Pedestrian and Bicycle Information Center

Evaluation of Bicycle-Related Roadway Measures: A Summary of Available Research

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Introduction

This document represents an effort to compile all known research on the effect of the bicycle safety countermeasures discussed in *BIKESAFE*. It is intended to serve as a companion document for the guide, providing a complementary overview of the researchers, research methods, and evaluation results that have guided the development and design of bicycle safety countermeasures.

Methodology

This document grew out of the Highway Safety Manual (HSM) unpublished "Knowledge Document," which was originally written 2006 (by C. Zegeer for an iTrans study for NCHRP, as part of the HSM development) and updated in 2008 for the FHWA Office of Research. In February 2014, a thorough review of bicycle safety research was conducted using the Transportation Research Board's *TRID* database, PubMed, and general internet keyword searches.

Articles and reports were considered for inclusion in this subject literature review report if they provided an evaluation of bicycle safety countermeasures using rigorous research methods. While the majority of sources come from peer-reviewed journals and presentations or Federal Highway Administration (FHWA) reports, a handful come from state Departments of Transportation who have begun to conduct their own in-house countermeasure safety assessments. Results were generally limited to studies conducted in the United States and Canada to match the focus and context of *BIKESAFE*.

1.0 Shared Roadway

1.1 Roadway Surface Improvements

There are currently no resources for this section.

1.2 Bridge and Overpass Access

There are currently no resources for this section.

1.3 Tunnel and Underpass Access

There are currently no resources for this section.

1.4 Lighting Improvements

A 2007 article by Kim, Kim, Ulfarsson, and Porello used a multinomial logit model and police reported accident data to identify factors that increased the probability of a bicyclist experiencing a severe or fatal injury in the event of a bicyclist-motorist collision. Their analysis indicated that a lack of streetlights at night was associated with a 111 percent increase in the probability of a fatal outcome, and a less than 100 percent increase in the probability of an incapacitating injury. The authors explained that lighting affected not only bicyclist visibility but also decreased the likelihood of the driver taking evasive action (such as swerving or braking) that would reduce injury severity. They also cautioned that this study did not account for the presence or absence of illumination equipment on bicycles (1).

A 2009 article by Wanvik used 20 years of Dutch collision statistics to examine the effect of road lighting on the odds of collisions for all road users. Their analysis indicated that road lighting was associated with a 60 percent decrease in bicyclist injury collisions (95% confidence intervals, 54%-65%) in dark conditions on rural roads. The observed safety effect was significantly greater for bicyclists than for automobiles, and some protective effect of roadway lighting was observed for twilight hours as well (2).

References

1. Kim, J.-K., S. Kim, G. F. Ulfarsson, and L. A. Porello. Bicyclist Injury Severities in Bicycle-Motor Vehicle Accidents. *Accident Analysis and Prevention*, Vol.39, No. 2, 2007, pp. 238-251.
2. Wanvik, P. O. Effects of Road Lighting: An Analysis Based on Dutch Accident Statistics 1987-2006. *Accident Analysis and Prevention*, Vol. 41, No. 1, 2009, pp. 123-128.

1.5 Parking Treatments

On-street parking can affect the safety of bicyclists along the roadway. Cyclists who are not confident riding in the roadway with cars will often ride in the roadway as far to the right as possible. On streets with parking, this situation causes cyclists to ride in what is known as the “door zone” of parked cars. The door zone is the area within about four feet of both sides of parallel-parked cars, where an opened car door protrudes into the roadway. Doors opened suddenly may result in bicyclists swerving into traffic lanes or colliding with the open door, a common collision type for cyclists. A 1999 report by the City of Toronto Transportation Services Division classified all police-reported vehicle and cyclist collisions from 1997 and 1998 according to type. Running into open car doors was the third most frequent type of collision, accounting for 11.9 percent of the 2,574 reported collisions. Additionally, this type of collision led to more severe injuries when compared to other types identified in the report (1).

Figure 1. A potential "dooring" event.

[Caption: Figure 8 from Hunter et al. (2010), showing a potential "dooring" event (2). Dooring accidents occur when bicyclists collide with the open door of a car.]

Two studies have found that vehicles parked intermittently along the roadway provide the greatest hazard to bicyclists. On roadways where not many cars park on the street, cyclists seemed to ride mostly within the parking lane. Upon approaching a parked car, cyclists often made large changes in their lateral positioning in order to go around it. They also did not leave as much space between themselves and the parked car, increasing the chance of a dooring incident. Duthie, Brady, Mills, and Machemehl (2010) determined that the lateral position of cyclists was safer when they rode next to a row of parked cars than when they rode next to only a few parked cars (3).

A 2010 study by Furth, Dulaski, Buessing, and Tavakolian studied the relationship between the width of parallel parking lanes and operating space for bicycles. They measured the distance that cars parked from the curb on two arterials in Boston, Massachusetts, comparing it to the width of the parallel parking stall. They found that, as parking lane width increased from 6 feet to 9 feet, the proportion of vehicles parking over 12 inches (the legal limit) from the curb, increased from 1 percent to 60 percent. They also found that for every one foot increase in parking lane width, bicyclist trajectory would need to increase by 0.44 feet from the curb. The width of the adjacent lane, the presence or absence of bicycle lanes, and whether parking was paid or free had no significant effect on parking offset. The results of their study indicated that decreasing parking lane width can be an effective strategy for increasing operating space for bicyclists (4).

A 2012 study by Teschke and colleagues looked at 690 bicycle crashes in Toronto and Vancouver, Canada, and compared the infrastructure at the location where the injury occurred to a randomly selected control site from the same trip. Using this case-crossover method, the researchers created a collection of control sites that approximated the frequency of the different route types' occurrence while controlling for personal characteristics and trip conditions like age, gender, risk-taking propensity, weather, helmet use, and time of day. The most frequently observed road type, major street routes with parked cars, was used for the reference category. The researchers compared the number of injuries observed on each type of route compared to the number of times that type of route was randomly selected as a control site. This analysis allowed them to calculate odds ratios to reflect the risk of an injury occurring on each of the 14 route types compared to the most commonly occurring type of site. Three types of major street routes without on-street parking were considered: without bike infrastructure, with shared lanes, and with bike lanes. The table below gives the unadjusted and adjusted odds ratios for each of these route types. Confidence intervals whose range includes one are not considered statistically significant (5).

Table 1: Comparison of route types at injury and control sites, Vancouver and Toronto

Variable	Number of Injury Sites	Number of Control Sites	Unadjusted OR (95% C.I.)	Adjusted OR (95% C.I.)
Major street route with parked cars and no bike infrastructure	155	114	1.00 (Reference category)	1.00 (Reference category)
Major street route, no parked cars and no bike infrastructure	112	118	**0.65* (0.44, 0.97)**	**0.63* (0.41, 0.96)**
Major street route, no parked cars and shared lane	13	12	0.66 (0.24, 1.82)	0.60 (0.21, 1.72)
Major street route, no parked cars and bike lanes	35	46	**0.47* (0.26, 0.83)**	0.54 (0.29, 1.01)

* Indicates a p-value of <.05.

[Caption: Excerpt from Table 4 of the Teschke et al. (2012) article showing a comparison of the risk of injury on road types compared to randomly selected control sites. For those odds ratios marked with an asterisk, the association between that type of route and injury risk was statistically significant at the 95% confidence level. (5)]

Their analysis showed that there was an association between the presence of on-street parking and the risk of injury. The results of the adjusted odds ratio analysis were significant only in the case of major street routes without parked cars and bike infrastructure. Riding on a major street route without parked cars and bicycle infrastructure was associated with a statistically significant 37 percent decrease in the risk of experiencing an injury when compared to the same type of road, but with on-street parking. Data from the Metro Vancouver route preference survey, which used the same route classification criteria, also indicated a public preference for major streets without on-street parking - and with shared lanes or bike lanes (5).

A 2013 paper by Barnes and Schlossberg evaluated the impact of retrofitting a Eugene, Oregon, one-way street segment to better accommodate pedestrians and bicyclists. The redesign included restricting parking to one side of the street, implementing back-in angle parking in place of parallel parking, combining the single lane of traffic and bike lane into one shared lane, and removing physical barriers that separated contraflow bicyclists from vehicular traffic. The researchers recorded and analyzed video footage taken before and after the street conversion to compare bicycle traffic volumes, bicyclist-motorist conflicts, and collisions. Analysis of footage indicated that the volume of bicyclists increased by 68.5 percent in the direction of traffic flow and 96.9 percent in the contra-flow direction on the street while automobile volumes decreased marginally, indicating that the street redesign did not compromise motorist access. At the same time that bicyclist volumes increased, actions that led to conflicts increased (e.g. motorists parking in the contraflow bike lane, wrong way travel by bicyclists and motorists), but there was no increase in close calls. No collisions were observed before or after the street redesign. The researchers concluded that the street redesign improved bicyclist facilities without compromising vehicular access, attracting greater numbers of bicyclists and improving their safety (6).

Figure 2. Before and after photos from a Complete Streets redesign in Eugene, Oregon.

[Caption: Photos from Barnes and Schlossberg (2013), showing East 13th Avenue before (above) and after (below) the Complete Streets-inspired redesign. The redesign restricted parking to one side of the street, implemented back-in angle parking in place of parallel parking, combined the bike lane on the right with the vehicle lane, and removed the barriers that physically separated the contraflow lane from traffic (6).]

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2. Hunter, W. W., L. Thomas, R. Srinivasan, and C. Martell. *Evaluation of Shared Lane Markings*. Publication FHWA-HRT-10-041. FHWA, U.S. Department of Transportation, 2010.
3. Duthie, J., J. Brady, A. Mills, and R. Machemehl. Effects of On-Street Bicycle Configuration on Bicyclist and Motorist Behavior. Presented at the 89th Annual Meeting of the Transportation Research Board. Washington, D.C., 2010.
4. Furth, P. G., D. M. Dulaski, M. Buessing, and P. Tavakolian. Parking Lane Width and Bicycle Operating Space. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2190, 2010, pp. 45-50.
5. Teschke, K., M. A. Harris, C. O. O. Reynolds, M. Winters, S. Babul, M. Chipman, M.D. Cusimano, J. R. Brubacher, G. Hunte, S. M. Friedman, M. Monro, H. Shen, L. Vernich, and P. A. Cripton. Route Infrastructure and the Risk of Injuries to Bicyclists: A Case-Crossover Study. *American Journal of Public Health*, Vol. 102, No. 12, 2012, pp. 2336-2343. Retrieved May 6, 2013 from http://ajph.aphapublications.org/doi/pdf/10.2105/AJPH.2012.300762
6. Barnes, E., and M. Schlossberg. Improving a Cyclist and Pedestrian Environment While Maintaining Vehicle Throughput: A Pre- and Post-Construction Street Analysis. Presented at the 92nd Annual Meeting of the Transportation Research Board, Washington, D.C., 2013.

1.6 Median/Crossing Island

There are currently no resources for this section.

1.7 Driveway Improvements

There are currently no resources for this section.

1.8 Lane Reduction (Road Diet)

A 2012 article by Chen, Chen, Ewing, McKnight, Srinivasan, and Roe evaluated the effectiveness of road diets in increasing bicyclist safety at intersections. The researchers used a two-group pretest-posttest research design to compare collision statistics following the implementation of road diets at 324 intersections throughout New York City. Bicycle collision statistics were collected for the five-year period preceding road diet implementation, as well as the two-year period following it, and the authors used ANCOVA analysis in order to control for potential regression-to-the-mean effects. Analysis of their results indicated that bicyclist crash incidence actually increased by 5.9 percent at intersection road diet sites, compared to a decrease of 25.6 percent at comparison intersections. This resulted in an ANCOVA-adjusted increase in bicyclist collisions of 21 percent at intersections; however, results were not significant at the 0.05 level. Because bicyclist volumes were not recorded before and after the implementation of the road diets, the researchers could not definitively state whether the increase in collisions exceeded the increase in exposure from higher volumes of bicyclists using roadways that underwent road diets (1).

Table 2. Observed change in bicycle collisions following road diet implementation in New York City

Collision Location	Group	Number of sites	Percent change in bicycle collisions	Unadjusted crash modification factor and standard error	ANCOVA-adjusted crash modification factor and standard error
Intersections	Treatment	324	+5.88%	1.06 (0.31)	1.21 (0.30)
	Control	2346	-25.86%		

[Caption: Data from Tables 4, 5, and 6 from Chen et al. (2012) showing the number of study sites, percent change in bicycle collisions following road diet measures, and unadjusted and ANCOVA-adjusted crash modification factors and standard errors. Results were not significant at the 0.05 level (1).]

Figure 3. Before and after pictures from Urbana, Illinois, illustrate a typical road diet project.

[Caption: Photos from the Victoria Transport Policy Institute showing Philo Road in Urbana, Illinois, before and after a road diet. The road diet reduced the number of lanes from four to three and added bike lanes, crossing facilities, and a pedestrian refuge island. http://www.vtpi.org/tdm/tdm122.htm]

A 2013 article by Hamann and Peek-Asa analyzed the association between on-road bike facilities and bicycle crashes in Iowa from 2007 to 2010. The researchers matched 147 collision sites to 147 non-collision control sites and analyzed the data using conditional multivariate logistic regression. Results of their analysis indicated that, for every 10 foot increase in the width of the roadway, the odds of the roadway being the site of a bicycle crash increased by 38 percent (adjusted odds ratio 1.38, 95% confidence interval 6%-79%). The researchers were not able to specify whether collisions took place when bicyclists were crossing the roadway or when they were riding along the roadway (2). The results of this analysis indicate that reducing the width of a roadway may be associated with a decreased risk of collisions for bicyclists.

References

1. Chen, L., C. Chen, R. Ewing, C. McKnight, R. Srinivasan, and M. Roe. Safety Countermeasures and Crash Reduction in New York City—Experience and Lessons Learned. *Accident Analysis and Prevention*, Vol. 50, 2013, pp. 312-322. http://dx.doi.org/10.1016/j.aap.2012.05.009
2. Hamann, C., and C. Peek-Asa. On-Road Bicycle Facilities and Bicycle Crashes in Iowa, 2007-2010. *Accident Analysis and Prevention*, Vol. 56, 2013, pp. 103-109.

1.9 Lane Narrowing

There are currently no resources for this section.

1.10 Streetcar Track Treatments

There are currently no resources for this section.

2.0 On-Road Bike Facilities

2.1 Bike Lanes

Bike lanes are a portion of the roadway designated for the preferential or exclusive use of bicyclists and which are separated from motor vehicle traffic through the use of pavement markings. According to Pucher, Buehler, and Seinen (2011), improving and increasing the number of bike paths and lanes has been the main approach to making cycling safer in Europe and North America (1).

Figure 4. Bicyclists use a bike lane in Montreal.

[Caption: Two adults and a child wait at a red light on a bike lane in Montreal. Photo by Jacob-uptown http://www.flickr.com/photos/7995989@N03/4931842773/]

One of the first major studies of bike lanes was conducted by Lott and Lott in 1976 in Davis, California. They compared relative frequencies of bicycle-motor vehicle collision types to determine the effect of the presence of bike lanes on the frequency of various types of bicycle-motor vehicle collisions. The research team used four years of police records to compare collision statistics on roads that had bike lanes to those without bike lanes. Crash records in Davis were also compared with those of Santa Barbara, California, a comparable city that did not use bike lanes (2). All of the bicycle-motor vehicle collisions were categorized into a ten-class system, and the relative frequency with which each type of collision occurred in bike lane segments versus non-bike-lane segments was assessed. Three types of bicycle-motor vehicle accidents that seemed unaffected by bike lanes were used as a standard for evaluating the role of bike lanes in other categories of accidents. Specifically, accidents where a bicyclist failed to stop or yield at a controlled intersection, where a motorist failed to stop or yield at a controlled intersection, and where a motorist made an improper left turn were analyzed. The analysis found differential decreases in crash frequencies across five classes of bicycle-motor vehicle collisions at locations with bike lanes: bicyclists exiting driveways, motorists exiting driveways, bicyclists on the wrong side of the street, motorists overtaking bicyclists, and motorists making improper rights. The research team found a higher frequency of crashes in the case of bicyclists making improper left turns. The authors concluded that the results indicated an overall reduction in bicycle-motor vehicle collisions in Davis following the installation of bicycle lanes (2).

Table 3: Percentage and frequency of bicyclist-motor vehicle collisions by type and presence or absence of bike lanes

Accident Type	Percentage of all accidents by type of street		Expected rate of accidents by type of street	
	With Bicycle Lanes	Without Bicycle	With Bicycle Lanes	Without Bicycle

		Lanes		Lanes
A Bicyclist exited driveway	1.45	7.89	1.03	7.89
B Motorist exited driveway	5.90	3.95	2.06	3.95
C Bicyclist did not stop/yield	11.59	7.89	N/A	N/A
D Bicyclist improper left	14.49	5.26	10.29	5.26
E Bicyclists wrong side	7.25	18.42	5.15	18.42
F Motorist overtook bicyclist	1.45	7.89	1.03	7.89
G Motorist did not stop/yield	20.29	19.74	N/A	N/A
H Motorist improper left	28.99	15.79	N/A	N/A
I Motorist improper right	11.59	13.16	8.23	13.16
J Motorist opened car door	0.00	0.00	N/A	N/A
Total	--	--	27.79	56.57

[Caption: Data taken from Tables 3 and 4 of the Lott and Lott (1976) article showing the author's comparison of bicycle-motor vehicle collision percentages and frequencies by type of street (with or without bicycle lanes)(2).]

Twelve years later, a 1988 study by Smith and Walsh looked at bike lanes installed along a pair of opposite-direction, one-way arterial streets in Madison, Wisconsin. The bike lane installation resulted in a statistically significant increase in the number of bicycle-motor vehicle crashes associated with turning movements during the first year after the bike lane installation; however, the number dropped sharply after the first year that the bike lanes had been in operation. The authors concluded that, overall, the bike lanes did not have an adverse effect on bike safety. The one roadway section where crashes increased during the first year was something of an anomaly, in that it was installed on the left side of a one-way street (3).

A 1997 study by Jensen looked at the effect of bike lanes on collision rates at signalized intersections and at priority intersections (at priority intersections, traffic is controlled by signage rather than signals and one road has priority over the other) in Denmark. Results indicated that the implementation of bike lanes caused no change in the number of either bicycle-motor vehicle or overall crashes at signalized intersections. However, there was an increase in bicycle-motor vehicle crashes at priority intersections. The study also found a reduction in all crashes along the stretches of roadway between intersections (4).

A 1999 report for the Federal Highway Administration by Hunter, Stewart, Stutts, Huang, and Pein compared the safety of bike lanes to the safety of wide curb lanes. The infrastructure of Santa Barbara, California; Gainesville, Florida; and Austin, Texas, was studied using videotapes of bicyclists approaching and riding through eight intersections with bike lanes and eight others with wide curb lanes. In total, 2,700 cyclists were observed at the bike lane locations and 1,900 cyclists were observed at the wide curb lane intersections. Additionally, on-site interviews were conducted with 2,900 cyclists and an analysis was performed using crash data from bicycle-motor vehicle crashes (5).

Using video-coded analysis, the authors determined that wrong-way riding was significantly associated with wide curb lane sites, with 7 percent of bicyclists riding the wrong way at wide curb lane sites as opposed to 2.3 percent at bike lane sites. However, when wrong-wide sidewalk riding was removed, wrong-way riding on the roadway dropped to 1.7 percent at wide curb lane sites and 1 percent at bike lane sites. Motorists were also more likely to encroach upon the adjacent lane when passing bicyclists in a wide curb lane compared to a bike lane (17 % to 7 %).

In terms of conflicts occurring at the actual intersection, 198 were recorded on tape. Of these, 79 percent were bicycle-motor vehicle conflicts, 10 percent were bicycle-bicycle conflicts, and 10 percent were bicycle-pedestrian conflicts. More bicycle-bicycle conflicts occurred in the bike lanes than in wide curb lanes, with a greater proportion of bicycle-pedestrian problems in the wide curb lanes. Over 90 percent of all midblock and intersection conflicts noted in this study were considered minor (5). Based on their findings, Hunter et al. conclude that bike lanes should be installed where there is adequate width because "Bike lanes are more likely to increase the amount of bicycling than wide curb lanes" (5).

A 2005 article by Hunter, Feaganes, and Srinivasan examined the effects of striping 14-ft wide curb lanes to create an 11-ft travel lane and a 3-ft "undesignated lane" intended for use by bicyclists in Broward County, Florida. The researchers collected before-and-after videotaped footage of bicyclists at six midblock and four intersection sites where striping took place. They then extracted data about the distance between the bicyclist and passing motor vehicles as well as the distance of bicyclists and motorists from the gutter pan seam or edge of roadway. Analysis of the results showed a greater lateral distance from the gutter pan seam for bicyclists and motorists following the addition of the stripe. At some sites, motor vehicles passed at closer distances following the addition of the stripe, while at other sites, motorists passed at greater distances. On average, motor vehicle encroachments into adjacent lanes upon passing bicycles decreased 15 percent following the installation of the stripe. The researchers concluded that the striping of the undesignated lane led to greater safety effects for bicyclists and motorists at study sites (6).

A 2006 report by the Center for Transportation Research at the University of Texas studied the effect of the presence of bike lanes on the extent to which motorists entered adjacent lane space. To do so, they videotaped motorist movement in the presence of volunteer bicyclists in a bike lane. From an analysis of their field observations, the researchers concluded that:

- Designated bike lanes of four feet or more led to less change in lateral position for motorists travelling along the roadway. Therefore, they were considered operationally superior to wide curb lanes for both cyclists and motorists.
- The characteristics of the adjacent lane affect motorist behavior. Motorists behaved differently when the adjacent lane contained oncoming traffic when compared to same-direction or two-way left-turn lanes. When faced with oncoming traffic, motorists drove closer to the bicycle lane when they were not passing a bicyclist.
- Cyclist and motorist roadway placement differed between high-volume, high-speed streets and residential streets. Motorists were observed giving bicyclists greater passing distance in residential areas.

These conclusions were used by the Texas Department of Transportation to create a guide for deciding when and how to retrofit existing roadways with bicycle facilities when without changing roadway width. They also demonstrated that the presence of bike lanes benefitted motorists by reducing the degree to which motorists veer into adjacent lanes to pass bicyclists (7).

A 2008 analysis by Jensen was one of the first studies that used pre- and post-treatment data from treatment and comparison groups to evaluate the effect of bicycle lane installation on bicyclist and other road users' safety. Jensen studied the effects of 5.6 km of bicycle lanes that were marked between 1988 and 2002 in Copenhagen, Denmark. To do so, he used a stepwise methodology designed to account for regression-to-the-mean effects, crash trends, and traffic volumes. He chose equally long before and after periods for each road that was analyzed, as well as data from what he called a "before-before" period, a 5-year period 8-12 years before lanes were marked, in order to control for potential regression-to-the-mean effects at sites chosen for treatment. Using pre-treatment data adjusted for increases in traffic volumes, Jensen generated a predicted number of collisions in the absence of treatment to use for comparison purposes (8).

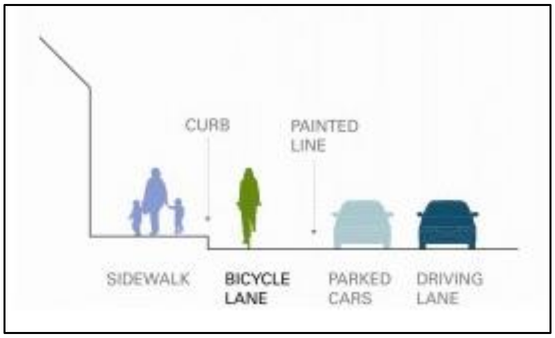

Figure 5. Cross section view of a street showing bicycle lanes as used in Copenhagen, Denmark.

[Caption: The bike lane is separated from the sidewalk by a curb and from the roadway by a pavement marking. A line of parked cars between moving traffic and the cycle track offers an additional buffer from roadway traffic. Image by Lars Gemzøe, Gehl Architects, a member of the Cycling Embassy of Denmark.]

Results of Jensen's analysis demonstrated changes in safety for different road users as a result of marking bike lanes. One unique feature of this study was that bicyclists and moped riders were placed in the same category, because mopeds were permitted to use the bicycle lanes in Denmark. On roads where bicycle lanes were marked, there was a 5 percent increase in bicycle and moped traffic, with bicycles accounting for over 95 percent of that traffic. There was a decrease of 1 percent in motor vehicle traffic, but neither traffic increase (bicycle/moped or motor vehicle) was statistically significant. For bicycle and moped riders, the observed increase in injuries was 49 percent; however, that figure was not statistically significant. For all road users (pedestrians, bicyclists and moped riders, and motorists), crashes increased by 5 percent and injuries increased by 15 percent. Again, these increases were not statistically significant. Jensen also highlighted gender disparities in injuries, with a 22 percent increase in injuries in women following the installation of bicycle lanes, compared to an increase of 7 percent for men. Following the marking of bike lanes, a statistically significant increase of 73 percent in crashes between right-turning motor vehicles and bicyclists was observed, as well as a considerable increase in the number of rear-end crashes between two bicycles/mopeds. Jensen concluded by stating that bicyclist safety in some cases has decreased as a result of bicycling infrastructure; however, the observed increase in bicycling points to several health benefits such as more physical activity and reduced air pollution, the results of which should be carefully weighed against potential safety costs (8).

Pucher and Buehler (2008) analyzed data from the Netherlands, Denmark, and Germany to determine why bicycling is safer in those countries than in the United States. The provision of bike lanes and paths was one of eight treatments that they identified as improving safety for all roadway users (9).

A 2010 study by Duthie, Brady, Mills, and Machemehl looked at 48 sites in Austin, Houston, and San Antonio to determine how bike lanes, wide curb lanes, and on-street parking affected bicyclist safety. Using over 13,900 observations recorded on video, Duthie et al. used regression model analysis to conclude that bike lanes were safer for bicyclists than wide curb lanes because the bicyclists positioned themselves better within the space to avoid obstacles, such as open car doors (10). A buffer zone between the bike lane and the parking lane led to even safer bicycle positioning, as shown in the following graph:

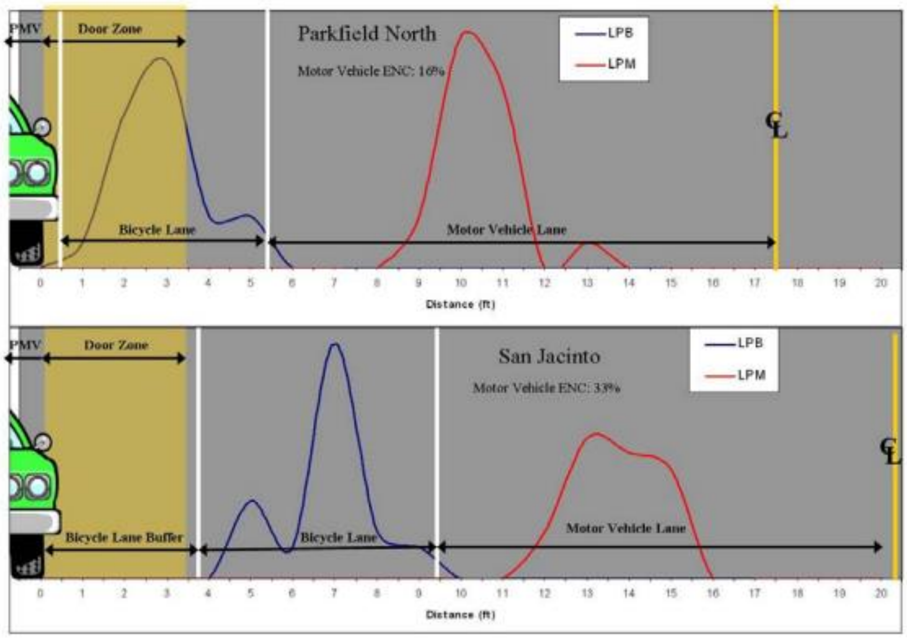

Figure 6. Summary of motorist and bicyclist distances from the curb before and after implementation of a buffer.

[Caption: Figure 2 from Duthie, Brady, Mills, and Machemehl (2010), showing the distributions of bicyclist and motorist positions in feet from the curb (10).]

Bike lanes also reduced the change in lateral positioning of motorists during passing and non-passing events, which showed the motorists felt comfortable passing bicyclists without encroaching upon another traffic lane (10).

A 2012 article by Chen, Chen, Ewing, McKnight, Srinivasan, and Roe evaluated the effectiveness of bike lanes in increasing bicyclist safety at intersections and on roadway segments. The researchers used two-group pretest-posttest research design to compare collision statistics following the installation of bike lines at 669 intersections and on 660 roadway segments throughout New York City. Bicycle collision statistics were collected for the five-year period preceding bike lane installation, as well as the two-year period following it, and the authors used ANCOVA analysis to control for potential regression-to-the-mean effects. Analysis of their results indicated that bicyclist crash incidence actually increased by 25.4 percent at intersection sites, compared to a decrease of 10 percent at comparison intersections. On roadway segments, bicyclist crashes decreased by 2.8 percent on treated roadway segments, but decreased by 49.6 percent on comparison roadway segments. This resulted in an ANCOVA-adjusted increase in bicyclist collisions of 58 percent at intersections and by 138 percent on roadway segments, results that were significant at the 0.05 level. Because bicyclist volumes were not recorded before and after the bike lane installation, the researchers could not definitively state whether the increase in collisions exceeded the increase in exposure from higher volumes of bicyclists using the bike lanes after they were installed (11).

Table 4: Observed change in bicycle collisions following installation of bicycle lanes in New York City

Collision Location	Group	Number of sites	Percent change in bicycle collisions	Unadjusted crash modification factor and standard error	ANCOVA-adjusted crash modification factor and standard error
Segments	Treatment	660	-2.78	0.83 (0.21)	2.38 (0.76)
	Control	2227	-49.63		
Intersections	Treatment	669	25.35	1.09 (0.10)	**1.58* (0.19)**
	Control	1768	-10.20		

* Indicates a p-value of <.05.

[Caption: Data from Tables 3, 5, and 6 from Chen et al. (2012) showing the number of study sites, percent change in bicycle collisions following bicycle lane installation, and unadjusted and ANCOVA-adjusted crash modification factors and standard errors. Bold numbers indicates significance at the 95% confidence level (11).]

A second 2012 article by Chen, Chen, Srinivasan, McKnight, Ewing, and Roe used the same data as the above study but examined the safety effects of bicycle lanes in New York City in greater detail. The authors used two-stage research design. First, they identified a comparison group consisting of intersections and roadway segments that were comparable to the intersections and roadway segments on which bike lanes had been installed from 1996-2006. Using police records, the researchers examined the frequency of five categories of crashes (total, multi-vehicle, pedestrian, bicyclist, and injury/fatal) for the five years previous to and the two years following the installation of bicycle lanes. Second, the authors utilized generalized estimating equation methodology to apply Poisson and negative binomial regression models to analyze the pre- and post-treatment collision data in the treatment and control groups (12).

Figure 7. Bicyclists use a New York City bike lane.

[Caption: A bike lane on 9th Avenue in New York City. Photo by Kyle Gradinger/BCGP http://www.flickr.com/photos/19243288@N00/2367382978/]

The data were further divided into intersection and roadway segment groups to account for the different risk characteristics of each location type. Data about daytime population density, retail density, and bicycle trip density were added to the model to account for exposure, while data about bus stops, parking, truck routes, intersection control type, and number of intersection arms were added to account for bicycle-motor vehicle conflicts. Results of the analysis showed that, on roadway segments, all types of collisions decreased for the treatment and comparison groups, with the exception of bicyclist crashes, which increased by 1.2 percent in the treatment group. At intersections, all types of collisions decreased for treatment and comparison groups, with the exception of bicyclist and pedestrian collisions, which also increased in the treatment group (by 22.2% for bicyclists and by 8.6% for pedestrians). The increase in bicyclist collisions on bicycle facilities, coupled with the decrease in collisions on comparison sites, was assumed to have been a result of an increase in exposure not properly controlled for with the bicycle trip density variable. The lack of pre- and post-treatment volume data for the studied sites made these results difficult for the researchers to interpret. Overall in New York City, bicycle volume increased 51 percent from 1996-2006, and by 48 percent from 2006-2008. Because intersections emerged as the site of many bicycle-motor vehicle conflicts following the installation of bike lanes, the researchers recommended the use of further safety treatments at intersections such as marking the path of the bike lane across the intersection and installing bike boxes to increase visibility in order to reduce conflicts (12).

Table 5: Observed change in bicycle collisions following installation of bicycle lanes in New York City

	Before Period (5 Years)	After Period (2 Years)	Percent

					Change
Crash Type	Total	Average	Total	Average	
Crashes on Segments					
Total crashes					
Treatment group	827	0.2857	209	0.1805	-36.8
Comparison group	2164	0.2247	537	0.1394	-38.0
Bicycle crashes					
Treatment group	47	0.0162	19	0.0164	1.2
Comparison group	112	0.0116	25	0.0065	-44.0
Crashes at Intersections					
Total crashes					
Treatment group	4577	1.5837	1494	1.2924	-18.4
Comparison group	13450	1.6273	4124	1.2474	-23.2
Bicycle crashes					
Treatment group	317	0.1097	155	0.1341	22.2
Comparison group	680	0.0823	244	0.0738	-10.3

[Caption: Excerpt from Table 2 of Chen, Chen, Srinivasan, McKnight, Ewing, and Roe (2012) showing the number of crashes at bicycle lane locations by type (total or bicycle only), location (segment or intersection), group (treatment or control), and study period (before or after) (12).

A 2012 study by Teschke and colleagues looked at 690 bicycle crashes in Toronto and Vancouver, Canada and compared the infrastructure at the crash site to a randomly selected control site from the bicyclist's route. Using this case-crossover method, the researchers created a collection of control sites that approximated the frequency of the different route types' occurrence while controlling for personal characteristics and trip conditions like age, gender, risk-taking propensity, weather, helmet use, and time of day. The most frequently observed road type, major street routes with parked cars, was used for the reference category. The researchers compared the number of injuries observed on each type of route compared to the number of times that type of route was randomly selected as a control site. This analysis allowed them to calculate odds ratios to reflect the risk of an injury occurring on each of the 14 route types compared to the most commonly occurring type of site (13).

Figure 8. A bike lane in Toronto.

[Caption: Bicyclists use a bike lane and the roadway during a Critical Mass ride in Toronto. Photo by Commodore Gandalf Cunningham. http://www.flickr.com/photos/25716750@N06/2416976731]

Two types of routes with bike lanes were considered: major street routes without parked cars and major street routes with parked cars. The table below gives the unadjusted and adjusted odds ratios for each of these route types. Confidence intervals whose range includes 1 are not considered statistically significant (13).

Table 6: Comparison of route types at injury and control sites in Vancouver and Toronto

Variable	Number of Injury Sites	Number of Control Sites	Unadjusted OR (95% C.I.)	Adjusted OR (95% C.I.)
Major street route with parked cars and no bike infrastructure	155	114	1.00 (Reference category)	1.00 (Reference category)
Major street route with parked cars and bike lane	25	28	0.53 (0.26, 1.07)	0.69 (0.32, 1.48)
Major street route without parked cars and bike lane	35	46	**0.47* (0.26, 0.83)**	0.54 (0.29, 1.01)
Local street route with designated bike route	52	57	**0.53* (0.30, 0.94)**	**0.49* (0.26, 0.90)**

* Indicates a p-value of <.05.

[Caption: Excerpt from Table 4 of the Teschke et al. (2012) article showing a comparison of the risk of injury on road types compared to randomly selected control sites. For those odds ratios marked with an asterisk, the association between that type of route and injury risk was statistically significant at the 95% confidence level.(13).]

Their analysis showed that there was an association between the type of street and presence of a bike route and the risk of injury risk. Riding on a major street with a designated bike route was associated with a statistically significant 51 percent decrease in the risk of experiencing an injury. For the major street routes with bike lanes, the results of the adjusted odds ratio analysis were not significant whether or not there was on-street parking. Based on the results of all 14 classes of route type, the researchers concluded that bicycle route infrastructure, including bike lanes, can be designed to prevent injury to cyclists (13).

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2.1.1 Colored Bike Lanes

In 2011, the Federal Highway Administration (FHWA) issued interim approval for the use of green colored pavement within marked bike lane and where bicycle lanes continue through intersections and traffic conflict areas. Prior to their approval, various agencies conducted experiments with green bike lanes, including the Vermont Agency of Transportation, the Minnesota Department of Transportation, the Pennsylvania Department of Transportation, and the Cities of Chicago, Illinois; New York, New York; St. Petersburg, Florida; San Francisco, California; Portland, Oregon; Columbia, Missouri; Long Beach, California; Austin, Texas; Nashville, Tennessee; Missoula, Montana; and Golden, Colorado. A FHWA review of data from the experiments led them to conclude that green pavement markings were satisfactory at improving operational effects, such as more accurate bicycle position, increased awareness of bicyclist presence, and increased perceptions of safety by bicyclists. The use of blue and red lanes, such as in Denmark or the Netherlands, has not been approved in the U.S. Blue is the primary color of accessible parking, and is not dedicated exclusively for bike lanes. Red is currently being tested for a use other than bike lanes (1).

Figure 9. Red bike lanes in the Netherlands.

[Caption: Red bike lanes as used in the Netherlands (1). Red bike lanes are not officially approved for use in the United States.]

Figure 10. Blue bike lanes in Denmark.

[Caption: A bicyclist uses a blue bike lane in Copenhagen, Denmark. Blue bike lanes are not officially approved for use in the United States. Photo courtesy of Steven Vance. http://www.flickr.com/photos/jamesbondsv/5355971166/]

Figure 11. Green bike lanes in Portland, Oregon.

[Caption: A cyclist uses a green bike lane in Portland, Oregon. Photo courtesy of Will Vanlue. http://www.flickr.com/photos/wv/7688988620/]

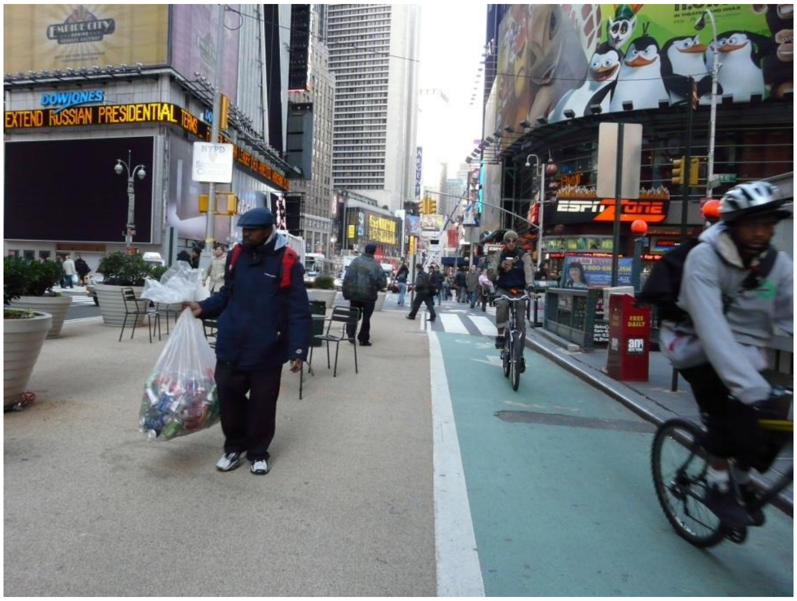

Figure 12. Bicyclists use a green bike lane in New York City, New York.

[Caption: Bicyclists in New York City riding on a bike lane on Broadway Avenue. Photo by adrimcm http://www.flickr.com/photos/adrimcm/3055726814/]

A 2000 article by Hunter, Harkey, Stewart, and Birk considered the bicycle safety impact of blue bike lane treatments utilized in conjunction with signs in Portland, Oregon. The blue bike lanes were installed by the City of Portland at 10 high-traffic and high-conflict locations where motor vehicles crossed the bike lane in order to turn right or merge onto a street. The researchers collected videotaped data before and after the installation of the bike lanes, and extracted data about bicyclist characteristics, bicyclist and motorist behavior, and bicyclist-motorist interactions. Some notable outcomes were that:

- A significantly greater percentage of bicyclists followed the marked path in the after period (an increase from 85% in the before period to 93% in the after period).
- A significantly lower percentage of bicyclists scanned for a vehicle in the after period (a decrease from 43% in the before period to 26% in the after period).
- A significantly lower percentage of bicyclists slowed or stopped upon approaching the conflict area in the after period (a decrease from 11% in the before period to 4% in the after period).
- A significantly greater percentage of motorists yielding to bicyclists in the conflict area in the after period (an increase from 72% in the before period to 92% in the after period).
- The number of bicyclist-motorist conflicts was small in the before and after period, but decreased from 0.95 per 100 bicyclists in the before period to 0.59 per 100 bicyclists in the after period.
- An intercept survey of bicyclists indicated that 76 percent of bicyclists felt that the blue bike lanes increased bicyclist safety.

Based on the results of the evaluation, the researchers concluded that the blue bike lanes appeared to create a safer bicycling environment by heightening bicyclist and motorist awareness in conflict zones (2).

Figure 13. Examples of blue bike lanes as used in Portland, Oregon.

[Caption: Photos of blue bike lanes in Portland, Oregon, used to denote and call attention to locations where bike lanes cross right-turn lanes, exit ramps, and entrance ramps (3).

A 2007 article by Sadek, Dickason, and Kaplan evaluated the effectiveness of high-visibility green bike lanes and green crossing treatments at ramp locations on a cloverleaf exchange in Burlington, Vermont. The researchers collected video and visual data about bicyclist and motorist behavior at two treatment and two control sties following the installation of the treatments. The results indicated that, when the green bike lane was available, of those bicyclists who were traveling in the same direction as traffic (about 65% of those observed), 73.6 percent used the lane, 12.3 percent used the road, and 14.2 percent used the sidewalk. At control sites, 27.4 percent of bicyclists used the road and 72.6 percent used the sidewalk. Of those who travelled against traffic, 36 percent used the bike lane, 1.3 percent used the road, and 62.7 percent used the sidewalk at treatment sites. At control sites, 1.3 percent of bicyclists used the road, and 98.7 percent used the sidewalks. The authors concluded that the bicyclists were encouraged to use the bike lanes at treatment sites, especially for those bicyclists riding legally with the direction of traffic. Responses to concurrent surveys of motorists and bicyclists indicated that both groups felt that the green lane markings and crossings increased bicyclist and motorist awareness at the site. However, this study did not use statistical tests to determine whether differences in proportions were statistically significant (4).

A 2008 report by Hunter, Srinivasan, and Martell examined the use of green pavement and signing used in a bike lane weaving area in St. Petersburg, Florida. The study site was located on a five-lane, one-way street with one right-turn-only lane. The green bicycle lane was used to highlight where motorists had to cross the bicycle lane to enter the right turn only lane. The researchers wished to determine if the green paint and signs created safer conditions for bicyclists and motorists. The behavior of bicyclists and motorists was recorded by video before and after the lanes was installed. Recorded observations included details about the bicyclist (e.g., age, gender) as well as data about bicyclist and motorist behavior and their interactions. It was observed that a significantly higher percentage of motorists yielded to bicyclists (98.5% in the after period, compared to 86.7% in the before period) and used a right turn signal before changing lanes (89.2% in the after period, compared to 85.2% in the before period) following the installation of the green bike lane. For bicyclists, a significantly higher percentage scanned for nearby vehicles in the after period, with 12 percent scanning in the after period, compared to 6 percent in the before period. Although the percentage of motor-vehicle conflicts decreased in the after period (from 2.2% to 0.7%), the difference was not statistically significant. The researchers concluded that these changes in behavior represented an increase of safety at this site, but cautioned that further study in other locations and settings should be conducted (5).

Figure 14. Before and after photos of the installation of a green bike lane weaving area in St. Petersburg, Florida.

[Caption: Figure 1 and Figure 2 from Hunter, Srinivasan, and Martell (2008) showing the site where green bike lanes were installed and evaluated (5).]

A 2011 paper by Furth, Dulaski, Bergenthal, and Brown evaluated the effects of bicycle priority treatments on the position of bicyclists sharing a roadway lane with vehicular traffic. They studied the 2008 implementation of a green bike lane applied in a lane where there was already a shared lane marking in downtown Salt Lake City, Utah. The purpose of the colored bike lane was to encourage bicyclists to use the middle of the lane, encourage motorists to change lanes to pass bicyclists, and to decrease the percentage of bicyclists using the sidewalk. The research team conducted observations of bicyclist position for three weekdays prior to and following the installation of the green bike lane. The percentage of bicyclists who rode at least four feet from the curb increased from 17 percent prior to treatment installation to 92 percent 11 months later. No effect was recorded for the percentage of motorists changing lanes to pass bicyclists, or the number of bicyclists using the sidewalk (6).

Table 7. Cyclist position before and after the installation of a green bike lane in Salt Lake City, Utah.

Cyclist users	Cyclist position	Before	After
All cyclist users	Sidewalk	46%	46%
Cyclists in the road	0-4 feet from curb	83%	8%
Cyclists in the road	More than 4 feet from curb in right lane (including green lane)	17%	92%

Figure 15. A green bike lane in Salt Lake City, Utah.

[Caption: The bicyclist priority lane in Salt Lake City as evaluated in Furth, Dulaski, Bergenthal, and Brown (2011) (6).]

A 2011 article by Brady, Loskorn, Mills, Duthie, and Machemehl evaluated the use of green coloring to mark bike lanes at two conflict areas where bicycle lanes crossed motor vehicle lanes in Austin, Texas. The bike lanes were painted green in conjunction with "Yield to Bikes" signs to clarify the meaning of the bike lanes. The researchers collected before-and-after data to determine if there was a change in the number of bicyclists who used the lane to approach and navigate the conflict area and the number of motorists who yielded to bicyclists and used turn signals following the installation of the lane. Analysis of results indicated that painting the bike lanes green led to changes in bicyclist and motorist behavior. The researchers noted that the coloring appeared to be more effective at the study site where a freeway exit ramp crossed the bike lane. At that site, motorists were 95 percent more likely to yield to oncoming bicyclists and were 24 percent more likely to signal their crossing into the conflict area in the after period. At the site where motorists crossed the bike lane to enter a right-turn-only lane, motorists were 47 percent less likely to yield to bicyclists but 42 percent more likely to use their turn signal in the after period. At this site, bicyclists were also more likely to negotiate the conflict area in the bike lane after it was painted. The researchers concluded that painting the bike lanes green increased motorist awareness of the conflict zone, but may have provoked confusion about how to cross the bicycle lane at the second site (7).

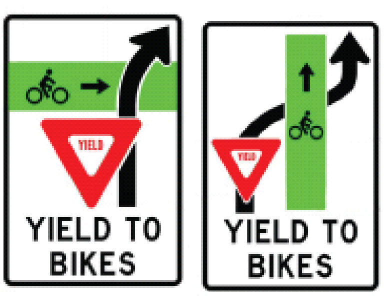

Figure 16. Two examples of "Yield to Bikes" signs used at green lane sites in Austin, Texas.

[Caption: "Yield to Bikes" signs as installed with green bike lanes at study sites in Brady, Loskom, Mills, Duthie, and Machemehl (2011) (7).]

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2.1.2 Buffered Bike Lanes

A 2013 article by Goodno, McNeil, Parks, and Trainor examined the impact of a median buffered bike lane installed in Washington, D.C., on the safety, comfort, and convenience of all corridor road users. The two-way buffered bike lane was five feet wide in each direction, with three-foot buffers between the bike and traffic lanes. At some intersections, left-turn and U-turn restrictions were implemented to reduce bicyclist conflicts with turning vehicles. The researchers conducted before-and-after analyses of bicycle and motor vehicle volumes; bicycle, motor vehicle, and pedestrian level of service (LOS); bicyclist and motorist corridor travel times; bicyclist, motorist, pedestrian, business owner, and resident satisfaction with the cycle track; and the bicycle collision rates for the four years preceding and one year following the cycle track installation. Following the installation, bicyclist volumes increased by over 200 percent at peak hours. In comparison, motor vehicle volumes decreased by 15 percent and 21 percent on each of the two study segments. Analysis using the Danish Bicycle LOS indicated that bicyclist LOS increased from E to C throughout the corridor following the installation of the lanes, while motor vehicle LOS remained unchanged. With regards to safety, the rate of crashes increased by approximately one crash per year in both segments following the installation of the cycle track, even when accounting for greater bicyclist volumes. However, 44 percent of respondents felt that the signals, signs, and street markings did not adequately clarify road user right-of-way at intersections, which may explain the increase in conflicts and collisions. As a result, the researchers recommended improvements to signals, signs, and roadway markings to address this confusion. Finally, an intercept survey of bicyclists using the cycle track indicated that bicyclists overwhelmingly felt that bicyclist was safer and easier with the addition of the cycle track. Likewise, motorist attitudes toward the cycle track were generally positive. The researchers concluded that the cycle track successfully increased cyclist comfort and convenient without sacrificing motor vehicle operations. Safety data will continue to be monitored and the research team made several recommendations to improve safety in the corridor as a result of their analysis (1).

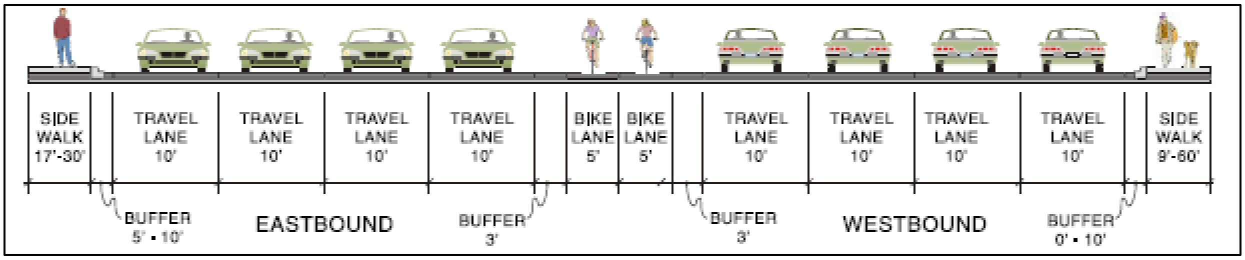

Figure 17. Cross-section of buffered median bike lanes on Pennsylvania Avenue, Washington, D.C.

[Caption: Portion of Figure 3 from Goodno, McNeil, Parks, and Trainor showing the median buffered bike lanes evaluated in the article (1).]

Figure 18. Median buffered bike lanes, Washington, D.C.

[Caption: Portion of Figure 3 from Goodno, McNeil, Parks, and Trainor showing the median buffered bike lanes evaluated in the article (1).]

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2.2 Wide Curb Lanes

In cases where right-of-way limitations prevent the installation of a five-foot bike lane, one alternative is to design the curb lane so that it is wide enough to accommodate both bicyclists and motor vehicles and to facilitate passing maneuvers. These wide curb lanes are often enhanced with shared lane markings to increase awareness of the presence and position of bicyclists.

A 1997 Harkey and Stewart study for the Florida DOT compared motorist and bicyclist behavior on roadway segments where there was a bike lane, a wide curb lane, or a paved shoulder. An analysis of their results revealed that motorists passed at a distance of approximately six feet regardless of the type of facility. When passing a bicyclist in a bike lane, motorists tended to shift about one foot laterally, regardless of the width of the bike lane. Motorists tended to move over an additional 1.3 feet when passing bicyclists in a wide curb lane compared to bike lanes and paved shoulders. However, bicyclists were more likely to ride further from the curb in a bike lane or paved shoulder than in a wide curb lane. Based on their observations, the researchers concluded that bike lanes and paved shoulders offered safety advantages over wide curb lanes (1).

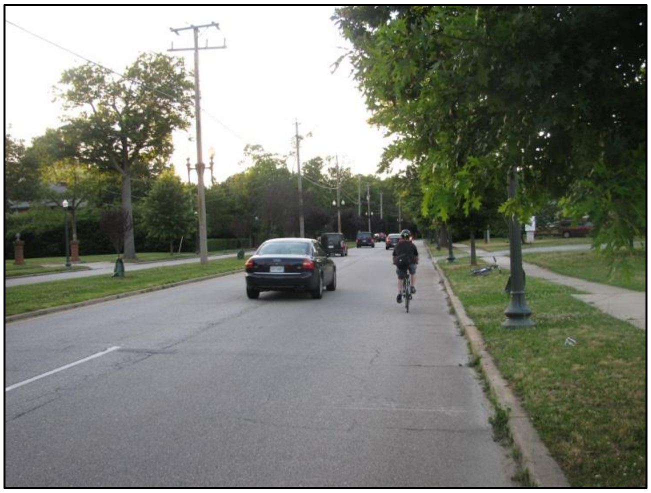

Figure 19. A bicyclist rides in a wide curb lane in Virginia

[Caption: Photo courtesy of Jason James. http://www.vabike.org/position-your-position/]

Hunter, Stewart, Stutts, Huang, and Pein (1999) conducted a comparative analysis of bicycle lanes versus wide curb lanes at sites in Santa Barbara, California; Gainesville, Florida; and Austin, Texas. The researchers videotaped motor vehicle-bicyclist interactions at 48 study sites and recorded 276 conflicts between motor vehicles and bicyclists. Analysis of the data indicated that a statistically significant higher percentage of vehicles passing bicyclists on the left encroached into the adjacent traffic lane at wide curb lane locations (17%) than at bike lane sites (7%); however, lane encroachments hardly ever caused conflict with motor vehicles using the other lane. In cases where bike lane width was 5.2 feet or less, the average bicyclist distance from the curb or gutter pan seam was less than for wide curb lanes, whereas at locations where the bike lane width was greater than 5.2 feet, the average bicyclist distance from the curb was greater than for wide curb lanes. The researchers concluded that bike lane and wide curb lanes were both effective for improving bicyclist safety but recommended the installation of bike lanes at sites where roadway width permits, due to greater preference for and comfort on bike lanes (2).

A 2011 article by Sando, Chimba, Kwigizile, and Moses analyzed the effects of site characteristics on motorist behavior when passing bicyclists on wide curb lanes. The researchers videotaped 956 passing events at 10 sites in Tallahassee, St. Petersburg, and Brandon, Florida using volunteer bicyclists at peak traffic hours. Data about vehicle type, lateral separation distance between bicycles and vehicles, lateral distance between bicycle and curb, encroachments, the presence of vehicles in the inside lane, and the bicyclists gender and dress were extracted from the recordings for analysis. The researchers developed a multivariate regression model to understand which variables were significant. For lateral separation distance between bicyclists and vehicles, it was found that SUVs and pickup trucks provided greater lateral distance upon passing than passenger vehicles. Female gender was also associated with greater passing distance. An increase in the width of the outside lane was associated with greater lateral separation distance, while high and medium traffic levels and the presence of vehicles in the inside lane were associated with decreased passing distances (3). Results of this study indicate that motorist passing distance is influenced by environmental factors, such as lane width; contextual factors, such as the presence or absence of cars in adjacent lanes; and bicyclist characteristics, such as gender.

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2.3 Paved Shoulders

Hunter (1999) evaluated the use of red paint on new shoulders along one mile of a scenic roadway in Tavares, Florida, to determine if the treatment enhanced safety for bicyclists. Video was used to record footage of bicyclists traveling along the roadway at three locations with the red shoulders and one location without shoulders. Analysis of data indicated that 80 percent of bicyclists used the new shoulders throughout their ride, and an additional 6 percent used them partially. At the sites without shoulders, the distance at which motor vehicles passed bicyclists was 0.6 feet greater than at sites with shoulders, a difference that was statistically significant. At this site, motorists also experienced greater numbers of motor vehicle-motor vehicle conflicts. No difference in mean vehicle speed was recorded between treatment and comparison sites. An intercept survey conducted at the survey site found that 79 percent of bicyclists felt that the painted red shoulders increased safety; interestingly, bicyclists also felt that the shoulders led to more space between bicyclists and passing vehicles, the opposite of what was observed. The author concluded that the red shoulders produced operational benefits for bicyclists and motorists at the Florida site (1). Because the installation of the shoulders took place concurrently with when they were painted, it is impossible to separate the effect of the paint from the effect of widening the roadway to add shoulders.

Figure 20. Red shoulder and comparison site, Tavares, Florida.

[Caption: Figure 5 and Figure 6 from Hunter (1999) showing the Tavares, Florida comparison site without shoulders (left) and one of the three study sites with red painted shoulders (right) (1).]

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2.4 Shared Bus-Bike Lanes

To date, only one before-and-after study has evaluated the safety impacts of shared bicycle/bus lanes in the United States. The City of Minneapolis Department of Public Works released a report in 2011 that evaluated the reconfiguration of a one-mile segment of a downtown street. The street was converted from one-way with a contraflow bus lane and center two-way bicycle lane to a two-way street with a designated shared lane for bicyclists, buses, and right turning motor vehicles. To enhance visibility and awareness, the shared lane was marked with green paint and markings. To understand bicyclist, motorist, and bus interactions in the new shared lane, the department collected video recordings before and after the reconfiguration of the street. While bicyclist crash rates decreased overall, the number of bus and bicyclists interactions was too small (n=21) to derive statistically significant conclusions about the safety results of the shared lane conversion (1).

1. City of Minneapolis Department of Public Works. *Hennepin Avenue Green Shared Lane Study*. 2011. http://www.ci.minneapolis.mn.us/www/groups/public/@publicworks/documents/images/wcms1p-085711.pdf

2.5 Contraflow Bike Lanes

There are currently no resources for this section.

2.6 Cycle Tracks

A 2008 analysis by Jensen was one of the first studies that used pre- and post-treatment data from treatment and comparison groups to evaluate the effect of cycle track installation on bicyclist and other road users' safety. Jensen studied the effects of 20.6 km of cycle tracks that were built between 1978 and 2003 in Copenhagen, Denmark. To do so, he used stepwise methodology designed to account for regression-to-the-mean effects, crash trends, and traffic volumes. He chose equally long before and after periods for each road that was analyzed, as well as data from what he called a "before-before" period, a 5-year period that occurred 8-12 years before lanes were installed, in order to control for potential regression-to-the-mean effects at sites chosen for treatment. Using pre-treatment data adjusted for increases in traffic volumes, Jensen generated an expected number of collisions if no treatment had been applied to use for comparison purposes (1).

Figure 21. Cross section view of a street showing Copenhagen-style cycle tracks.

[Caption: The cycle track is separated from the sidewalk by one curb and from the roadway by a second curb. A line of parked cars between moving traffic and the cycle track offers an additional buffer from roadway traffic. Image by Lars Gemzøe, Gehl Architects, a member of the Cycling Embassy of Denmark.]

Results of Jensen's analysis demonstrated changes in safety for different road users as a result of marking bike lanes. One unique feature of this study was that bicyclists and moped riders were placed in the same category, because mopeds were permitted to use the bicycle lanes in Denmark. On roads where bicycle tracks were installed, there was a 20 percent increase in bicycle and moped traffic, with bicycles making up over 95 percent of that traffic. There was a decrease of 10 percent in motor vehicle traffic, and both changes in traffic (bicycle/moped or motor vehicle) were statistically significant. For bicycle and moped riders, the observed increase in injuries was 49 percent; however, that figure was not statistically significant. For all road users (pedestrians, bicyclists and moped riders, and motorists), crashes decreased by 10 percent and injuries decreased by 4 percent. These decreases were not statistically significant. However, results for bicycle/moped injuries differed somewhat. On roadway segments, injuries decreased by 13 percent, but the effect was not statistically significant. At intersections, there was a statistically significant increase in injuries of 24 percent. Jensen also highlighted gender disparities in injuries, with an 18 percent increase in total injuries (all modes) for women following the installation of cycle tracks, compared to an increase of just 1 percent for men (1).

Figure 22. A bicyclist uses a cycle track in Copenhagen, Denmark

[Caption: Photograph of a bicyclist using a cycle track in Copenhagen. Image by Lars Gemzøe, Gehl Architects, a member of the Cycling Embassy of Denmark.]

Jensen also observed marked changes in the frequency of different crash types following the installation of cycle tracks. Three statistically significant changes occurred, which positively impacted road safety. First, there was a 63 percent decrease in crashes where a motorist hit a bicyclist/moped rider from behind. Secondly, there was a 41 percent decrease in crashes between left-turning bicycles/mopeds and other bicycles/mopeds. Third, there was a 38 percent decrease in bicycles/mopeds against parked cars. On the other hand, these three safety increases were outweighed by increases in the frequency of other types of collisions. A 120 percent increase was observed in the number of bicycles/mopeds hitting other bicycles/moped from behind. All types of right turn crashes increased, with a 140 percent increase in crashes between bicycles/mopeds and right-turning motor vehicles. Likewise, crashes between bicycles/mopeds and left-turning motor vehicles also increased by 48 percent. Finally, crashes caused by conflicts between bicycles/mopeds and pedestrians boarding or disembarking busses also increased significantly (1).

In interpreting the findings, Jensen referred to his own earlier research, which found that cycle tracks were perceived to be safer by bicyclists when compared to travelling in mixed traffic, and addressed the discrepancy in findings in the two analyses. He also discussed whether the new bicycle facilities attracted riders with different characteristics, such as older, younger, or less experienced riders, which might have changed the frequency of accidents. Finally, he speculated about whether the observed decreases in safety outweighed some of the other health benefits associated with higher levels of bicycle use, such as increased physical activity and decreased air pollution, concluding that the design of bicycle facilities has both positive and negative safety implications that should be carefully considered (1).

A 2011 study of Montreal, Canada, cycle tracks by Lusk, Furth, Morency, Miranda-Moreno, Willett, and Dennerlein determined that, compared to reference streets, cycle tracks were associated with a 28 percent decrease in the risk of injury (relative risk 0.72, 95% confidence interval 60% to 85%). The researchers looked at injury statistics from six two-way cycle tracks and compared them to nearby reference streets without bicycle facilities. The cycle tracks had 8.5 injuries and 10.5 crashes per million bicycle kilometers. Additionally, 2.5 times as many bicyclists used the cycle tracks than the reference streets. The authors concluded that, at the very least, cycle tracks do not increase the risk to bicyclists when compared to riding in the road (2).

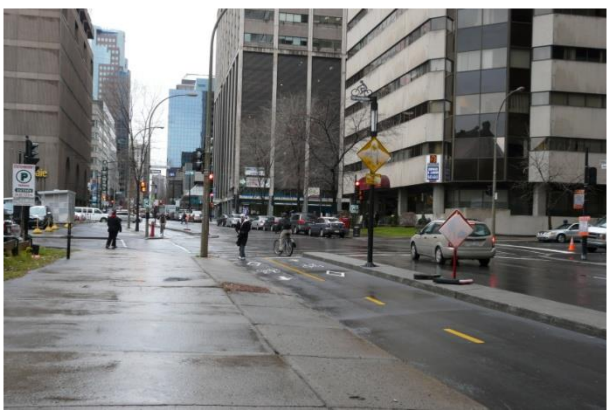


Figure 23. Downtown Montreal cycle track.

[Caption: Cycle tracks in downtown Montreal. Photo by adrimcm. http://www.flickr.com/photos/adrimcm/4173834360]

Figure 24. A bike lane in Toronto.

[Caption: Bicyclists use a bike lane and the roadway during a Critical Mass ride in Toronto. Photo by Commodore Gandalf Cunningham. http://www.flickr.com/photos/25716750@N06/2416976731]

A 2012 study by Teschke and colleagues looked at 690 bicycle crashes in Toronto and Vancouver, Canada and compared the infrastructure at the crash site to a randomly selected control site from the bicyclist's route. Using this case-crossover method, the researchers created a collection of control sites that approximated the frequency of the different route types' occurrence while controlling for personal characteristics and trip conditions like age, gender, risk-taking propensity, weather, helmet use, and time of day. The most frequently observed road type, major street routes with parked cars, was used for the reference category. The researchers compared the number of injuries observed on each type of route compared to the number of times that type of route was randomly selected as a control site. This analysis allowed them to calculate odds ratios to reflect the risk of an injury occurring on each of the 14 route types compared to the most commonly occurring type of site (3).

Cycle tracks were studied along with four other types of off-street bicycle route: sidewalks, paved shared-use paths, unpaved shared-use paths, and bike paths. The table below gives the unadjusted and adjusted odds ratios for each of these route types. Confidence intervals whose range includes 1 are not considered statistically significant (13).

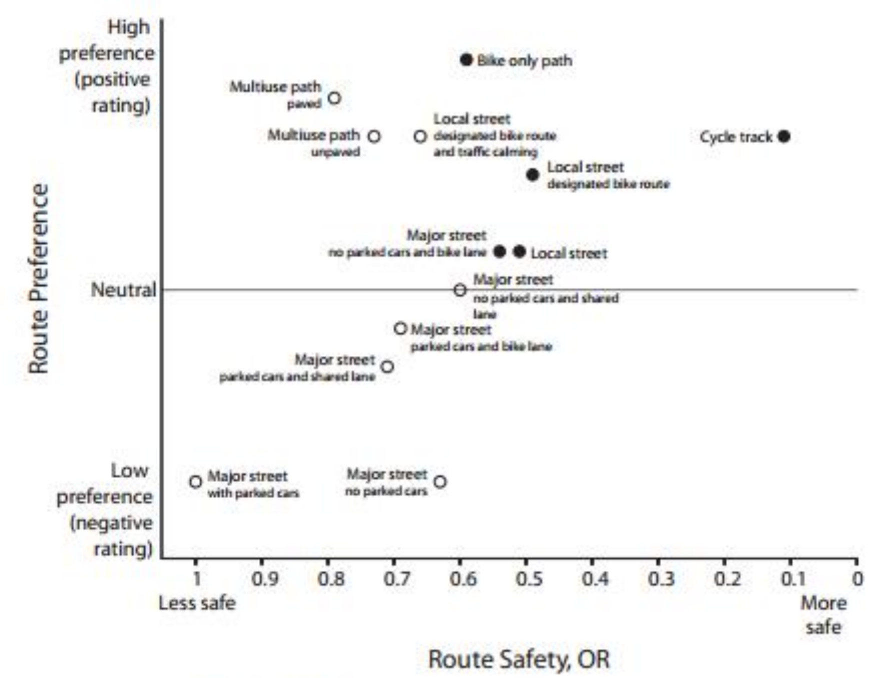
Table 8: Comparison of route types at injury and control sites in Vancouver and Toronto

Variable	Number of Injury Sites	Number of Control Sites	Unadjusted OR (95% C.I.)	Adjusted OR (95% C.I.)
Major street route with parked cars and no bike infrastructure	155	114	1.00 (Reference category)	1.00 (Reference category)
Sidewalk	52	47	0.73 (0.42, 1.28)	0.87 (0.47, 1.58)
Paved shared-use path	64	56	0.75 (0.42, 1.34)	0.79 (0.43, 1.48)
Unpaved shared-use path	12	11	0.63 (0.21, 1.85)	0.73 (0.23, 2.28)
Bicycle path	21	21	0.54 (0.20, 1.45)	0.59 (0.20, 1.76)
Cycle track	**2**	**10**	**0.12* (0.03, 0.60)**	**0.11* (0.02, 0.54)**

* Indicates a p-value of <.05.

[Caption: Excerpt from Table 4 of the Teschke et al. (2012) article showing a comparison of the risk of injury on route types compared to randomly selected control sites. For those odds ratios marked with an asterisk, the association between that type of route and injury risk was statistically significant at the 95% confidence level.(13).]

Cycle tracks were associated with an 89 percent reduction in injury risk when compared to major streets with parked cars and without bicycle infrastructure, which was the lowest injury risk of all studied infrastructure. Additionally, data from the Metro Vancouver route preference survey indicated that cycle tracks were preferred to many other types of bicyclist infrastructure. Teschke et al. concluded that cycle tracks are an effective method of injury prevention for cyclists.



Source. Route preference data from 2006 Metro Vancouver opinion survey.[24]
Note. OR = odds ratio. Closed circles represent route types with positive preference rating and adjusted injury OR < 0.6 (safest route types). Open circles represent route types with negative or neutral preference rating or adjusted injury OR ≥ 0.6. "Sidewalk or other pedestrian path" was not included because this route type was not queried in the preference survey. ORs for injury risk are plotted in reverse order.

Figure 25. Bicyclist infrastructure types by safety and preference.

[Caption: Figure 1 from Teschke et al. (2012) showing types of bicyclist infrastructure organized by route preference and route safety. Note the preference for cycle tracks and their relative safety. (3)]

A 2013 article by Harris et al. used the same data as the Teschke et al. study (2012), but different analytical techniques to understand the association between different roadway infrastructure types and bicyclist injury in Toronto and Vancouver, Canada. They divided the 690 intersection sites into intersection and non-intersection locations. Of the 478 non-intersection injury sites, they compared the risk of experiencing an injury while bicycling on cycle tracks to streets without any pedestrian or bicyclist infrastructure Conditional logistic regression was conducted with one or two control sites per injury site to estimate the association between injury occurrence and infrastructure type. An adjusted odds ratio was computed using all significant variables. The researchers found that cycle tracks were associated with a statistically significant 95 percent decrease in the risk of a bicycling injury (adjusted odds ratio 0.05, 95% confidence interval -99% to -59%). Based on the results of their analysis, the researchers supported the use of facilities separated from motor vehicles as a means of injury prevention for bicyclists (4).

Figure 26. A cycle track in Vancouver.

[Caption: A cyclist uses a cycle track in Vancouver. Photo by clauretano http://www.flickr.com/photos/83569292@N00/5969248472]

A 2013 article by Goodno, McNeil, Parks, and Trainor examined the impact of a cycle track installed in Washington, D.C., on the safety, comfort, and convenience of all road users. The two-way cycle track was eight feet wide, with a three-foot buffer delineated by white bollards. At some intersections, signal timing was changed to reduce bicyclist conflicts with left-turning vehicles. The researchers conducted before-and-after analyses of bicycle and motor vehicle volumes; bicycle, motor vehicle, and pedestrian level of service (LOS); bicyclist and motorist corridor travel times; bicyclist, motorist, pedestrian, business owner, and resident satisfaction with the cycle track; and bicycle collision rate for the four years preceding and one year following the cycle track installation. Following the installation, bicyclist volumes increased on all cycle track segments, with a 200 percent increase observed on some segments. In comparison, motor vehicle volumes remained relatively constant. Analysis using the Danish Bicycle LOS indicated that bicyclist LOS increased from D and E to A and B throughout the corridor.

With regards to safety, the rate and number of crashes increased on one segment following the installation of the cycle track, even when accounting for greater bicyclist volumes. An analysis of videotaped data from intersections indicated that some bicyclists were following the signal for motor vehicles, rather than the pedestrian signal as intended. As a result, the researchers recommended the installation of bicycle signal heads to clarify the issue. Finally, an intercept survey of bicyclists using the cycle track indicated that bicyclists overwhelmingly felt that bicyclist was safer and easier with the addition of the cycle track. Likewise, motorist attitudes toward the cycle track were generally positive. The researchers concluded that the cycle track successfully increased cyclist comfort and convenient without sacrificing motor vehicle operations. Safety data will continue to be monitored and the research team made several recommendations to improve safety in the corridor as a result of their analysis (5).

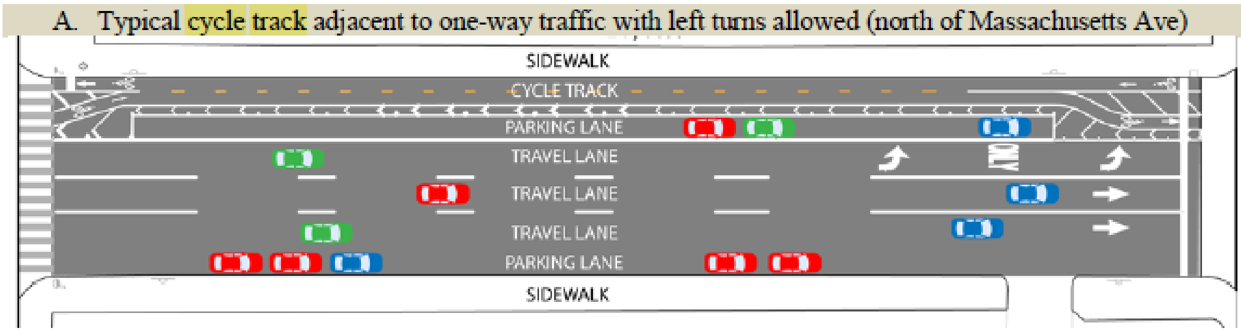


Figure 27. A typical segment of the 15th Street cycle track in Washington, D.C.

[Caption: A portion of Figure 2 from Goodno, McNeil, Parks, and Trainor (2013) showing the configuration of 15th Street with the cycle track in place (5).]

Figure 28. A bicyclist uses the 15th Street cycle track in Washington, D.C.

[Caption: Photo by Elvert Barnes. http://www.flickr.com/photos/perspective/5648324560/]

A 2013 article by Lusk, Morency, Miranda-Moreno, Willett, and Dennerlein analyzed data from 19 cycle track sites in the United States to determine whether the rate of vehicle-bicycle collisions on cycle tracks was lower than the rate of vehicle-bicycle collisions on roadways. Bicycle count and crash data were collected for cycle tracks in Carlsbad, Chula Vista, San Diego, and Santa Cruz, California; Boulder, Colorado; Orlando, Florida; Cambridge, Massachusetts; Minneapolis; New York; Eugene and Bend, Oregon; and Burlington, Vermont. In most cases, existing crash and count data were collected, and counts at two locations were conducted specifically for this study. A uniform set of expansion factors, based on continuous bicycle counts from Portland, Oregon and Vancouver, British Columbia, was used to adjust bicycle counts by month, day of the week, and time of the day. The rate of crashes at each cycle track location was estimated using reported crashes and a measure of exposure derived from the length of the cycle track and the number of bicyclists using the cycle track (6).

Overall, the average estimated bicycle crash rate on the studied cycle tracks was 2.3 crashes per 1 million bicycle kilometers traveled. Cycle track crash rates varied by location. Eight cycle tracks had no reported crashes (a crash rate of 0.0 crashes per 1 million bicycle kilometers traveled), while 8th Avenue in New York City was the scene of 20 crashes in just over two years (a crash rate of 16 crashes per 1 million bicycle kilometers traveled), although an analysis of the New York City data suggested that some crashes occurred on the road and not the cycle track. Lusk et al. compared the cycle track crash rate to the published crash rate for vehicle-bicycle crashes on roads, which ranges from 3.75 to 54 crashes per 1 million bicycle kilometers in the United States, leading them to suggest that bicycling on cycle tracks is safer than bicycling on the roads in the United States (6).

Figure 29. Two bicyclists use the Prospect Park West cycle track in New York City.

[Caption: Two bicyclists use the Prospect Park West cycle track in New York City, one of the cycle tracks studied in Lusk et al. (2013). As of the time of the study, no vehicle-bicycle crashes had been reported at this location. Photo by Kyle Gradinger. http://www.flickr.com/photos/kgradinger/8619588411/]

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3.0 Intersection Treatments

3.1 Curb Radius Revisions

There are currently no resources for this section.

3.2 Roundabouts

Modern roundabouts are a device to control the flow of traffic at intersections without the use of traffic signals or stop signs. The use of roundabouts in the United States dates back to 1905, but safety and efficiency concerns led to a limited use of roundabouts from the 1950s to the 1990s, with increasing use since then (1). Design speed differentiates older roundabouts from newer (known as "modern") roundabouts. Older roundabouts, built according to design standards from the 1940s or before, were designed to accommodate 35 mi/h entry speeds and 25 mi/h circulating speeds, while modern roundabouts are designed for 15-25 mi/h entry speeds in urban areas and 25-30 mi/h entry speeds in rural areas (2). While it has been demonstrated that roundabouts are safer for motorists than signalized intersections, the impact of roundabouts on bicyclist safety has been less favorable. The subject of bicyclists in roundabouts has been studied more thoroughly in Europe than in the U.S.

Figure 30. A bicyclist approaches a roundabout in Raleigh, North Carolina.

[Caption: Photo by Kristy Dactyl. http://www.flickr.com/photos/46070327@N05/6189085192]

Relatively few studies have been conducted on bicyclist safety in roundabouts in the United States. A 2006 report by Harkey and Carter, whose results also appeared in a 2007 NCHRP Report, analyzed bicyclist safety as part of a broader analysis of roundabout safety. Using cameras mounted at roundabout sites, researchers collected data for 690 bicyclist events at seven roundabouts. The study produced a number of observations of bicyclist behavior at roundabouts. Because there were no pre-treatment data available, it was unclear how bicyclists or motorists altered their behavior or travel patterns on account of the roundabouts. The data did not show any substantial safety concerns for bicyclists at roundabouts. Only four conflicts were observed between motorists and bicyclists, and no collisions were observed. The researchers concluded that, while few problems have been found for bicyclists at roundabouts, it will be important to design exit legs that prevent vehicle speeds from being too high and that maintain good sight lines. These design guidelines will help ensure that bicyclists can safely circle roundabouts. The researchers further note that European guidelines recommend that bicyclists occupy the circulatory lane on low-volume roundabouts and that bicyclists be provided a separate cycle track on high-volume roundabouts (3).

A before-and-after study of the effect of roundabouts on motor vehicle-bicyclist collisions in Belgium was published in 2008 by Daniels, Nuyts, and Wets. Although the study took place in Belgium, where the context differs from North America, no before-and-after studies on the subject of roundabouts have been conducted in North America to date. The researchers collected a minimum of four years of collision data from 91 roundabout sites and 172 comparison sites. The use of the comparison group allowed the researchers to control for broader traffic safety trends and regression to the mean. The researchers used odds ratios to calculate results. Their analysis indicated that the installation of roundabouts led to a 27 percent increase in the risk of crashes at roundabout sites. The risk of serious injuries and fatalities increased by 44 percent. Looking only at the subset of urbanized areas, the construction of a roundabout was associated with an increase in the risk of bicyclist injury of 48 percent. The researchers concluded that the effect of roundabouts on bicyclist safety should be taken into account when considering roundabout construction. They also recommended further research into which, if any, specific geometric features are associated with greater bicyclist accident risk (4).

A 2012 Transportation Research Board presentation by Hourdos, Shauer, and Davis discussed the results of an ongoing investigation into the effects of two urban roundabouts in Minneapolis and St. Paul, Minnesota, on bicyclist safety. Researchers recorded videotape data on bicyclist/vehicle interactions at each of the roundabout crossings, which were used to quantify the types of problems that bicyclists were having. The second phase of analysis involved studying the traffic conditions for drivers within the roundabout prior to the bicycle/vehicle conflict. Logistic regression was used to analyze the probability that a driver would yield to a bicyclist, given different variables. Results showed that a majority of drivers failed to yield to bicyclists at both roundabouts, and that direction of traffic, vehicle entrance/exit, bicyclist position, level of traffic, number of lanes, and general design are factors which influence driver yielding behavior within a roundabout (5).

Figure 31. Two cyclists use a modern roundabout in Arizona.

[Caption: Photo by Arizona Department of Transportation. http://www.azdot.gov/ccpartnerships/roundabouts/users_guide.asp]

A 2013 study by Harris et al. calculated the risk of bicyclist injury on traffic circles (a type of roundabout measuring 20-25 feet in diameter, used at the intersection of two local streets) when compared to intersections with traffic lights and without bicyclist controls. The researchers collected data from 210 bicycle crashes at intersections locations in Toronto and Vancouver, Canada, and compared the infrastructure at the crash site to a randomly selected control intersection from the bicyclists' route. Conditional logistic regression was conducted with one or two control sites per injury site to estimate the association between injury occurrence and infrastructure type. The researchers found that traffic circles were associated with a nearly 700 percent increase in the risk of a bicycling injury (adjusted odds ratio 7.98, 95% confidence interval 1.79 to 35.6), when compared to the reference category of intersections with traffic lights and no cyclist controls, even though the intersection of two local streets was otherwise associated with an 81 percent lower risk of injury (adjusted odds ratio 0.19, 95% confidence interval 0.05 to 0.66). The two main types of collisions reported at traffic circle sites were motor vehicle-bicycle collisions and single bicyclist crashes (6).

Figure 32. A traffic circle in Vancouver, British Columbia.

[Caption: Photo from Harris et al. (2013), showing one of the residential traffic circles associated with a higher risk of bicyclist injury (6).]

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Effects of Infrastructure on Bicycling Injury at Intersections and Non-Intersections Using a Case-Crossover Design. *Injury Prevention*, Vol. 19, No. 5, 2013, pp. 303-310.

3.3 Intersection Markings

The advanced stop line (ASL), or "bike box," is a pavement marking pattern designed to give priority to bicyclists over motor vehicles at signalized intersections, while also serving to increase visibility between motorists and bicyclists. This treatment is used at signalized intersections on roads with a marked bike lane. The stop line for motor vehicle traffic is applied in advance of the intersection, which creates a clear space where cyclists can wait in front of the cars and then proceed ahead of the cars into the intersection when the light turns green. This treatment reduces conflicts between bicyclists and turning motor vehicles by making the cyclists easier to see (1). Cities in New Zealand have also experimented with advanced cycle lanes, which expand the bike lane past the stop line for vehicles, producing similar results to advanced stop lines and bike boxes (2).

In the United States, Hunter (2000) analyzed the use of a bike box in Eugene, Oregon. The main purpose of the bike box at the intersection was to help bicyclists move from a left-side bike lane before the intersection to a right-side bike lane after the intersection. Using before-and-after video footage, Hunter noted that no conflicts took place when the bike box was used as intended. However, only 11 percent of bicyclists used the bike box as intended. Motor vehicle encroachment of the bike box occurred 52 percent of the time. Hunter found the use of the bike box to be promising and encouraged more studies into its effectiveness (3).

Figure 33. A bicyclist waits in a bike box in Eugene, Oregon.

[Caption: Photo by Derek Severson. http://www.flickr.com/photos/derekdiamond/6154035295/]

A 2007 article by Sadek, Dickason, and Kaplan evaluated the effectiveness of green bike lane crossing treatments at a cloverleaf exchange in Burlington, Vermont. The researchers compared two treatment sites, where the green bike lane extended across the street, adjacent to the crosswalk, and two control sites, where only a crosswalk was available, using video and visual data about bicyclist and motorist behavior at the sites. The results indicated that, when the green bike lane was available, only 47.8 percent used the green crossing, while 22.8 percent used the crosswalk and 29.3 percent crossed on the roadway outside of the green crossing and crosswalk. No difference was detected for pedestrians looking over their shoulders for oncoming traffic at treatment and control sites. Additionally, fewer motorists yielded to bicyclists at the treatment sites (less than 1.4%) than at control sites (11.9%), which contradicted bicyclist and motorist survey results that predicted that the markings would lead to increased motorist yielding behavior. No tests of statistical significance were performed on the data collected by the researchers (4).

Loskorn, Mills, Brady, Duthie, and Machemehl (2011) evaluated motorist and bicyclist behavior before and after the installation of bicycle boxes at two intersections in Austin, Texas. Data were collected from the sites prior to the installation of a bicycle box, after the bicycle box was installed, and after the bicycle box and approaching bike lane were painted chartreuse. To evaluate bicyclist and motorist behavior, video cameras were installed at the intersections, and researchers recorded details about each bicyclist trip through study intersections. Although there was no reduction in motorist encroachment once bicycle boxes were painted green, the number of bicyclists who stopped in the box increased from 9.1 percent to 15.1 percent at one site, and from 52 percent to 92 percent at the other site. The researchers concluded that bicycle boxes, when coupled with right-turn-on-red prohibitions, can improve the safety of bicyclists at intersections (5).

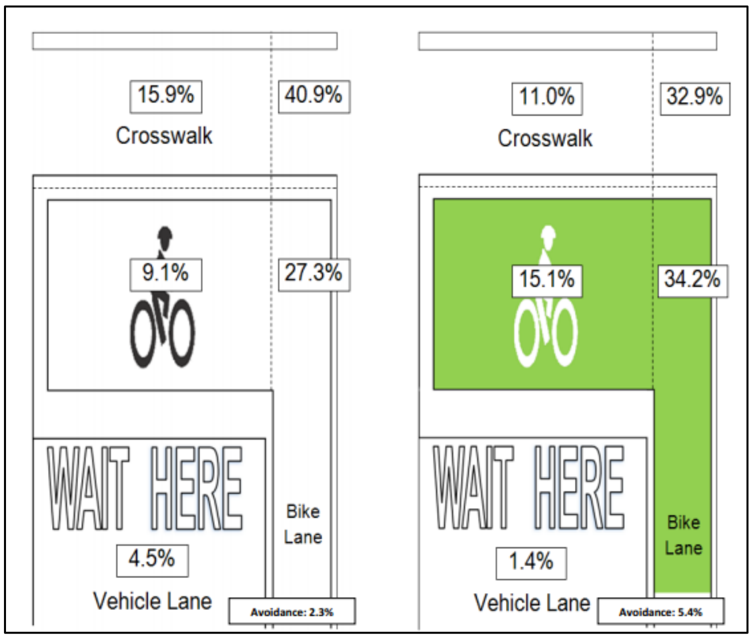

Figure 34. Stopping location by position from an Austin, Texas bicycle box evaluation.

[Caption: Figure 6 from Loskom et al. (2011) showing bicyclist stopping position at one study site by percentage prior to and following the marking of the bicycle box with green paint (5).]

Dill, Monsere, and McNeil (2012) conducted a before-and-after study of bike boxes in Portland, Oregon. The researchers used video surveillance data from 10 intersections with bike boxes (7 of which were green and 3 of which were uncolored) and 2 control intersections in order to determine whether the bike box increased safety for bicyclists and whether the green color enhanced the safety effect. Assistants reviewing the video looked for motorist encroachment of the crosswalk, yielding behavior, and bicyclist position within the bike box. Following the installation of the bike boxes, bicyclist volumes at study intersections increased by 94 percent, while the number of conflicts between bicyclists and vehicles fell by 9 percent. However, there were mixed effects with regards to motorist encroachment into the bicycle box. While fewer motorists encroached in the bike lane while preparing to make a right turn, more motorists encroached in the bike lane while executing a right turn. Finally, results of an intercept survey of bicyclists and motorists indicated that the boxes helped to increase awareness of bicyclists and perceptions of safety at the study intersections and that green colored lanes and bicycle boxes were preferred by both motorists and bicyclists.

The researchers concluded that, overall, the bicycle boxes affected behaviors that could make bicycling safer and that responses from motorists and bicyclists were favorable (6).

Figure 35. Examples of bike boxes in Portland, Oregon.

[Caption: An uncolored bike box (left) and a group of bicyclists using a box bike in Portland, Oregon (right). Left: Photo from Dill, Monsere, and McNeil (6). Right: Photo by Cheryl & Rich. http://www.flickr.com/photos/cherylandrich/2609888772/]

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6. Dill, J., C. M. Monsere, and N. McNeil. Evaluation of Bike Boxes at Signalized Intersections. *Accident Analysis and Prevention*, Vol. 44, No. 1, pp. 126-134, 2012.

3.4 Sight Distance Improvements

There are currently no resources for this section.

3.5 Turning Restrictions

There are currently no resources for this section.

3.6 Merge and Weave Area Redesign

Cities throughout Europe use colored lanes near intersections to alert motorists of bicycle infrastructure, such as bike lanes, that may interfere with a right-turn movement. The hope is that these colored merge markings will reduce the number of conflicts between motor vehicles and bicyclists. Relatively few studies of merge and weave areas have been conducted in the United States.

Figure 36. A merge-and-weave area for bicyclists and motorists in Michigan.

[Caption: An example of an unpainted merge-and-weave area in Michigan. The dashed lines show where the bicycle lane intersects the motor vehicle lane. Photo by League of Michigan Bicyclists. http://www.flickr.com/photos/leagueofmichiganbicyclists/3753848360/]

A 2000 report by Hunter evaluated a narrow version of a combined bicycle lane and right-turn lane that was being tested in Eugene, Oregon. Hunter studied two locations with the combined bicycle lane and right-turn lane, one of which featured a standard-width 12-foot right-turn lane with a 5-foot bike lane, while the other location featured an experimental combined lane with a 7-foot right-turn lane and a 5-foot bike lane. Videotaped observations were used to compare motorist and bicyclist behavior at both sites. Significant differences included:

- A greater proportion (97%) of bicyclists approaching the intersection in the bike lane at the narrow-lane site compared to the standard-lane site (83%) ($p < 0.001$).
- A smaller proportion (57%) of bicyclists positioned beside motor vehicles while stopped at the traffic signal at the narrow-lane site compared to the standard-lane site (98.6%) ($p < 0.001$). The remaining 43.1 percent of bicyclists stopped in front of or behind motor vehicles at the narrow-lane site, compared to 1.4 percent at the standard-lane site.
- A greater proportion (93.3%) of motorists yielded to bicyclists at the narrow-lane site compared to the standard-lane site (48%) ($p < 0.001$).

Based on evaluation findings, Hunter concluded that the narrow right-turn/bicycle lane configuration worked well at the study intersection. Hunter recommended further evaluation in other contexts to better determine its effectiveness in other settings (1).

Figure 37. Two configurations of combined bicycle lane/right-turn lanes

[Caption: The two combined lanes evaluated in Hunter (2000) (1). The photo on the left shows the narrow-lane site and the photo on the right shows the standard-lane site.]

A 2000 article by Hunter, Harkey, Stewart, and Birk considered the bicycle safety impact of blue bike-lane treatments utilized in conjunction with signs in Portland, Oregon. The blue bike lanes were installed by the City of Portland at 10 high-traffic and high-conflict locations where motor vehicles crossed the bike path in order to turn right or merge onto a street. The researchers collected videotaped data before and after the installation of the bike lanes, and extracted data about bicyclist characteristics; bicyclist and motorist behavior; and bicyclist-motorist interactions. Notable outcomes include:

- A significantly greater percentage of bicyclists followed the marked path in the after period (an increase from 85% in the before period to 93% in the after period).
- A significantly lower percentage of bicyclists scanned for a vehicle in the after period (a decrease from 43% in the before period to 26% in the after period).
- A significantly lower percentage of bicyclists slowed or stopped upon approaching the conflict area in the after period (a decrease from 11% in the before period to 4% in the after period).
- A significantly greater percentage of motorists yielded to bicyclists in the conflict area in the after period (an increase from 72% in the before period to 92% in the after period).
- The number of bicyclist-motorist conflicts was small in the before and after period, but decreased from 0.95 per 100 bicyclists in the before period to 0.59 per 100 bicyclists in the after period.
- An intercept survey of bicyclists indicated that 76 percent of bicyclists felt that the blue bike lanes increased bicyclist safety.

Based on the results of the evaluation, the researchers concluded that the blue bike lanes appeared to create a safer bicycling environment by heightening bicyclist and motorist awareness in conflict zones. However, they also noted that bicyclists were less likely to scan for approaching vehicles or use hand signals after the blue thermoplastic was installed, indicating a potentially false sense of security for bicyclists (2).

Figure 38. Examples of merge and weave lanes as used in Portland, Oregon.

[Caption: Photos of bike lanes painted blue at merge and weave areas in Portland, Oregon. The blue paint is used to call attention to locations where bike lanes cross right-turn lanes, exit ramps, and entrance ramps (3).]

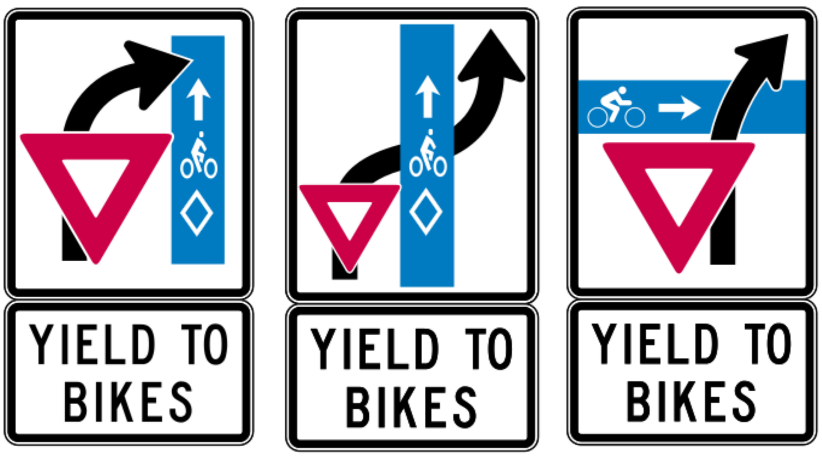

Figure 39. Examples of "Yield to Bikes" signs as used in Portland, Oregon.

[Caption: "Yield to Bikes" signs as used in Portland, Oregon (3).]

A 2008 report by Hunter, Srinivasan, and Martell evaluated the redesign of a St. Petersburg, Florida street to include a bike lane with green paint in the merging segment. The study site was located on a five-lane, one-way street with one right-turn-only lane. The green bicycle weaving lane was used to highlight where motorists had to cross the bicycle lane to enter the right-turn-only lane. The researchers wished to determine if the green paint and signs created safer conditions for bicyclists and motorists. The behavior of bicyclists and motorists was recorded by video before and after the lanes was installed. Recorded observations included details about the bicyclist (i.e. age, gender) as well as data about bicyclist and motorist behavior and their interactions. It was observed that a significantly higher percentage of motorists yielded to bicyclists (98.5% in the after period, compared to 86.7% in the before period) and used a right turn signal before changing lanes (89.2% in the after period, compared to 85.2% in the before period) following the installation of the green bike lane. For bicyclists, a significantly higher percentage scanned for nearby vehicles in the after period, with 12 percent scanning in the after period, compared to 6 percent in the before period. Although the percentage of motor-vehicle conflicts decreased in the after period (from 2.2% to 0.7%), the difference was not statistically significant. The researchers concluded that these changes in behavior represented an increase of safety at this site, but cautioned that further study in other locations and settings should be conducted (4).

Figure 40. Before and after photos of the installation of a green bike lane weaving area in St. Petersburg, Florida.

[Caption: Figure 1 and Figure 2 from Hunter, Srinivasan, and Martell (2008) showing the site where green bike lanes were installed and evaluated (4).]

References

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4.0 Maintenance

4.1 Repetitive/Short-Term Maintenance

There are currently no resources for this section.

4.2 Major Maintenance

There are currently no resources for this section.

4.3 Hazard Identification Program

Construction sites are one type of hazard that can increase the risk of bicyclist injury. A 2013 study by Harris et al. calculated the risk of bicyclist injury in construction zones compared to non-construction zones. The researchers collected data from 478 non-intersection injury sites in Toronto and Vancouver, Canada, and compared the infrastructure at the crash site to a randomly selected control intersection from the bicyclists' route. Conditional logistic regression was conducted with one or two control sites per injury site to estimate the association between injury occurrence and infrastructure type. The researchers found that construction zones were associated with a statistically significant 167 percent increase in the risk of a bicycling injury (adjusted odds ratio 2.67, 95% confidence interval 1.70 to 4.19). Based on the results of their analysis, the researchers recommended demarcated route detours that would allow bicyclists to avoid construction zones (1).

Figure 41. A construction zone in Chicago, Illinois.

[Caption: A bicyclist navigates in front of a tractor (center) in a construction site in Chicago, Illinois. Construction zones have been shown to increase the risk of bicyclist injury. Photo by Steven Vance. http://www.flickr.com/photos/jamesbondsv/5879600633/]

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1. Harris, M. A., C. C. O. Reynolds, M. Winters, P. A. Cripton, H. Shen, M. L. Chipman, M. D. Cusimano, S. Babul, J. R. Brubacher, S. M. Friedman, G. Hunte, M. Munro, L. Vernich, and K. Teschke. Comparing the Effects of Infrastructure on Bicycling Injury at Intersections and Non-Intersections Using a Case-Crossover Design. *Injury Prevention*, Vol. 19, No. 5, 2013, pp. 303-310.

5.0 Traffic Calming

A 2007 article by Kim, Kim, Ulfarsson, and Porello used a multinomial logit model and police reported accident data to identify factors that increased the probability of a bicyclist experiencing a severe or fatal injury in the event of a bicyclist-motorist collision. Their analysis indicated that the probability of fatal and incapacitating injuries increased with an increase in vehicle speeds. It was found that the probability of fatal or incapacitating injury increased greatly once speeds exceeded 20 mi/h and that at speeds in excess of 40 mi/h, the probability of fatal injury increased by over 1,000 percent. Additionally, in collisions where motorist speeding was a factor, the probability of fatal injury increased by 300 percent. The table below gives the increase in probability of fatal injury at different ranges of vehicle speeds when compared to speeds of less than 20 mi/h (1).

Table 9. Increase in probability of fatal injury with greater vehicle speeds

Speed	Increase in the probability of fatal injury
Less than 20 mi/h	Reference class
20-30 mi/h	+92.5%
30-40 mi/h	+302.7%
40-50 mi/h	+1,159.1%
50 mi/h or more	+1,503.9%

The authors concluded that their analysis supported 20 mi/h speed limits in residential neighborhoods as well as the separation of bicyclists from high-speed vehicle traffic, such as separate facilities for bicyclists on roadways with speed limits of 30 mi/h or more (1).

Figure 42. Traffic calming that allows bicycle through travel while limiting through vehicle travel.

[Photo by Richard Drdul. http://www.flickr.com/photos/drdul/180847952/]

A 2009 article by Grundy et al. used 20 years of police-reported collisions to examine the safety effect of implementing 20 mi/h zones throughout London. Injury counts for all users (pedestrians, bicyclists, motor vehicle occupants, and motorcyclists) were compared in the before- and after-intervention periods, as well as between streets with and without the intervention. Information about the dates, locations, and types of collisions from 1986-2006 were geocoded using a geographic information system (GIS), and each roadway segment within the planned 20 mi/h zones was given a code of "pre-intervention," "under construction," or " post-implementation" for each year of the study. A conditional fixed effects Poisson model was used to estimate the change in injuries as the 20 mi/h speed zones were implemented. Results of the analysis indicated that all bicyclist injuries decreased by 16.9 percent (95% confidence interval, 4.8 % to 29.0 %) on roadways that became 20 mi/h speed zones. The number of bicyclists who were killed or seriously injured decreased by 37.6 percent (95% C.I., 14.4% to 60.9%). For bicyclists ages 0-15, injuries decreased by 27.7 percent (95% C.I. 6.3% to 49.1%) as roads were converted to speed zones. All reductions were statistically significant at 0.05. An analysis of roadways in areas adjacent to the speed zones indicated that injuries were not being displaced to nearby roads. The researchers concluded that the 20 mi/h speed zones were effective in reducing bicyclists' risk of injury or death, with the greatest decrease found for bicyclist collisions leading to death or serious injury.

Figure 43. A sign at the entrance to a 20 mi/h speed zone in Manchester, England

[Caption: A sign at the entrance to a 20 mi/h speed zone in Manchester, England. Photo used courtesy of Flickr user Mikey. https://www.flickr.com/photos/raver_mikey/2791270176]

A 2013 study by Harris et al. calculated the risk of bicyclist injury at intersections with motor vehicle speeds of 30 km/h or less (approximately 19 mi/h) compared to intersections with motor vehicle speeds between 30 km/h and 50 km/h (between 19 mi/h and 31 mi/h). The researchers collected data from 210 bicycle crashes at intersections locations in Toronto and Vancouver, Canada, and compared the infrastructure at the crash site to a randomly selected control intersection from the bicyclists' route. Conditional logistic regression was conducted with one or two control sites per injury site to estimate the association between injury occurrence and infrastructure type. The researchers found that motor vehicle speeds of 30 km/h or less at intersections were associated with a 48 percent decrease in the risk of a bicycling injury (adjusted odds ratio 0.52, 95% confidence interval 0.29 to 0.92). At speeds greater than 50 km/h, there was a slight, but not statistically significant, increase in the adjusted odds ratio. The researchers concluded that intersections with speed limits of 30 km/h or less were associated with half of the risk of bicyclist injury than intersections with speed limits of 30 km/h or greater, consistent with 30 km/h speed limits on residential streets in northern Europe (3). These results indicate that the decreased vehicle speeds associated with traffic calming can have a positive effect on bicyclist safety.

References

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5.1 Mini Traffic Circles

There are currently no resources for this section.

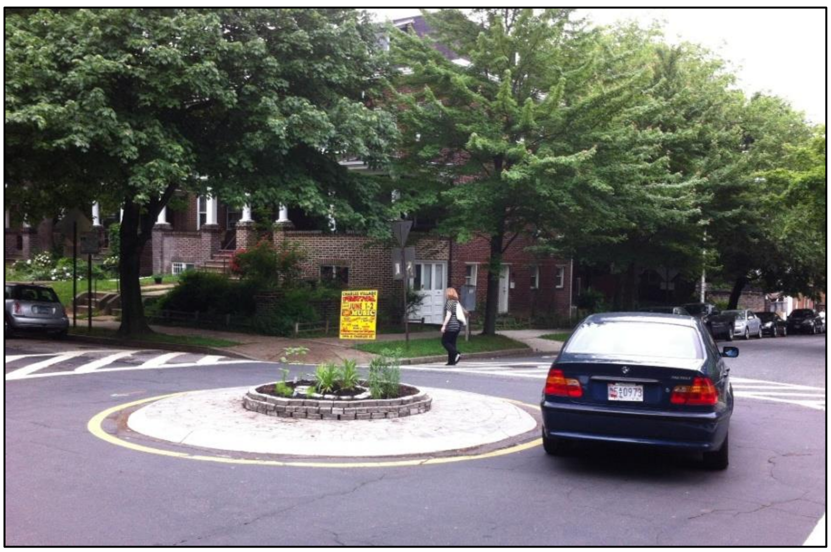

Figure 44. Mini traffic circle in Baltimore, Maryland.

[Caption: A mini traffic circle in Baltimore, Maryland. Photo by Bmore Bikes. http://www.bmorebikes.com/32nd-guilford-circle-gets-an-upgrade/]

5.2 Chicanes

There are currently no resources for this section.

5.3 Speed Tables, Humps, & Cushions

A 2012 article by Chen, Chen, Ewing, McKnight, Srinivasan, and Roe evaluated the effectiveness of speed humps in increasing bicyclist safety at intersections. The researchers used two-group pretest-posttest research design to compare collision statistics following the installation of bike lines at 324 intersections throughout New York City. Bicycle collision statistics were collected for the five year period preceding bike lane installation, as well as the two year period following it, and the authors used ANCOVA analysis to control for potential regression-to-the-mean effects. Analysis of their results indicated that bicyclist crash incidence decreased by 27.8 percent at intersection sites, compared to a decrease of 28.6 percent at comparison intersections. This resulted in an ANCOVA-adjusted increase in bicyclist collisions of nine percent at intersections. However, results were not significant at the 0.05 level. Because bicyclist volumes were not recorded before and after the bike lane installation, the researchers could not definitively state whether the increase in collisions exceeded the increase in exposure from higher volumes of bicyclists (1).

Figure 45. Speed hump in Pennsylvania.

[Caption: A motorist passes over a speed hump that was added to the on-road portion of the Schuylkill River bicycle trail as part of a series of traffic calming measures. Photo by the Philly Bike Coalition. http://www.flickr.com/photos/philly_bike_coalition/4432292200/]

Table 10. Observed change in bicycle collisions following installation of speed humps in New York City

Collision Location	Group	Number of sites	Percent change in bicycle collisions	Unadjusted crash modification factor and standard error	ANCOVA-adjusted crash modification factor and standard error
Intersections	Treatment	324	-27.84	0.97 (0.21)	1.09(0.23)
	Control	2346	-28.57		

[Caption: Data from Tables 3, 5, and 6 from Chen et al. showing the number of study sites, percent change in bicycle collisions following bicycle lane installation, and unadjusted and ANCOVA-adjusted crash modification factors and standard errors. These results were not statistically significant at the 0.05 level (1).]

References

1. Chen, L., C. Chen, R. Ewing, C. McKnight, R. Srinivasan, and M. Roe. Safety Countermeasures and Crash Reduction in New York City—Experience and Lessons Learned. *Accident Analysis and Prevention*, Vol. 50, 2013, pp. 312-322. http://dx.doi.org/10.1016/j.aap.2012.05.009

5.4 Traffic Diversion

A 2013 study by Harris et al. calculated the risk of bicyclist injury at intersections on local roadway segments with traffic diverters compared to roadway segments without any pedestrian or bicycle infrastructure. The researchers collected data from 478 bicycle crashes on roadway segments in Toronto and Vancouver, Canada, and compared the infrastructure at the crash site to a randomly selected control intersection from the bicyclists' route. Conditional logistic regression was conducted with one or two control sites per injury site to estimate the association between injury occurrence and infrastructure type. The researchers found that local streets with traffic diverters were associated with a 96 percent decrease in the risk of bicyclist injury (adjusted odds ratio 0.04, 95% confidence interval 0.003 to 0.60). The results of their analysis indicated that traffic calming measures such as discouraging through traffic are effective strategies for decreasing bicyclist injury risk (1).

Figure 46. A bicyclist rides down a traffic-calmed street in Vancouver, Canada.

[Caption: This traffic-calmed Vancouver street features diverters that limit vehicular through traffic and a 30 km/h speed limit. Photo by Paul Krueger. http://www.flickr.com/photos/30604571@N00/6004507796]

References

1. Harris, M. A., C. C. O. Reynolds, M. Winters, P. A. Cripton, H. Shen, M. L. Chipman, M. D. Cusimano, S. Babul, J. R. Brubacher, S. M. Friedman, G. Hunte, M. Munro, L. Vernich, and K. Teschke. Comparing the Effects of Infrastructure on Bicycling Injury at Intersections and Non-Intersections Using a Case-Crossover Design. *Injury Prevention*, 2013 Vol. 19, No. 5, 2013, pp. 303-310.

5.4.1 Bike Boulevards

Bicycle boulevards are traffic-calmed streets that generally run parallel to or near major arterials. Relatively few studies have analyzed the effectiveness of bicycle boulevards. Minikel (2011) analyzed the bicycle boulevard network in Berkeley, California, to determine whether bicyclists were safer on the bicycle boulevards than on the adjacent arterials.

After studying police-reported collision data and City of Berkeley bicycle counts, Minikel determined that, while the rate of severity for bicycle injuries on arterials and bicycle boulevards were similar, the overall collision rate was higher on arterials. (1).

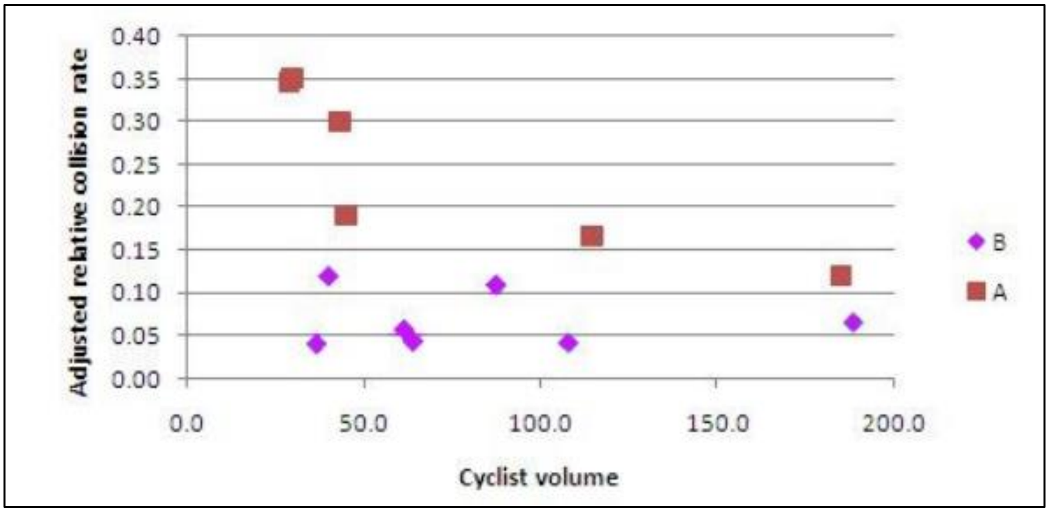

Figure 47. Collision rates compared to cyclist volumes on arterials (A: red squares) and bicycle boulevards (B: purple diamonds).

[Caption: Figure 4 from Minikel (2011) comparing collision rate to cyclist volume on Berkeley arterials (A) and bicycle boulevards (B) (1).]

Figure 48. A bicyclist rides on a bicycle boulevard in Berkeley, California.

[Caption: Photo by Payton Chung. http://www.flickr.com/photos/41813589@N00/1322594444]

Dill (2009) also studied bicycle boulevards during a study in which Portland cyclists were given a GPS device to attach to their bicycles. The device recorded the routes chosen by the cyclists over a seven-day period. The data allowed Dill to determine the types of bicycle infrastructure preferred by cyclists. While bicycle boulevards made up less than one percent of Portland's road network, approximately nine percent of all travel recorded by the GPS devices occurred on bicycle boulevards (2).

Table 1: Distribution of recorded bicycle travel by facility type, compared to network mileage

	% of bicycle travel (miles)		
	All travel (%)	***Utilitarian travel (%)***	***% of network***
Roads without bicycle infrastructure	51	48	92
Primary roads/highways, no bicycle lanes	4	3	4
Secondary roads, no bicycle lanes	19	16	13
Minor streets, no bicycle lanes	27	28	63
Driveways, alleys, unimproved roads	2	1	12
Bicycle infrastructure	49	52	8
Primary roads/highways, with bicycle lanes	9	9	3
Secondary roads, with bicycle lanes	14	15	2
Minor streets, with bicycle lanes	3	3	1
Bicycle/multi-use paths	14	14	2
Bicycle boulevards	9	10	<1
N (miles)	7,479	6,131	10,564

Figure 49. Percent bicycle travel miles by facility type, compared to percent of network mileage.

[Caption: Table 1 from Dill (2009) showing that bicycle boulevards captured nine percent of bicycle travel miles, despite comprising less than one percent of bicycle network infrastructure (2).]

References

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2. Dill, J. Bicycling for Transportation and Health: The Role of Infrastructure. *Journal of Public Health*, 2009. http://www.palgrave-journals.com/jphp/journal/v30/nS1/pdf/jphp200856a.pdf. Accessed Aug 20, 2012.

5.5 Visual Narrowing

There are currently no resources for this section.

6.0 Trails/Shared-Use Paths

6.1 Separate Shared-Use Path

A 1994 article by Tinsworth, Cassidy, and Polen discussed the results of a study by the U.S. Consumer Product Safety Commission to determine which circumstances were associated with bicycle-related injuries. Nearly 600 cases of bicycle injury data from 90 U.S. hospital emergency rooms were identified using the National Electronic Injury Surveillance System (NEISS). Of those cases, investigators were able to collect data about injury circumstances from 474 bicyclists, and of those, 420 met all inclusion criteria. Relative risk was computed for different factors associated with bicyclist injuries, including bike paths. For children, it was found that riding on a bike path was associated with an 88 percent reduction in the risk of injury when compared to riding in the street. For adults, it was found that riding on a bike path was associated with an 86 percent reduction in the risk of injury when compared to riding in the street. The authors concluded that, in the interest of bicyclist injury prevention, it would be reasonable to encourage bicycle use on lower-risk infrastructure (1).

Figure 50. Bicyclist on a separate shared-use path.

[Caption: A bicyclist uses the 12.3 mile Elyria-Oberlin-Kipton bike path in northern Ohio. Photo by Ed Chadwick. http://www.flickr.com/photos/67278751@N00/539644733]

In a similar vein, Rodgers (1997) evaluated the association between bike paths/lanes and adult bicyclist crash risk. Analysis data came from a mail survey conducted in 1990. Qualifying respondents were at least 18 years old and owned bicycles that had been new when purchased. Nearly 3,000 in-depth questionnaires were collected, which provided information about falls or crashes experienced within the previous year as well as primary riding surface. Over nine percent of respondents reported a crash or fall in the previous year. Results of data analysis showed that bike paths/lanes (which were studied together), were associated with a 40 percent reduction in the risk of falls or crashes when compared to riding on roadways (OR: 0.60, CI: 0.38-0.95), results which were significant at the 0.05 level. Three potential limitations were the self-report of results, the lack of injury data, and the lack of differentiation between bike paths and bike lanes. The authors concluded that the higher risk of crashes and falls on the roadway compared to bike paths/lanes indicates the importance of the riding environment on bicyclist safety (2).

References

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2. Rodgers, G. B. Factors Associations with the Crash Risk of Adult Bicyclists. *Journal of Safety Research*. Vol. 28, No. 4, 1997, pp. 233-241.

6.2 Path Intersection Treatments

Crossings between paths and major roadways can be particularly dangerous for bicyclists. Two recent studies have evaluated treatments for improving the visibility of path crossings. Researchers at the UNC Highway Safety Research Center (Hunter, Srinivasan, and Martell, 2012) evaluated the effectiveness of rectangular rapid flash beacons (RRFBs) for a mid-block crossing of a multi-use trail with significant bicycle traffic in St. Petersburg, FL. The RRFBs were evaluated through a before and after study of motorist yielding rates. When the beacon was activated, there was a motorist yielding rate of 54 percent (an increase of 2% from pre-installation). Trail users were also trapped in the middle of the intersection less often. Considering that only 32 percent of trail users pushed the button to activate the beacon, the authors concluded that some educational follow-up may be necessary to achieve better results (1).

A 2012 presentation by Dougald, Dittberner, and Sripathi detailed an experimental zig-zag pavement marking treatment in Loudoun County, Virginia. In 2009, the Virginia Department of Transportation installed the markings at two locations where pedestrians and bicyclists use the Washington and Old Dominion Trail to cross area highways. Researchers measured vehicle speeds and driver attitudes pre- and post-treatment. They concluded that the use of the markings increased motorist awareness of the crossings, as evidenced by lower mean vehicle speeds and self-reported yielding behavior. However, surveys revealed limited driver understanding of the markings' purpose (2).

Figure 51: Zig-zag roadway markings in Virginia.

[Photo caption: The zig-zag markings used by the Virginia Department of Transportation to increase motorist awareness. Photo by the Virginia Department of Transportation.]
http://www.virginiadot.org/vtrc/main/online_reports/pdf/11-r9.pdf

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6.3 Share the Path Treatments

There are currently no resources for this section.

7.0 Markings, Signs, and Signals

7.1 Rectangular Rapid Flashing Beacon (RRFB)

While the majority of studies to evaluate rectangular rapid flashing beacons (RRFBs) focus on their pedestrian safety benefits, the beacons' ability to increase motorist yielding at midblock crossings benefits bicyclists crossing at RRFB locations as well.

A 2009 report by Hunter, Srinivasan, and Martell summarized the effects of installing a pedestrian-activated RRFB at the location of one uncontrolled trail crossing at a busy (15,000 ADT), four-lane urban street in St. Petersburg, Florida. The researchers used a mounted video camera to collect pre- and post-treatment data about trail user (bicyclists and pedestrians) and driver interactions at the trail crossing. Analysis of the data showed a statistically significant reduction in trail user crossing delay, as well as a statistically significant ($p<0.001$) increase in motorist yielding (from 2 percent pre-treatment to 35 percent post-treatment, and 54 percent when the beacon was activated). The researchers concluded that there was an increase in safety at the intersection as a result of installing the RRFB (1).

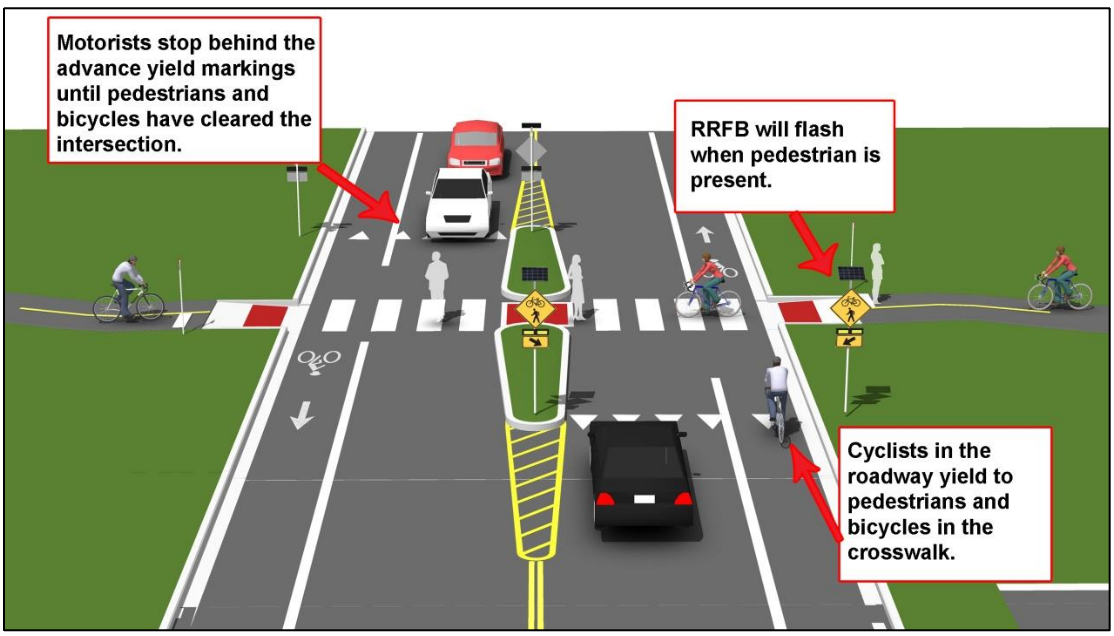

Figure 52. Diagram showing the intersection of a trail and roadway enhanced with an RRFB.

[Caption: Diagram by the city of Bloomington, Indiana. http://bloomington.in.gov/documents/viewDocument.php?document_id=7158]

A 2010 report by the Federal Highway Administration by Shurbutt and Van Houten reported on the effects of installing RRFBs at 22 multilane, uncontrolled crosswalks in St. Petersburg, Florida; Washington, D.C.; and Mundelein, Illinois. On average across all sites, 4 percent of drivers yielded to pedestrians pre-treatment, while at the two-year follow-up, an average of 84 percent of drivers yielded to pedestrians at all sites, demonstrating the measure's maintenance of effect over time. Data collected at night showed an increase in driver yielding behavior from 4.8 percent pre-treatment to 84.6 percent (two-beacon RRFB) and 99.5 percent (four-beacon RRFB) post-treatment. The authors concluded that the RRFB appeared to be an effective tool for greatly increasing the number of drivers yielding to pedestrians at uncontrolled crosswalks (2).

A 2011 Oregon Department of Transportation report by Ross, Serpico, and Lewis evaluated RRFB installation at three Bend, Oregon, crosswalks where signs and pavement markings were also improved. Data were collected by observing the crosswalks and also by using staged pedestrian crossings to assess motorist yielding behavior and speed. Prior to the installation of the RRFBs, the average motorist yielding rate across study sites was 17.8 percent. Following the installation of RRFBs, the average yielding rate across sites increased to 79.9 percent. Average motorist speed decreased at only one of the sites. No tests of statistical significance were conducted. Based on their findings, the authors suggested that that RRFBs should be considered for facilities where posted speeds exceed 35 miles per hour, if pedestrians and bicyclists use the facilities and there is the potential for, or history of, collisions They also recommended that RRFB installation should take place concurrently with other measures to improve the visibility of the crossing (3).

Figure 53. Push button activation of the rectangular rapid flashing beacon (left) and the beacon under the sign (right).

[Caption: (Right) Figure 2.6 from the Ross, Serpico, and Lewis report showing the push button used to activate the RRFBs evaluated in their study (3). (Left) Close up photograph of the modified bicycle-and-pedestrian warning sign and beacon.]

Figure 54. A rectangular rapid flashing beacon installation site in Bend, Oregon.

[Caption: Figure 3.3. from Ross, Serpico, and Lewis (2011) showing a bicyclist crossing at an RRFB in Bend, Oregon (3).]

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2. Shurbutt, J., and R. Van Houten. *Effects of Yellow Rectangular Rapid-Flashing Beacons on Yielding at Multilane Uncontrolled Crosswalks*. Publication FHWA-HRT-10-043, FHWA, U.S. Department of Transportation, 2010.
3. Ross, J., D. Serpico, and R. Lewis. *Assessment of Driver Yielding Rates Pre- and Post-RRFB Installation, Bend, Oregon*. Oregon Department of Transportation, Salem, Oregon, 2011.

7.2 Pedestrian Hybrid Beacon (HAWK Signal)

As the name suggests, the pedestrian hybrid beacon (PHB) was developed to enhance pedestrian safety where minor streets intersect with major arterials. However, the significant increase in motorist yielding at locations where PHBs have been installed greatly enhances safety for those crossing on bicycles as well.

A 2006 report by Fitzpatrick et al. evaluated various midblock crossing treatments, including the PHB, in terms of their effect on pedestrian safety. The researchers used trained data collectors and video recordings to collect motorist and pedestrian behavior data at five PHB sites in Tucson, Arizona. Post-treatment data were collected for staged and non-staged pedestrian crossings, and measures of effectiveness such as pedestrian crosswalk compliance, pedestrian-vehicle compliance, and motorist yielding were used to evaluate the safety performance of the treatments. Results from the five PHB sites showed an average of 97 percent motorist yielding across all sites, comparable to the other treatments in the red signal or beacon category (see figure below). Nearly all of the red signals or beacons studied were used on high-volume, high-speed arterial streets. Although the report only considered pedestrians, the results of this study indicate that bicyclists crossing at PHB sites may likewise benefit from high motorist yield rates (1).

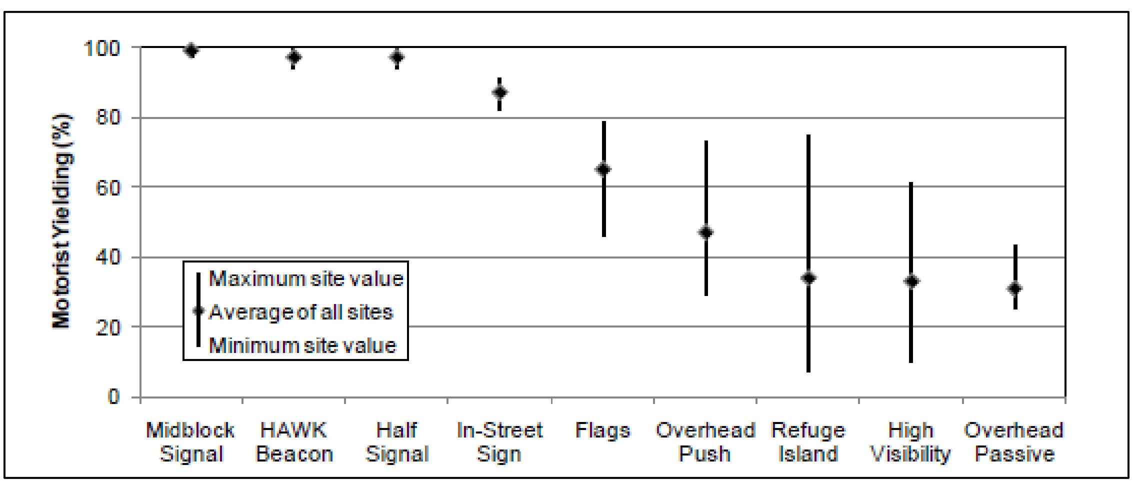

Figure 55. Percent of motorists yielding by beacon type.

[Caption: Figure 6 from the report showing the effect of various countermeasures on motorist yielding at study sites. The PHB, or HAWK, beacon is shown second from the left (1).]

A 2010 report by Fitzpatrick and Park published by the Federal Highway Administration evaluated the safety effectiveness of the PHB at 21 sites in Tucson, Arizona. The researchers used collision data from three years pre-treatment and three years following treatment, as well as nearby treated and untreated reference sites, to calculate reduction in expected collisions using the empirical Bayes method. While the researchers only used Bayesian analysis for total crashes, severe crashes, and pedestrian-motor vehicle crashes, data collected as part of the study demonstrated that bicycle-motor vehicle crashes decreased from 13 in the pre-PHB study period to 7 in the three years following its installation. While statistical analysis is necessary to prove the significance of this decrease, it indicates greater safety at PHB sites for bicyclists. Their analysis of pedestrian-motor vehicle collisions indicated a statistically significant 69 percent reduction in pedestrian crashes, indicating safety benefits for other vulnerable road users (2).

References

1. Fitzpatrick, K., S. Turner, M. Brewer, P. Carlson, N. Lalani, B. Ullman, N. Trout, E. S. Park, D. Lord, and J. Whitacre. *Improving Pedestrian Safety at Unsignalized Crossings*, TCRP/NCHRP Report 112/ 562. Transportation Research Board, Washington, DC., 2006. http://www.fhwa.dot.gov/publications/research/safety/10042/10042.pdf
2. Fitzpatrick, K., and E. S. Park. *Safety Effectiveness of the HAWK Pedestrian Crossing Treatment*. Publication FHWA-HRT-10-042. FHWA, U.S. Department of Transportation, 2010. Resource available at http://www.fhwa.dot.gov/publications/research/safety/10042/10042.pdf

7.3 Optimize Signal Timing for Bicycles

A 2002 study by Retting, Chapline, and Williams evaluated the impact of a series of signal timing changes on pedestrian and bicycle injury collisions in Suffolk and Nassau counties in New York. Study and control intersections were randomly selected from a pool of 122 eligible signals so that half would undergo signal timing changes and half would remain unchanged. Crash statistics were collected for three years before and three years after the implementation of the signal timing changes. Intersection locations where the signal timing was changed demonstrated a statistically significant 37 percent reduction in the number of pedestrian and bicyclist injury collisions when compared to the control group. While the specific effects on bicyclists were not calculated, the study offers evidence that signal timing can influence intersection safety for pedestrians and bicyclists (1).

References

1. Retting, R. A., J. F. Chapline, and A. F. Williams. Changes in Crash Risk Following Re-Timing of Traffic Signal Intervals. *Accident Analysis and Prevention*, Vol. 34, 2002, pp. 215-220.

7.4 Bike-Activated Signal Detection

There are currently no resources for this section.

7.5 Sign Improvements for Bicyclists

In 2012, Kay, Savolainen, and Gates conducted a before-after study to evaluate the addition of Share the Road plaques (W16-1) to existing bicycle warning signs (W11-1) along a two-lane rural segment of Michigan Highway 109. The researchers selected two similar roadway segments that were 0.5 miles in length and separated by a 1.1 mile segment. Each segment was 11 feet wide with 4-foot paved shoulders and minimal curvature; however, one of the segments also had centerline rumble strip, allowing the researchers to observe the effects of the rumble strip on motor vehicle lateral placement when motorists passed bicyclists (1).

Figure 56: A bicycle warning sign with a Share the Road sign.

[Caption: A bicycle warning sign (W11-1, above) with the Share the Road plaque (W16-1, below). In the Kay, Savolainen, and Gates study (2012), the researchers were evaluating whether the addition of the Share the Road sign had any effect on motorist behavior (1, 2).]

The researchers used pole-mounted cameras to record motorist-bicyclist interactions throughout the study area before and after the Share the Road signs were installed. During each phase of the study, the researchers collected data from natural and staged bicyclists along each roadway segment, for a total of 2,425 observed passing events. For each event, the researchers recorded vehicle type; presence or absence of oncoming vehicles; presence or absence of centerline rumble strips; lateral position of the vehicle; and the distance between the motor vehicle and bicyclist. The researchers used linear and logistic regression to determine whether the addition of the Share the Road message affected the chosen measures of effectiveness, which were passing distance and center lane position. Results of the analysis indicated that the presence of the sign led to greater motorist distance from the right edge of the travel lane. However, the presence of the sign had no discernible effect on the distance at which motorists passed bicyclists, with no significant difference observed in the proportion of passes where motorists passed bicyclists at five feet or less. The presence of centerline rumble strips similarly reduced passing distance, as did the presences of oncoming vehicles. The researchers concluded that the combination of both signs led to a moderate difference in lateral placement for passing vehicles, but did not significantly increase the distance given to bicyclists by motorists (1).

A 2011 article by Brady, Loskorn, Mills, Duthie, and Machemehl evaluated the use of "Bikes May Use Full Lane" signs to mark bike lanes at two multilane facilities in Austin, Texas. The researchers collected before-and-after data to determine if there was a change in the percentage of bicyclists who used the roadway rather than the sidewalk and who occupied a central position within the lane, as well as the percentage of motorists who encroached on adjacent lanes or changed lanes when passing bicyclists. Analysis of results indicated that the installation of "Bikes May Use Full Lane" signs led to significant changes in bicyclist and motorist behavior at one of the two sites. At the Lamar Boulevard site, there was a significant increase in average bicyclist distance from the curb from 2.42 to 2.73 feet ($p<0.001$). Likewise, motorist passing distance increased significantly from 3.69 to 5.34 feet. Data collected from the Pleasant Valley Road site was less conclusive, with a decrease in the percentage of bicyclists using the full lane and an increase of bicyclists using the sidewalk. Due to an insufficient number of observations of bicyclists using the roadway, the researchers were unable to evaluate before and after lateral position and motorist passing behavior. The researchers concluded that the "Bikes

May Use Full Lane" sign can be an effective method of improving bicyclist safety, but that the efficacy of the sign may be dependent on contextual factors. They recommended further study of such signs in other contexts to gain a better understanding of bicyclist and motorist behavior (3).

Figure 57. " Bicycles May Use Full Lane" sign in Austin, Texas.

[Caption: The sign evaluated in Brady, Loskorn, Mills, Duthie, and Machemehl (3).]

References

1. Kay, J., P. T. Savolainen, and T. J. Gates. An Evaluation of the Impacts of a Share the Road Sign on Driver Behavior Near Bicyclists. Presented at the 92nd Annual Meeting of the Transportation Research Board, Washington, D.C., 2013.
2. Federal Highway Administration. *Manual on Uniform Traffic Control Devices*. Federal Highway Administration, U.S. Department of Transportation, 2009.
3. Brady, J., J. Loskorn, A. Mills, J. Duthie, and R. Machemehl. Operational and Safety Implications of Three Experimental Bicycle Safety Devices in Austin, Texas. Presented at the 90th Annual Meeting of the Transportation Research Board, Washington, D.C., 2011.

7.6 Pavement Marking Improvements

One type of pavement marking improvement is the shared lane marking. Shared lane markings, also known as sharrows, are bike-and-chevron pavement markings that show bicyclists the safe space to ride within the roadway while encouraging them to use more of the travel lane to avoid unsafe spacing between bicycles and the side of the road. Shared lane markings also inform motorists of the need to share the road with bicyclists. Shared lane markings were first evaluated in a 1999 Gainesville, Florida, study by Pein, Hunter, and Stewart. Pein et al. found that sharrows were associated with a statistically significant, albeit small (three inch) increase in the distance between the curb and the bicyclist. There was also a statistically significant shift in the percentage of bicyclists riding in the roadway instead of on the sidewalk (1).

This report was followed by a study by the San Francisco Department of Parking & Traffic in 2004, where before-and-after video analysis was used to evaluate the effectiveness of shared lane markings. The markings were found to increase the distance between bicyclists and parked cars by eight inches, when no vehicle was present. When a vehicle was passing the bicyclist, the shared lane markings increased the distance from parked cars by three to four inches. This study recommended the use of the sharrows to denote a shared-lane due to the statistically significant distance improvements noted in the table below, as well as their observation that the an 80 percent reduction in wrong-way riding followed the installation of the sharrow. Additionally, the shared lane marking reduced riding on the sidewalk by 35 percent. Based on their findings, the study team recommended the use of the sharrow marking to indicate shared-use lanes on appropriate streets in San Francisco (2).

Table 11. A summary of motorist and bicyclist behavior before and after the installation of sharrows.

Behaviors	Before	After	
	(No marking) sample size=1158	Bike-in-House sample size=570	Bike-and-Chevron sample size=794
Sidewalk riders	6.5%	**4.9%**	**4.2%**
Wrong-way riders	3.0%	3.3%	**0.60%**
Hostile behaviors	0.15%	0.17%	0.12%
Distance of cyclists to parked cars	3'-4"	**4'-0"**	**4'-0"**
Distance of cyclists to cars in travel lanes	2'-7" sample size=150	**4'-7"** sample size=59	**4'-10"** sample size=150
Distance of cars in travel lane to parked cars (no bike present)	4'-8"	**5'-8"**	**5'-6"**

Significant differences are indicated in **boldface**.

[Caption: Table 2 from the San Francisco Department of Parking & Traffic study showing a summary of bicyclist and motorist behavior before and after the installation of the shared lane markings (2).]

A 2010 report by Hunter, Thomas, Srinivasan, and Martell evaluated the impact of shared lane markings on bicyclist safety under different conditions in Cambridge, Massachusetts; Chapel Hill, North Carolina; and Seattle, Washington. In Cambridge, Massachusetts, the researchers conducted a before-after evaluation of shared lane markings as installed on a four-lane divided street. The objective of the study was to determine the effects of shared lane markings placed at 10 feet from the curb (as opposed to the 11 feet recommended by the 2009 MUTCD) on bicyclist and motorist position in the roadway. Data was collected from video footage of motorist and bicyclist behavior. The researchers found that motorists increased their distance from parked cars by 14 inches after the installation of the markings, which would result in more operating space for bicyclists. They concluded that markings could be effective when placed 10 feet from the curb (3).

Figure 58. A bicyclist rides over a shared lane marking in Cambridge, Massachusetts.

[Caption: Photo from Hunter et al. (2010), showing a bicyclist on the street where shared lane markings were evaluated in Cambridge, Massachusetts (3). Shared lane markings indicate to bicyclists and motorists that bicyclists are permitted to ride closer to the center of the lane than to parked vehicles. They also raise motorist awareness of bicyclist presence.]

In Chapel Hill, North Carolina, the researchers collected data from before and after the installation of shared lane markings on a four-lane, undivided street with no on-street parking and a shared left-turn lane. The markings were placed at 43.5 inches from the curb, at a distance chosen to encourage lane sharing and keep bicyclists at a safe distance from drainage gates. The researchers coded images extracted from videotaped footage to analyze bicyclist and motorist behavior in the before and after periods. An analysis of results indicated that bicyclist behavior varied whether bicyclists were riding up- or downhill. More bicyclists rode over the marking in the downhill direction (97%) than in the uphill direction (88%); however, all bicyclists rode an average of 2.5 inches closer to the curb following the installation of shared lane markings. The proportion of bicyclists riding on the sidewalk decreased significantly from 39 percent in the before period to 10 percent in the after period in the downhill direction, but no change was observed in the uphill direction. In the downhill direction, motorist passing distance decreased by seven inches, and increased by one inch in the uphill direction. The authors concluded that operations and safety were improved in the downhill direction by shared lane marking installation, but that overall, there was only "possible enhancement to the safety of bicyclists" in this location (3).

Figure 59. Shared lane marking placement as evaluated in Chapel Hill, North Carolina.

[Caption: Figure 12 from Hunter et al. (2010), showing shared lane marking placement in Chapel Hill, North Carolina, and Figure 14 showing bicyclists riding over the markings (3).]

The final location where Hunter et al. (2010) evaluated shared lane markings was Seattle, Washington. The markings were installed on Fremont Street, a two-lane street with parking on both sides. As indicated in the figure below, the centerline of the street was shifted to accommodate a five-foot bike lane on one side, while the shared lane marking was placed on the opposite side. Similar to the Cambridge, Massachusetts, and Chapel Hill, North Carolina study sites, data were extracted and coded from videotape footage taken before and after installation of the markings. Their analysis found that a low percentage of bicyclists rode within the door zone prior to sharrow installation and no change was observed in the after period. This may have been due to the fact that, compared to other locations, the sample of bicyclists consisted of a greater number of experienced commuters. Similarly, there was no change in the percentage of bicyclists riding in the center of the lane from the pre- to post-sharrow period. It was theorized that narrowing the traffic lane had a greater effect on bicyclist and motorist behavior than the shared lane marking because only 15 percent of bicyclists rode over the sharrow in the after period. The researchers concluded that the Seattle evaluation yielded inconclusive results about the effects of sharrows on bicyclist safety (3).

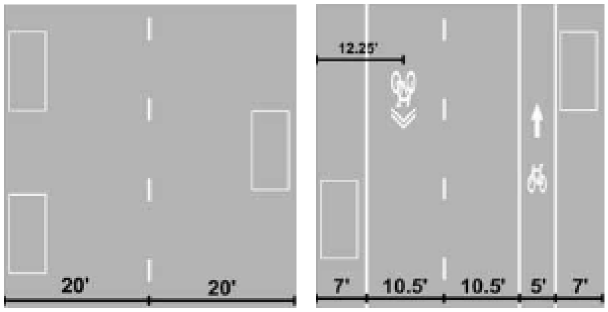

Figure 60. The reconfiguration of Fremont Street in Seattle, Washington.

[Caption: Figure 19 from Hunter et al. (2010) showing the configuration of Fremont Street before and after the installation of shared lane markings (3).]

Brady, Loskorn, Mills, Duthie, and Machemehl (2011) evaluated the effectiveness of sharrows by conducting a before-after study of three locations where shared lane markings were installed in Austin, Texas. To do so, they collected video footage prior to and following sharrow installation. They then extracted data about safe motorist and bicyclist behavior. Safe bicyclist behavior consisted of riding in the street, outside of the door zone and towards the center of the lane. Safe motorist behavior consisted of making complete lane changes when passing, and not encroaching into adjacent lanes. An analysis of results found that shared lane markings encouraged bicyclists to utilize the full lane and to ride closer to the center of the lane. However, sharrows were not wholly effective at reducing unsafe biking behaviors such as riding the wrong way or on a sidewalk (4). The figure below, from the article, gives an overview of notable motorist and bicyclist behaviors at the three sharrow study sites.

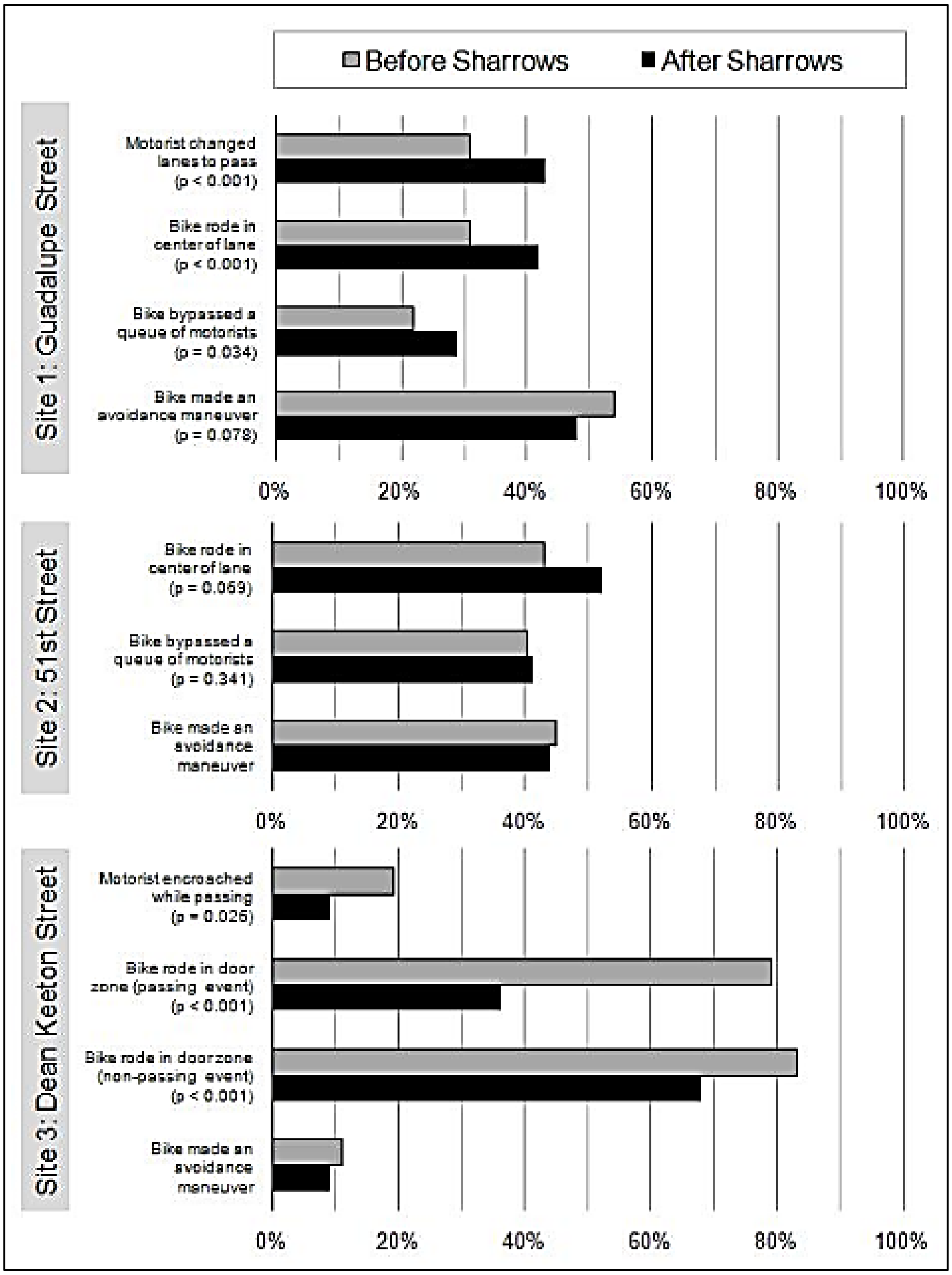

Figure 61. A summary of motorist and bicyclist behavior before and after the installation of sharrows in Austin, Texas.

[Caption: Figure 3 from Brady et al. (2011), showing bicyclist and motorist behaviors at the shared lane marking study sites (4).]

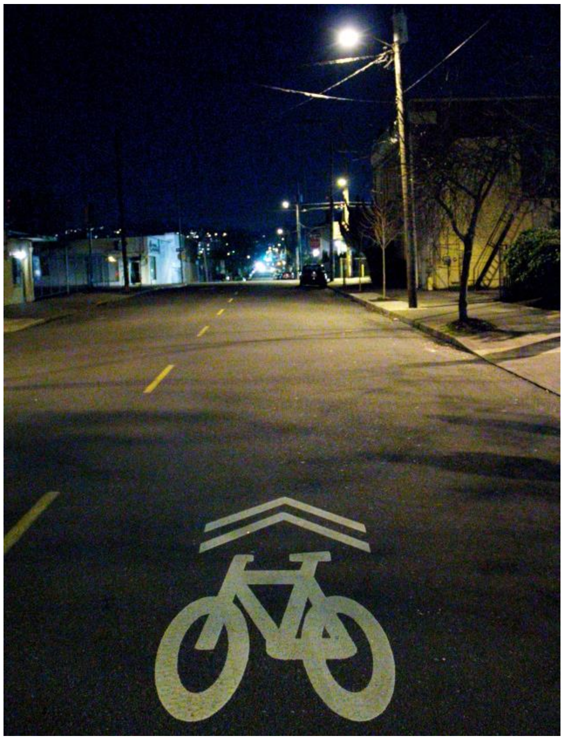

Figure 62. A sharrow in Oregon.

[Caption Sharrow on an Oregon street at night. Photo courtesy of Will Vanlue. http://www.flickr.com/photos/wv/6855160130/]

A 2011 article by Furth, Dulaski, Bergenthal, and Brown evaluated the effects of enhancing shared lane markings with dotted line treatments on the position of bicyclists sharing a roadway lane with vehicular traffic. They studied the 2010 implementation of the sharrows and dotted line enhancements on Longwood Avenue in Brookline, Massachusetts. The purpose of the dotted line markings was to encourage bicyclists to ride away from the door zone and encourage motorist acceptance of bicyclists who did. An analysis of pre- and post-treatment observations showed that the percentage of bicyclists riding more than 10.5 feet from the curb increased from 51 percent before the treatment to 72 percent at five weeks following treatment implementation. Results were not analyzed for statistical significance (5).

Figure 63. Sharrows with dotted lines as evaluated in Brookline, Massachusetts.

[Caption: Photo showing the dotted lane markings used to enhance sharrow markings and encourage bicyclists to ride in the middle of the lane as evaluated in Furth et al. (2011) (5).]

A 2012 report by Hunter, Srinivasan, and Martell analyzed the impact of shared lane markings on bicyclist safety on a street with a high incidence of "dooring" crashes in Miami Beach, Florida. The researchers collected video recordings of bicyclist-motorist interactions before and after the shared lane markings were implemented. Data extracted from the video recordings included bicyclist age and gender, as well as several measures of bicyclist and motorist behavior, including: bicyclist placement within the lane, the distance between the bicyclist and parked motor vehicle, the distance between motorists and parked vehicles, the operations of bicyclists and motorists upon motorist passing, and bicyclist interactions with motor vehicles in parking spaces. Six hundred interactions were analyzed for each of the before and after periods. It was found that the installation of shared lane markings led to a statistically significant increase in the percentage of bicyclists riding in the center of the lane (from 10% to 30%). Additionally, the percentage of bicyclists riding closer to parked vehicles than to the center of the lane decreased significantly from 71 percent to 55 percent. While few in number, the number of near-doorings was decreased in the after period, and the average distance between bicyclists and parked cars increased by a statistically significant 10.5 inches in the after period. Overall, the researchers observed a decrease in the number of bicyclists riding in the "door-zone," which would be expected to decrease the number of dooring incidents along the roadway (6).

Figure 64. A sharrow in Miami Beach, Florida.

[Caption: Photo from Hunter et al. (2012) showing the shared lane markings as applied in Miami Beach, Florida (6).]

A 2013 paper by Sando, Angel, Hunter, Chimba, and Kwigizile examined the influence of shared lane markings on bicyclist-motorist interactions on two roadway segments in Jacksonville and Saint Augustine, Florida. The researchers chose sites in Jacksonville and Saint Augustine that had high volumes of nonmotorized traffic; relatively higher morning and evening peak vehicle volumes; and lane width of 12 feet or less. With the help of volunteer bicyclists, the research team videotaped 136 bicyclist-motorist interactions at both sites in the before and after conditions. Footage was analyzed for lateral distance between the bicyclists and the curb and bicyclists and vehicles; vehicle movement into adjacent lanes when passing a bicyclist; the presence of vehicles in adjacent lanes; type of vehicle; and the age, gender, and type of dress of the bicyclist. Analysis of results indicated an increase of 0.63 feet in lateral separation between vehicles and bicyclists, as well as an increase of 0.51 feet between bicyclists and the curb. Vehicle encroachment into adjacent increased as well. Multivariate regression analysis of the results showed that the presence of the shared lane markings was statistically significantly correlated with greater lateral vehicle clearance. The absence of vehicles in adjacent lanes was also significantly correlated with greater lateral vehicle clearance. The researchers concluded that installing shared lane markings led to positive safety benefits for bicyclists (7).

References

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7.7 Bicycle Signal Heads

There are currently no resources for this section.

Figure 65. Bicycle signal in New York City.

[Caption: A bicycle signal alongside a pedestrian signal in New York City. Such signals are common where bicycle lanes cross an intersection. Photo by James Schwartz. http://www.flickr.com/photos/36871124@N04/5421491773/]

7.8 School Zone Improvements

A 2005 article by Boarnet, Day, Anderson, McMillan, and Alfonzo evaluated the impact of California's Safe Routes to School (SR2S) program on bicycling and bicyclist safety. The SR2S program began in California in 1999. The researchers evaluated the bicyclist safety impact of SR2S-funded bicycling infrastructure improvement projects by comparing pre- and post-treatment data and by comparing predicted results to measured results. Five schools implemented measures to improve bicyclist safety. Four schools implemented crosswalk and crosswalk signal improvements and one school installed bike lanes. At the four sites where crosswalks or crosswalk signals were improved, measured outcomes on vehicle yielding and vehicle speeds did not exceed expected levels. Likewise, due to the low number of observations of bicyclists at the bike path site (n=4 pre-treatment, n=14 post-treatment), the researchers were limited in their ability to make inferences about the success of the bike path. Overall, results of the SR2S program on bicyclist safety were inconclusive in this study (1).

Figure 66. Children on a Safe Routes to School bike ride.

[Caption: Seattle children participating in a Safe Routes to School bike ride in 2012. Photo by the Seattle Department of Transportation. http://www.flickr.com/photos/35660569@N08/7065643559]

A 2008 article by Gutierrez et al evaluated the effect of the California Safe Routes to School (SR2S) program on collision statistics at 125 project locations throughout California. Pre-treatment data were collected from the year 1998 until the award date for the project. Post-treatment data were collected for the period between treatment completion and the end of 2005. Intersections were considered to be in the treatment group if they were within 0.25 miles of a school entrance, and all other intersections within the city limits were used for control. An analysis of the results showed a 13 percent reduction in the number of injured child pedestrians and bicyclists in the post-treatment period (95% confidence interval, 2% to 23%); however, control sites demonstrated a similar decrease. However, the study did not collect information about potential increases in pedestrian and bicyclist volumes in school zones as a result of the SR2S treatments. The 5-12 age group had the largest observed reduction in injuries, with a statistically significant 27.6 percent decrease. While numbers of minor injuries were reduced, fatal and severe injuries did not show the same reduction; however, as relatively rare events, more data may be needed to study this trend. The number of collisions for bicyclists decreased by 11.6 percent, but the reduction was not statistically significant. Based on their analysis, the researchers concluded that the SR2S program appeared to increase pedestrian and bicyclist safety in school zones (2).

References

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2. Gutierrez, N., M. Orenstein, J. Cooper, T. Rice, and D. R. Ragland. Pedestrian and Bicyclist Safety Effects of the California Safe Routes to School Program. Presented at 87th Annual Meeting of the Transportation Research Board, Washington, D.C., 2008.

8.0 Other

8.1 Police Enforcement

There are currently no resources for this section.

8.2 Bicyclist/Motorist Education

There are currently no resources for this section.

8.3 Transit Access

There are currently no resources for this section.

8.4 Wayfinding

There are currently no resources for this section.

8.5 Aesthetics/Landscaping

There are currently no resources for this section.

8.6 Bike-Friendly Policies

A 2012 Love et al. article studied the effect of a three-foot bicycle passing law implemented in Baltimore, Maryland in 2010. Such laws were in place in fourteen states at the time of the article's publication. A convenience sample of five bicycle commuters volunteered to record their daily bicycle trips using a camera mounted under the seat that was pointed towards the roadway. Over 10 hours of video were recorded, producing footage of 586 motor vehicle passes. Each pass was analyzed to produce data about motorist passing distance. Multiple linear regression analysis revealed that lane width, bicycle infrastructure, cyclist, and street identity variables were responsible for 26 percent of the variation in vehicle passing distance. The researchers found that vehicles in Baltimore routinely passed bicyclists at a distance of three feet or less, indicating a lack of adherence to the new law as well as bicyclist safety concerns. Their regression analysis identified the role of supportive bicycle infrastructure in reducing dangerous pass frequency and they also called for strategic education and enforcement campaigns to enhance compliance with the law (1).

A 2013 article by Kerr, Rodriguez, Evenson, and Aytur was the first to study the association between the publication of local pedestrian and bicycle plans and rates of pedestrian and bicyclist injury. The researchers created a database of all of North Carolina's 533 municipalities, noting the existence or inexistence of a pedestrian and bicycle plan during the study time period (1999-2007), and collecting plans from the 130 municipalities that did. They collected injury statistics from the state bicycle and pedestrian crash database and calculated exposure estimates using data from the American Community Survey, U.S. Census, Safe Routes to School 2010 Report, and the 2009 National Household Transportation Survey. Using quasi-experimental, interrupted time series research design, the researchers estimated bicyclist injury risk ratios for municipalities with and without pedestrian and bicycle plans. Incident rate ratios were adjusted for year, demographic, and land use factors. Overall, nonfatal bicyclist injuries in North Carolina decreased over the length of the study period, while there was no evidence of a change in fatal injury rates. In municipalities where plans had been published between 1997 and 2007, no statistically significant change in bicyclist injury rate was observed. The authors conclude that further study is needed to understand how changes in injury rates are related to specific safety-related plan content, as well as the extent of implementation of plans and plan quality (2).

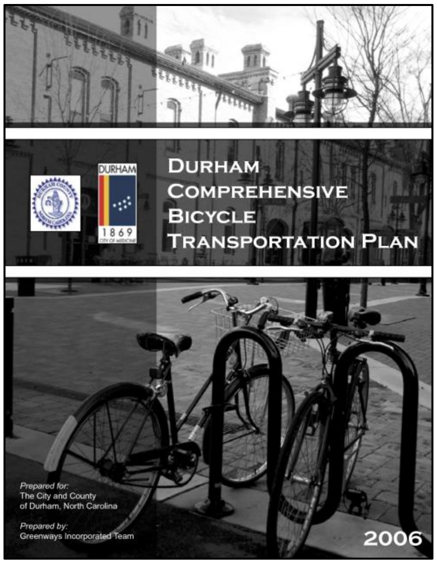

Figure 67. Durham, North Carolina, bicycle plan.

[Caption: Cover of one of the bicycle plans studied by Kerr, Rodriguez, Evenson, and Aytur (2013) (2).]

References

1. Love, D. C., A. Breaud, S. Burns, J. Margulies, M. Romano, and R. Lawrence. Is the Three-Foot Bicycle Passing Law Working in Baltimore, Maryland? *Accident Analysis and Prevention*. Vol. 48, 2012, pp. 451-456.
2. Kerr, Z., D. Rodriguez, K. Evenson, and S. Aytur. Pedestrian and Bicycle Plans and the Incidence of Crash-Related Injuries. *Accident Analysis and Prevention,* Vol. 50, 2013, pp. 1252-1258.

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