curb. Either way, considering a 6 ft wide vehicle cars parked 1 ft from the curb whose open door extends 3 ft, the standard 13-foot offset leaves 3 ft of clear operating space which, as the previous section on lane width discussed, is just barely sufficient; it should therefore only be employed only when motorist lanes have been narrowed as much as possible. The proliferation of wider vehicles makes a 13.5 or 14 ft offset from curb to inside of bike lane preferable.

Educated cyclists know that next to parking lane, one should ride in the extreme left of the bike lane because the right half is in the door zone. Because one function of markings is to guide cyclists, it is preferable to explicitly mark a buffer zone. A suggested division (parking / buffer / bike lane) is (7, 3, 3) or (7, 3, 4).

Stress from Parking Turbulence and Double Parking: Parking Occupancy Criteria

Commercial districts with parallel parking and high parking occupancy have turbulent traffic, posing a hazard to cyclists when motorists stop suddenly on finding an open spot, and creating a strong tendency for double parking, forcing cyclists to swerve into traffic. Double parked cars often stay for only a minute or so, making this kind of violation difficult to enforce.

For these reasons, it seems appropriate to adopt the Dutch design guide recommendation against bike lanes in commercial districts where parking occupancy exceeds 85% in the peak commercial period, or anywhere double parking is common.

This criterion makes it hard to provide a compliant bike route along a “main street” with parallel parking serving local businesses, creating a challenge to network design, since commercial centers are important destinations and are often major crossroads. The network proposed for Brookline meets this challenge by using narrow local streets without parallel parking, alleyways, and short passages through parking lots and open spaces to pass through commercial centers.

Contraflow Lanes and Stress from Oncoming Traffic

Bicycle contraflow means that a street that is one-way for motor traffic is designated two-way for bicycle traffic. Many one-way streets are too narrow to carry motor traffic in both directions, but can easily carry a bike and a car in opposite directions. Often, one-way restrictions are used as part of a deliberate scheme to inhibit through traffic, making the affected streets ideal bicycling routes.

The large number of cyclists riding contraflow (unlawfully) on low-speed streets shows that they find it to be safe. Counts on two separate Brookline streets showed more than 30 contraflow cyclists in an hour on each street, with no accident history. Making contraflow legal recognizes cyclists’ clearly spoken preference, and the signs and markings that come with formal designation improve safety through two mechanisms: they better alert motorists to contraflow cyclists, and they reduce the number of cyclists using the sidewalk or riding on the wrong side of the street.

Cities with extensive contraflow experience find that their contraflow streets have a lower crash rate than other streets. For example, the Etterbeek district of Brussels has not had a single reported injury in 15 years on its large network of bicycle contraflow streets (Frederik Deportere, personal communication, 4/25/07). The Brussels Capital Region has published extensive guidelines on contraflow design (11). Eugene OR, Madison WI, Oakland CA, Ottawa, Montreal, and Cambridge MA are among the North American cities with bicycle contraflow.

Where a contraflow lane is placed along a (left-side) parking lane, three factors combine to greatly reduce the “dooring” hazard. First, contraflow cyclists face the passenger side door, which is used only about 15% as often as driver’s side door. Second, contraflow cyclists approach parked cars from ahead rather than behind, making them much more visible to a person about to open a door, and speculated to reduce the risk of a cyclist not being seen by 80%. Together, these factors reduce the probability of being doored by 97% compared to with-flow travel. Third, in the event of a collision, the impact tends to close the door rather than open it further. For these reasons, the Brussels guide permits contraflow bike lanes next to a parking lane to be narrower than a with-flow bike lane next to a parking lane.

Contraflow is a valuable tool for network design. It creates new links that may enable one to create “bike boulevards” (streets carrying through bike traffic, but not through motor traffic) and avoid routing cyclists onto more dangerous streets. It also improves network directness by saving cyclists the need to make around-the-block detours often required by one way restrictions, which can be especially onerous when the roundabout route involves hills or busy intersections. Brookline’s proposed Easy Rider Bicycle Network has 14 contraflow segments, surprising all who were involved in the network plan, and underscoring the importance of this facility type.

Criteria for Continuously Marked Contraflow Lanes

While contraflow eliminates the stress of overtaking traffic, it presents a new stress, the stress of dealing with oncoming traffic.

A contraflow lane can be marked by a continuous lane line which serves as a roadway centerline, as shown in Figure 3a along with proposed dimensions. A centerline marking is a universally understood and respected way of separating directions; it effectively eliminates the stress of oncoming traffic for normal urban street speeds, provided the bike lane is wide enough to offer an adequate buffer between the two directions. The Brussels guidelines permit this layout for streets with speed limit up to 50 km/h (31 mph). Our proposed 85-percentile speed criterion for a contraflow alongside a curb varies from 32 to 28 mph as the lane width varies from 6 to 4 ft. For a contraflow lane next to parallel parking, the occasional need to encounter oncoming traffic when the bike lane is occupied by a car entering or leaving a parking space calls for lower speeds; the proposed speed criterion is 27 to 24 mph as the distance from curb to centerline varies from 14 to 12.5 ft.

To reinforce the “centerline” meaning of the lane line, contraflow markings should include arrows or chevrons to emphasize that the contraflow lane is unidirectional and discourage with-flow cyclists from riding in the lane.

Criteria for Intermittently Marked Contraflow Lanes

On narrow streets with a 30 km/h speed limit, the Brussels and Dutch guides permit contraflow without marking a continuous lane line. Just as on two-way streets that lack a centerline, safety depends on cyclists and motorists seeing one another and shifting to their right, supporting a speed criterion of about 22 mph as well as a volume criterion makes it unlikely for a cyclist to encounter more than one auto at a time; we propose the volume criterion to be 1,000 veh/day, which in peak periods implies two cars per minute.

A proposed marking and dimensional criteria are shown in Figure 3b, based on the Brussels guidelines, but modified for clarity and wider U.S. cars. The marking has a bike symbol and chevron inside parallel broken lines 3 ft (90 cm) apart and about 10 ft long, and is repeated at the start of end of each block. The low traffic speed makes less space needed for a bike and car to pass each other, as on a driveway, allowing the intermittent lane design to be applied on some streets that are too narrow to fit a continuously marked bike lane and motor vehicle lane, provided motor vehicle speeds are low enough. For example, with parking on one side of a street, an intermittently marked lane could be applied to a street whose curb-to-curb width is 20 ft, while the continuous lane marking requires a width of 21.5 ft.

Stress at Intersections

Where there is reason to expect that crossing traffic will not see or yield to cyclists, countermeasures are needed to protect them.

Figure 3a: Dimensions for Continuously Marked Contraflow Bicycle Lanes

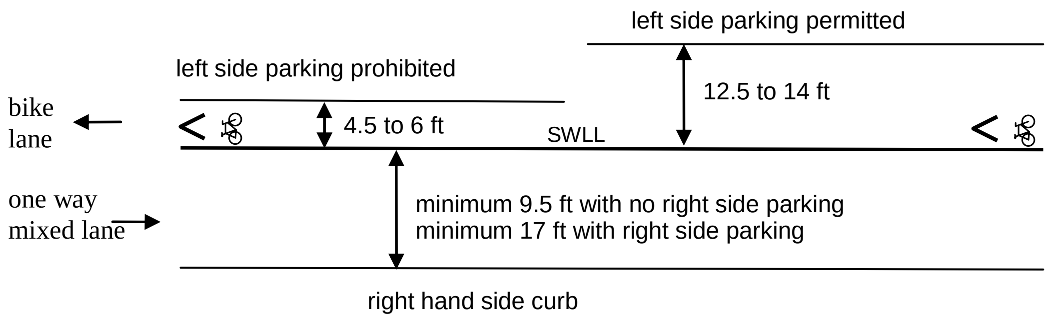
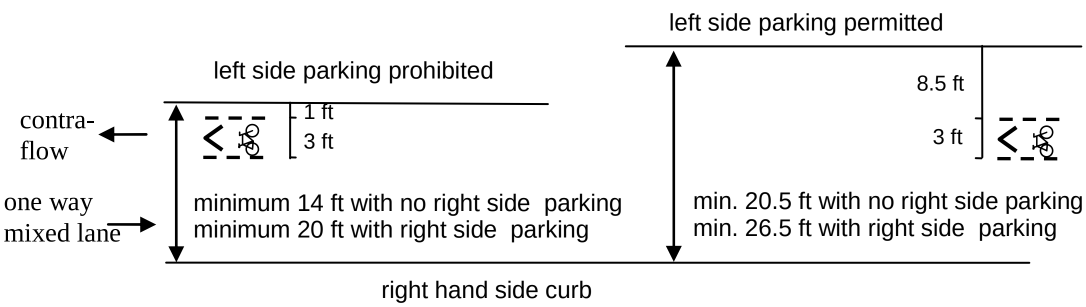


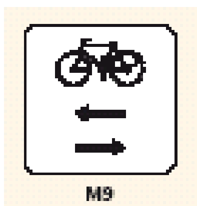
Figure 3b: Dimensions for Intermittently Marked Contraflow Bicycle Lanes



Signs for Contraflow Lane Crossings

When crossing a street with bicycle contraflow, motorists and pedestrians are not accustomed to looking both ways for cross traffic. An effective sign used in Belgium to call attention to contraflow traffic is shown in Figure 4. It can be posted on all cross streets as a supplemental plaque to Stop, Yield, or bicycle warning signs, and on all One Way signs including those opposite driveways and alleys. Signage should be accompanied by markings in the bike lane showing the bike symbol and an arrow or chevron indicating the direction of travel.\

Figure 4. Supplemental plaque for signs facing traffic crossing streets with bicycle contraflow.



Marking the Lane Through the Intersection

An effective means of reducing stress at intersections is to mark the bike lane through intersection in the form of a colored lane as in Brussels (red), Copenhagen (blue), and Portland OR (blue), continuous bike and chevron markings as in Paris and Montreal, or broken parallel lane lines as in the Netherlands (often with the bike lane painted red as well). Such a marking raises motorists' expectations, makes the cyclists' path more predictable, and reinforces the cyclists' right of way.

A study in Portland OR showed improved motorist yielding, and a decrease in cyclists' frequent, nervous scanning over their shoulder (12). While the authors of that study warn that the latter may suggest that the painted lane gave cyclists a false sense of security, we take it as strong evidence of reduced cyclist stress. With a lane painted through a wide intersection, cyclists no longer have to adjust their trajectory to gaps in the motor traffic stream, because the lane shows motorists what trajectory to expect bicyclists to follow.

Signal Control on Wide Streets

On streets that are wide or are so busy as to present a confusing environment, the likelihood that a crossing or left turning motorist doesn't see an approaching cyclist becomes unacceptably high. To protect cyclists on such a street, crossing conflicts should be eliminated by controlling all crossing movements, including left turns, by traffic signals (without "permitted" left turns, of course). At this time, we do not know of sufficient data to establish criteria on number of lanes or traffic volume calling for positive signal control.

Stress from Right Turning Traffic

Routine Right Turns

At unsignalized intersections at which it is feared that motorists may not notice a cyclist when turning right, marking the bike lane through the intersection, and / or adding bike lane markings (bike symbol, chevron or arrow) on the 50 ft or so approaching the intersection can help draw attention to the bike lane.

High Speed Right Turns

Right-turning motorists are supposed to yield the right of way to cyclists continuing through an intersection in a bike lane or a shared lane. When roadway geometry allows motorists to make a right turn at high speed (a common problem at freeway entrance ramps), motorists become unacceptably likely to challenge the cyclist's right of way, causing stress and possibly a serious crash.

Easy riders need to be protected from all high speed right turns. Options include altering intersection geometry, reducing turning speed to reduce turning vehicles' speed, or diverting the bike route onto a short parallel cycle track that intersects with the right turning traffic after the turn, with unambiguous right of way at that latter intersection.

Bike Lanes and Right Turn Lanes

Where there is right turn lane on an approach to a signalized intersection, cyclists lose their normally secure position along the right side of the road, creating a stressful conflict with a (typically) heavy flow of right turning traffic.

A standard option for resolving this conflict is to mark a bike lane between the right turn lane and the through lane, with right-turning traffic weaving across the bike lane in advance of the intersection. The stress of having cars weave across one's path is minimized if the cyclists' path is straight, plainly marked for both motorists and cyclists to see, and car speeds are no more than 15 mph above typical bike speeds. The layout that meets these criteria has the bike lane continuing straight ahead, highlighted with colored pavement, while a right turn only lane is created to its right. This kind of layout is commonly used by children and other easy riders on streets in the Netherlands, Denmark, and other parts of Europe. Layouts found in American guidelines in which the travel lane on the right becomes a turn lane, forcing the bike lane to shift to the left, or in which the bike lane simply vanishes, are unacceptably stressful.

To reinforce the cyclist's right of way and ensure that weaving cars yield to bikes, the, 85-percentile speed as cars reach the weave point should be less than 25 mph. One possible way to reduce the speed of turning traffic is to shorten the right turn lane, so that some of the right turning traffic's deceleration occurs before the weave.

A second option is for the bike route to separate from the roadway in a short section of one-way cycle track, with the bike traffic controlled at the traffic light so that it does not conflict with the right turning traffic. In this layout, right turning traffic conflicts with cyclists at the same place it conflicts with crossing pedestrians, so the signal control used to protect pedestrians can be used to protect cyclists as well. The network proposed for Brookline includes one such layout.

Lessons Learned in Network Design

Cyclists who prefer to be separated from traffic stress are not well served by prevailing American design guides. Reasonable criteria and design guidance for serving easy riders in on-road facilities can be developed by considering the various stress mechanisms they face. Innovative designs such as contraflow lanes, no-passing-bikes zones, narrow bike lanes, and bike lanes painted through intersections offer additional options for safe, low-stress bike accommodation where prevailing guides might not have found one.

Using the criteria developed, it was possible to propose a town-wide, continuous network connecting neighborhoods with all of the target destinations for the town of Brookline, MA. Bicycle contraflow and no-passing-bikes zones provide critical links that make low stress through routes possible.

One of the greatest challenges was finding safe crossings of two major arterials, Beacon Street and Route 9. In their present condition, they do not offer a single crossing meeting easy rider criteria, in part because many streets crossing them have added turning lanes. Design changes were proposed to create safe crossings. Some involve little capital expense and little impact to other road users (e.g., parking); others require more substantial investment. The other main challenge was passing through commercial areas, as discussed earlier.

Overall, we found that implementing an easy rider network in the more urban part of the town would involve only moderate construction cost and impact to others (e.g., loss of parking), because the dense street grid in this part of the town offered many direct routes on low volume streets. In the more suburban part of the town, more substantial roadway changes and investment will be needed because the only through streets carry high speed and high volume traffic.

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Off-road facilities can provide low-stress environments for bicycling and walking that are separate from motor vehicle traffic. They can be great places for novice and child bicyclists to try out their riding skills prior to taking trips on urban streets. While they have many positive features, design of off-road trails must be done with the same care and attention to recognized guidelines as design of bike lanes on roadways.Â More detail on multi-use trail design and engineering is provided in national guidelines set by AASHTO and the MUTCD. Trail user conflicts are an issue when on wide trails like this coastal trail in Santa Barbara, CA. 10.2 Multi-Use Trails. Only in very few instances is a trail used exclusively by one type of user. Many existing bicycle facility designs exclude most people who might otherwise ride, traditionally favoring very confident riders, who tend to be adult men. When selecting a bikeway design strategy, identify potential design users in keeping with both network goals and the potential to broaden the bicycling user base of a specific street. Children.Â Operational changesâ€"such as speed reduction, signalization and other conflict management, and proactive curbside managementâ€"improve bicycling conditions by reducing the level of traffic stress on a street. Operational strategies make streets more predictable, efficient, and safe without necessarily changing the streetâ€™s cross-section or the types of vehicles allowed. When designing facilities for bicycle riders, remember their ve basic requirements: 1. space to ride 2. smooth surfaces (slip-resistant) 3. speed maintenance 4. connectivity, and 5. information. Local Cycle Network Plans and Regional Cycle Network Plans: These identify routes that potentially will carry a high number of cyclists.Â This in turn may inuence the planning design and selection of the facility. If the site isÂ Where use is expected to be high or there is a variety of user skill levels and activities (such as children on bicycles, people walking dogs, joggers and experienced bicycle riders), adequate width is essential to minimise conict (see Brisbane City Council Case Study).Â roads or other paths). bicycle riders approaching intersections. Position holding rails. Analysis and Optimum Design of Rider-bicycle Mechanisms. product design presentation semester 3-unikl. Folding Bicycle.Â In the bicycle frame, we assume that all of the riders weight is placed on the seat. We assume that all the reaction forces are equal to the weight. 5 Analysis Before we begin our analysis of various components, it first necessary to find the required force applied on the pedal, such that the bicycle will accelerate at a rate of 15 ft/s2.Â 6 Test Design Tabulated below are the results for the maximum stresses experiences by various components on the bicycle. With a factor of safety of two, the maximum stresses are doubled. Table 1: Maximum Stress Found.Â Design and Optimization of Bicycle Frame for the Cyclist's Comfort. Uploaded by. Furth, P. G. (2008). On-road bicycle facilities for children and other â€˜easy ridersâ€™: Stress mechanisms and design criteria (paper 08-1074). Proceedings from the Transportation Research Board 87th Annual Meeting, Washington, DC. Furth, P. G., Mekuria, M. C., &, Nixon, H. (2016). Network connectivity for low-stress bicycling. Transportation Research Record, 2587, 41â€"49. Furth, P. G. (2017). Level of traffic stress criteria for road segments, version 2.0. Retrieved from http://www.northeastern.edu/peter.furth/criteria-for-level-of-traffic-stress/. Geller, R. (2006). Four types of cyclists.