2017 SAFETY EFFICACY CONFIDENCE LEVELS FOR PEDESTRIAN AND BICYCLE TREATMENTS

FEHR PEERS

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INTRODUCTION

As standards for the design of pedestrian- and bicycle-friendly intersections and streets continue to evolve in the United States, guidelines such as those published by the National Association of City Transportation Officials (NACTO) are increasingly becoming the state of the practice. This paper seeks to provide context for the safety efficacy of various improvements included in the NACTO Urban Bikeway Design Guide and the Urban Street Design Guide so that practitioners can make more informed decisions on each treatment's appropriate application. A review of the literature was completed for eighteen treatments to compile key conclusions and findings about crash reduction and other measures of effectiveness related to safety such as yielding behavior or level of user comfort. The summary sheets provide information on each treatment's documented benefits and limits of use, based on the reviewed studies. The quality of the studies was also documented for context on the sample size and the consistency of results. Treatments are organized into three categories based on the confidence of their documented safety efficacy – high, medium, and low - results for which are shown below.

Documented Safety Efficacy Confidence	High	Medium	Low
Devices	• Bicycle Boulevards • Green Pavement • Leading Pedestrian Interval • Raised Bicycle Crossing • Separated Bike Phasing (Traffic Signals)	• Bend-Out Crossing • Bike Boxes • Buffered Bike Lanes • Contraflow Bike Lanes • Conventional Bike Lanes • Coordinated Signal Timing • Mixing Zone • One-way Protected Bikeway • Two-way Protected Bikeway	• Bend-in Crossing • Combined Bike Lane/Turn Lane • Intersection Crossing Markings (Non-green) • Through Bike Lane • Two-stage Left Turn Box

HIGH CONFIDENCE LEVEL

Five of the nineteen reviewed treatments rose to the top, and detailed cut sheets that document the key literature findings for each are included below.

This category was reserved for devices with studies that include robust safety data and/or consistent findings across multiple studies that show a reduction in collisions. In the absence of documented crash reductions, some devices in this category had no evidence of a negative safety impact and provide an objective safety benefit that would lead to a strong positive recommendation for the treatment, such as bicycle signals. The Federal Highway Administration (FHWA) cites that this treatment can reduce the bicycle crash rate by up to 45 percent[14], and a published case study in Davis, California saw reductions from 16 bicycle and motor vehicle collisions before installation to 2 vehicle-only collisions after implementation[15]. A video-based study in multiple cities found that there were high levels of compliance at intersections with separated phasing compared to other bicycle treatments[16]. While there are a limited number of published studies for this treatment, the available research consistently shows positive safety results which leads to a high confidence level. In this confidence category, specific areas of caution are also included in the final conclusions and may apply when research is lacking.

BICYCLE BOULEVARDS

MUTCD Status: Allowable[a]

Image source: nacto.org

Claims

- Results in reduced vehicle speeds and less through traffic
- Signs and marking raise awareness of the designated routes and encourage people to properly position themselves in the roadway

Quantification of Benefits

Traffic Calming Measures: Studies show documented volume reductions of 5% to 44% and speed reductions of 1% to 23%.[1]

Shared lane markings: Studies show increase in distance between parked cars and cyclists of 8 inches, increase in distance between passing cars and cyclists of over 2 feet.[2]

Documented Crash Reduction

Results show that collision rates on Berkeley's bicycle boulevards are 50% to 88% lower than those on parallel, adjacent arterial routes.[3]

A study of bicycle injuries in Vancouver and Toronto, Canada found that local streets designated as bicycle routes experience a 51% lower risk of injury compared to major streets with on-street parking and no bicycle facilities.[4]

A later published version of the same study shows that traffic diverters on local streets were associated with about a 96% reduction in injury risk compared to roadways with no on-street bicycle facilities. It also found that at intersections, speeds of less than 30km/h (19 mph) were associated with a 48% reduction in injury risk compared to speeds of 30 km/h to 50 km/h (31 mph).[5]

Other MOE's

Bicyclists will go out of their way to ride on bicycle boulevards and women prefer riding on bicycle boulevards to busier streets with bike lanes.[6]

Areas of Caution

The effect of traffic calming on local streets on the relationship between relative risk of injury on local streets compared to major streets was inconclusive in the Canada study.[4]

Gaps in Research: Research is lacking on appropriate signage and traffic calming to ensure safety along the bicycle boulevard.

Study Details

Sample Size[b]: Medium

Notes on Quality/Consistency of Results: The difference in collision rates is highly statistically significant in the Berkeley study. The study controls for bicyclist volumes, indicating that the results cannot be easily refuted by self-selection or safety in numbers. The Canadian study interviewed injured cyclists from hospital records, which included injuries caused by all kinds of collisions, not just those involving vehicles.

Conclusion

Although this is based on two studies, the results and claims are considered reasonable, especially based on established research for traffic calming devices and shared lane markings. Bicycle boulevards, as local streets with reduced vehicle speeds, have a recognized safety efficacy when compared to major roads.

Recommended for:

- ***Local streets parallel to arterials with high levels of on-street parking and no bicycle facilities***
- ***Use with volume reduction measures such as diverters***

Not Yet Recommended for:

- ***Streets outside of residential areas***

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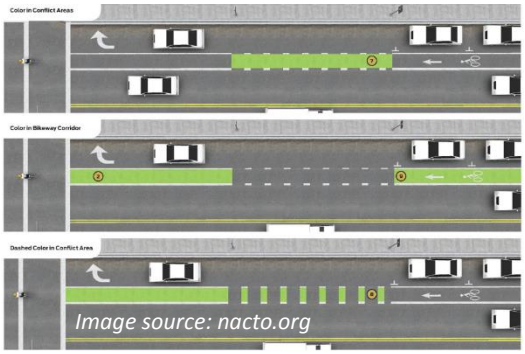
[a] MUTCD refers to shared lane markings and bike route signs only: Shared Lane Marking, Section 9C.07, 2014 MUTCD; Bicycle Guide Signs, Section 9B.20, 2014 MUTCD, Bicycle Route Signs, Section 9B.21, 2014 MUTCD

[b] Small = 1-2 cities, Medium = 3-5 cities, Large = >5 cities

GREEN PAVEMENT

MUTCD Status: Allowable through interim approval (IA-14[7])



Claims

- Increases visibility of cyclists, raises motorist and bicyclists awareness to potential areas of conflict
- Increases bicyclist comfort through clearly delineated space
- Increases motorist yielding behavior
- Helps reduce bicycle conflicts with turning motorists

Quantification of Benefits

In one study, 98.5% of motorists yielded to bicycles after green paint was applied, compared to 86.7% before.[11]

Documented Crash Reduction

10% decrease in collisions at signalized intersections with one colored marked bike crossing.[8]

Average annual total crashes, which included vehicle-only collisions, decreased by 12% on average for all applications of green pavement including along an entire corridor, only at conflict points, and except at conflict points.[9]

Rate of conflicts decreased from 0.95 to 0.59 conflicts per 100 bicyclists after colored pavement was added to conflict zones.[10]

Other MOE's

FHWA interim approval notes that bicyclists and motorists both have a positive impression of the effect of green pavement.[7]

In the Copenhagen study, all intersections with 3 legs experienced a decrease in collisions, regardless of whether one or two colored crossings were marked.[8]

Areas of Caution

In the Copenhagen study, intersections with 4 legs had mixed results – marking one colored crossing resulted in a decrease in collisions, however marking 2 or 4 crossings resulted in an increase in collisions.[8]

A documented collision increase of 23% and 60% for markings of two and four colored cycle crossings, respectively, was reported in the Copenhagen study. This increase was primarily rear-end collisions among motor vehicles and accidents with red-light driving vehicles.[8]

Bicycle crashes, not adjusted for volumes, increased at 25 study sites by 39% on average for all applications of green pavement. This included applications along an entire corridor, only at conflict points, and except at conflict points.[9]

Gaps in Research: Discouragement of illegal parking in bike lane and specific thresholds for efficacy of green pavement such as vehicle volumes.

Study Details

Sample Size[c]: Large

Notes on Quality/Consistency of Results: Some studies (where noted) did not adjust for volumes.

Conclusion

The increase in bicycle crashes indicated in the FHWA Crash Report is inconclusive since it is not adjusted for volumes. Removing that result, all other studies indicate positive results which mainly applies to applications at weaving zones or conflict points other than through an intersection. More study of green markings through intersections is needed in the US based on the results of the Copenhagen study, which suggests that there may be an upper limit to the efficacy of colored pavement at 4-legged signalized intersections where 2 or more colored crossings are marked. Additional research is needed to determine the potential cause for this result, which may be due to higher vehicle volumes or the size of the intersection rather than the number of marked bike crossings alone.

Recommended for:

- ***Weaving zones such as the extension of a bike lane across a dedicated turn lane***
- ***Focused use at smaller signalized intersections, such as marking the extension of bike lanes through a three-legged signalized intersection or to highlight one heavy bicycle crossing movement through a four-legged intersection with relatively low vehicle volumes***

Not Yet Recommended for:

- ***The only treatment at large signalized intersections. Additional protection may be needed at intersections with high vehicle volumes and long crossing distances.***

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[c] Small = 1-2 cities, Medium = 3-5 cities, Large = >5 cities

LEADING PEDESTRIAN INTERVAL

MUTCD Status: Allowable

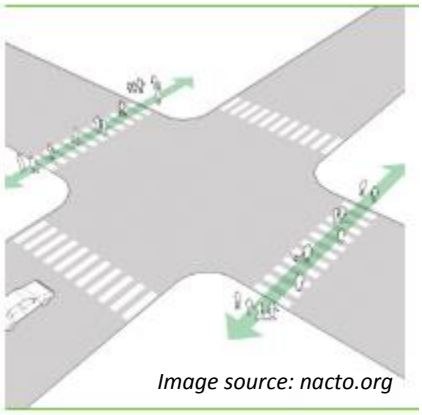


Image source: nacto.org

Claims

- LPIs increase the visibility of crossing pedestrians and give them priority within the intersection.
- LPIs have been shown to reduce pedestrian-vehicle collisions as much as 60% at treated intersections.
- LPIs typically require adjustments to existing signal timing that are relatively low cost compared to other countermeasures.

Quantifications of Benefits

Refer to "Documented Crash Reduction"

Documented Crash Reduction

According to a 2010 study, a crash reduction of 46.2% to 71.3% can be expected with the installation of LPIs; however, due to limitations of the study (there were sites with limited crashes in the before/after period), it is typically appropriate to assume a crash reduction of 58.7%.[42]

In 2016, NCHRP 498, Application of Pedestrian Crossing Treatments for Streets and Highways, was published and documented a 59% statistically significant reduction in pedestrian-vehicle crashes with a corresponding Crash Modification Factor (CMF) of 0.41.[43]

Other MOE's

None found.

Areas of Caution

None.

Gaps in Research: Research has not clearly identified reasons for the reduction in vehicle-pedestrian crashes following the installation of LPIS; however, it seems reasonable that the crash reduction can be attributed to increased visibility of crossing pedestrians.

Study Details

Sample Size[d]: Small

Notes on Quality/Consistency of Results: *The primary study used in identifying the expected crash reduction due to LPIs[42] examined 10 intersections in State College, Pennsylvania. Although this study only included data from one city at ten intersections, the study's methods were robust enough for the authors of NCHRP 498 to identify a Crash Modification Factor for LPIs.*

Conclusion

The research on Leading Pedestrian Intervals is amongst the highest-quality available for pedestrian and bicycle treatments.

Recommended for:

- ***Signalized intersections where high turning traffic volumes conflict with pedestrians in the crosswalk.***

Not Yet Recommended for:

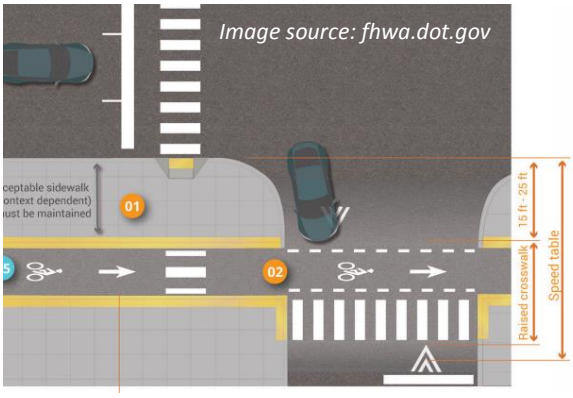
- ***N/A***

[d] Small = 1-2 cities, Medium = 3-5 cities, Large = >5 cities

RAISED BICYCLE CROSSING

Note: Device not included in NACTO

Approval Status: Not a traffic control device so no MUTCD restriction on its use



Claims

- Provides traffic calming for automobiles and can slow bicyclists

Quantification of Benefits

A Scandinavian study from 1998 reported a 40% reduction in vehicle turning speeds at crossings that were raised 12 cm (4.7 inches).[13]

The Scandinavian study found that the number of conflicts involving motorists was reduced by about 60%.[13]

Documented Crash Reduction

One Dutch study in 2011 reported a statistically significant 51% reduction in risk of a collision with the presence of raised crossings on minor side streets.[12]

A study in Sweden found an approximate 30% reduction in risk of a collision with a raised bicycle crossing on the minor approach compared to a conventional bicycle crossing (with curb cuts and ramps).[13]

Other MOE's

None found.

Areas of Caution

The study in Sweden found a 13% increase in speed for bicyclists using the elevated crossings compared to the non-elevated crossings.[13]

Gaps in Research: Existing research is in the context of the Netherlands and Sweden and is lacking for US cities. Appropriate situations in US where raised crossings are effective at reducing crashes, specifically on minor roadways when paired with "bend-out" design.

Study Details

Sample Size[e]: Large

Notes on Quality/Consistency of Results: The Dutch study chose non-signalized intersections where the major road with a speed limit of approximately 30 mph crosses a minor road. Seven municipalities were studied. Intersections were chosen based on high vehicle and bicycle volumes. The Swedish study chose intersections along one-way cycle tracks on major streets with the elevated crossing across the minor street.

Conclusion

Available studies show high efficacy at unsignalized intersections on the minor cross street. Practitioners should use caution when implementing since current research is based in non-US cities.

Recommended for:

- ***Lower-volume side streets or driveways, especially when paired with the "bend-out" design***
- ***Unsignalized intersections***

Not Yet Recommended For:

- ***Signalized intersections***
- ***Major roadways***
- ***High conflicting turning movements***

[e] Small = 1-2 cities, Medium = 3-5 cities, Large = >5 cities

SEPARATED BIKE PHASING (TRAFFIC SIGNALS)

MUTCD Status: Allowable through interim approval (IA-16[14])

Claims

- Increases convenience and safety of bicycling
- Discourages red light running by bicyclists

Quantification of Benefits

Refer to "Documented Crash Reduction"

Documented Crash Reduction

FHWA cites results that a bicycle signal can "reduce the overall number of bicycle crashes, or reduce the bicycle crash rate up to 45 percent where bicycle volumes concurrently increase."[14]

At a study intersection in Davis, CA, collisions were reduced from 16 bicycle and motor vehicle collisions prior to the installation of bicycle signal heads to 2 vehicle-only collisions after implementation of bicycle signal heads. The data collection period both before and after was a two-year period.[15]

Other MOE's

77-93% compliance with bicycle signal by bicyclists; 84-92% compliance by motorists to left-turn signal across protected bike lane.[16]

Areas of Caution

FHWA interim approval prohibits bicycle signals for any movement where bicycles share a lane with motorized vehicles.[14]

FHWA interim approval also prohibits an all-bicycle "scramble" phase.[14]

Gaps in Research: Further research needed on crash reduction effectiveness and effect on operations[17]

Study Details

Sample Size[f]: Medium

Notes on Quality/Consistency of Results: Limited published research.

Conclusion

Results of available research consistently report a positive safety effect and reduction in collisions. Specific signal phasing was not well documented in these publications, and further research is needed to understand the operational effects and for potential safety effects of an all-bicycle "scramble" phase.

Recommended for:

- ***Facilitating unusual or unexpected arrangements of bicycle movement through complex intersections, conflict areas, or signal control***
- ***Protected bike lanes through intersections with high conflicting turn volumes***

Not Yet Recommended for:

- ***Intersections with a shared through/right turn lane or low conflicting turning volumes***

[f] Small = 1-2 cities, Medium = 3-5 cities, Large = >5 cities

MEDIUM AND LOW CONFIDENCE LEVELS

The remaining reviewed devices were assigned to either the medium or low confidence levels. Similar cut sheets are available for these devices in the full technical paper at http://www.fehrandpeers.com/wp-content/uploads/2017/04/Cut-Sheets_4.25.17_FINAL.pdf. A complete list of references, including those used in the full technical paper, is provided at the end of this paper.

Medium Confidence Level

Devices were assigned to the medium confidence level when there were gaps in the research but ultimately no significant safety concerns. Many devices in this level have documented crash reductions but they may be referenced from a limited number of studies or there may be several nuances that aren't well understood. For example, studies consistently show positive safety impacts for bend-out crossings at unsignalized crossings across the minor street[13,18]; however, additional research is needed to better understand certain situations such as the offset distance for bend-out crossings, the efficacy of bend-out crossings at signalized intersections, and the general efficacy for bend-out crossings in the United States.

Low Confidence Level

The low confidence level category was assigned based on the quality of available data, or for devices for which there are limited if any studies. Studies in this category may not have documented the study sites well enough to fully understand the context of the results, such as an FHWA study for the bend-in crossing. This study aggregated data for bend-in crossings from multiple case studies and results were compared across cases where the device was applied on its own versus cases where the device was applied with other bicycle treatments; however, those other treatments are not documented nor are other site characteristics that may have contributed to the results. The study showed an increase in the absolute number of bicycle crashes per year[9]; however, the data was not controlled for volumes. In general, the low confidence level represents devices for which research is inconclusive or incomplete.

CONCLUSION

In order to feel confident in the overall application and effect of several of these treatments, there is a need for more rigorous safety studies. Such studies would allow for inclusion of more of these devices in the Highway Safety Manual and therefore a better quantification of benefits and costs. More rigorous quantification would also likely support bicycle safety projects competing more effectively for limited safety funds. Using standardized data collection protocols for as many projects as possible, especially the collection of bicycle volumes before and after project implementation, would be one key factor to help advance the state of research for bicycle treatments. Consistent, standardized data collection and additional studies of bicycle infrastructure treatments would improve guidance for transportation professionals and facilitate safer facility designs.

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