

BISMARCK-MANDAN INTERSECTION ANALYSIS STUDY

Pedestrian and Bicycle Control Fact Sheets



Bismarck-Mandan
METROPOLITAN PLANNING ORGANIZATION

KLJ
ENGINEERING, REIMAGINED

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ADVANCE STOP/YIELD LINES



Milwaukee, Wisconsin

source: Toole Design

Advance stop/yield lines are a solid line or “shark teeth” pavement marking placed 20 to 50 feet in advance of an uncontrolled or mid-block pedestrian crossing. This countermeasure discourages motorists from stopping too close to the crosswalk and blocking other motorists’ view of pedestrians and subsequently the pedestrians’ view of oncoming vehicles.

SAFETY BENEFITS

25% Reduction in pedestrian crashes.



Proven Safety Measure

ESTIMATED COST



\$200-\$1,000

Source: NDDOT Historical Bid Price

MODAL IMPACT



MOTORIST » Better visibility of the crossing area and raised awareness of a crossing pedestrian.



BICYCLIST » Impacts could be similar to motorists or pedestrians depending on the location and direction of bicycle travel.



PEDESTRIAN » Improved ability to see multiple lanes of oncoming traffic.
» Greater ability to identify non-compliant motorists and avoid conflicts.



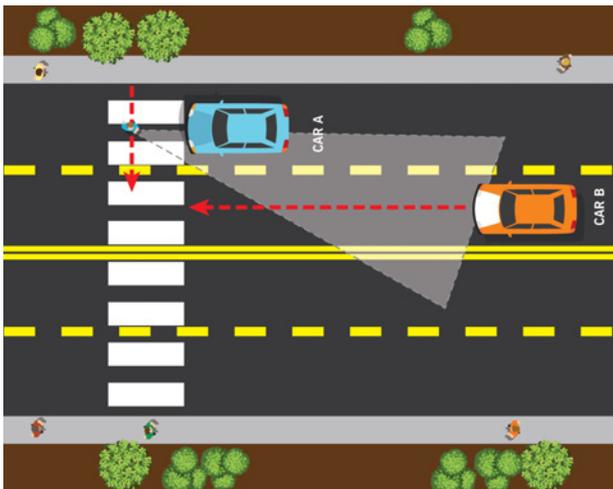
LARGE TRUCKS » Similar impact to motorists. With a larger vehicle size the potential visibility benefits are even greater for pedestrians to see and be seen around the large truck.

→ APPLICABLE CONTEXT

Advance stop/yield lines are appropriate at uncontrolled mid-block multi-lane crossings. While this countermeasure is most commonly used at mid-block crossings there are cases and examples for it to be used at intersection crossings. One example would be at locations where bicycle boxes are installed.

→ CONSIDERATIONS

- » Motorists may choose to ignore this countermeasure if the markings are placed too far in advance of the crossing.
- » Parking should be restricted between the crossing and advance marking lines.
- » This countermeasure is effective at preventing multiple-threat crashes. When a motorist stops too close to a crosswalk and lets a pedestrian cross, it masks the visibility of the adjacent travel lane, creating multiple threats to the pedestrian crossing. The benefits of this countermeasure are shown in the image below. Multiple-threat crashes are often high speed and injury related.



Source: KLJ Engineering

→ MITIGATED CRASH TYPES



Motorist failed to yield to pedestrian



Pedestrian failed to yield



Bicyclist crossing path with uncontrolled motorist



Pedestrian dash

→ COMPLEMENTARY COUNTERMEASURES

Required

- » Appropriate Signing
- » High visibility crosswalk

Optional

- » Bulb-outs
- » Lighting
- » Gateway Treatment
- » Rapid Rectangular Flashing Beacon (RRFB)
- » Pedestrian Hybrid Beacon (PHB)/ High-Intensity Activated Crosswalk Beacon (HAWK)
- » Raised Crosswalk
- » Reduce Corner Radius
- » Bicycle Boxes
- » Parking Removal

Additional Information & Resources

- » Crash Modification Factors Clearinghouse: <http://www.cmfclearinghouse.org/detail.cfm?facid=9017>
- » Bike Ped Safe: http://pedbikesafe.org/PEDSAFE/countermeasures_detail.cfm?CM_NUM=13
- » Manual on Uniform Traffic Control Chapter 3
- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)

CROSSWALK PAVEMENT MARKING AND SIGNING ENHANCEMENTS



Bismarck, North Dakota

source: Google Earth

The most fundamental infrastructure that may be evaluated to enhance visibility at crosswalks are marking styles (continental/ladder type) and warning signs placed at and/or in advance of the crosswalk. The NDDOT Traffic Operations Manual contains a flowchart with recommendations for when marking and not marking a crosswalk may be appropriate based on factors that include land use, sidewalks, traffic control, and pedestrian volume. If a crossing location is marked, the NDDOT Traffic Operations Manual also contains a table that guides which visibility enhancement treatment to consider based on factors that include traffic volumes, roadway speed, median, and number of lanes.

SAFETY BENEFITS

Undetermined

Many comprehensive literary reviews agree that there are no clear-cut results from studies that either marked or unmarked crosswalks are safer. These inconclusive results stem from the fact that many site characteristics play a role in placing appropriate marked crossings. Studies specific to the style of marked crossings show that continental/ladder markings are noticed by drivers up to twice as far away as non-enhanced markings to result in up to eight seconds of increase motorist awareness.

ESTIMATED COST



\$2,500-\$5,000

crosswalk pavement markings and signs

Varies with striping pattern, width of crosswalk and type of striping.

MODAL IMPACT



MOTORIST » Better visibility of the crossing area and raised awareness of a crossing pedestrian.



BICYCLIST » Impacts could be similar to motorists or pedestrians depending on the location and direction of bicycle travel.



PEDESTRIAN » Designates a specific crossing point and clarifies right of way.
» Increases visibility to motorists.



LARGE TRUCKS » Similar impact to motorists. With a larger vehicle size the potential benefits are even greater for increased pedestrian visibility.

→ APPLICABLE CONTEXT

High Visibility Crosswalks are appropriate at controlled intersections. While this countermeasure is most commonly used at controlled intersections, it may be used at uncontrolled intersections meeting the requirements listed in MUTCD Section 3B.18.

→ COMPLEMENTARY COUNTERMEASURES

Required

- » Appropriate Signing
- » Curb Ramps

Optional

- » All Other Pedestrian Countermeasures

→ MITIGATED CRASH TYPES



Motorist failed to yield to pedestrian



Pedestrian failed to yield



Pedestrian dash



Motorist left turn into pedestrian parallel path

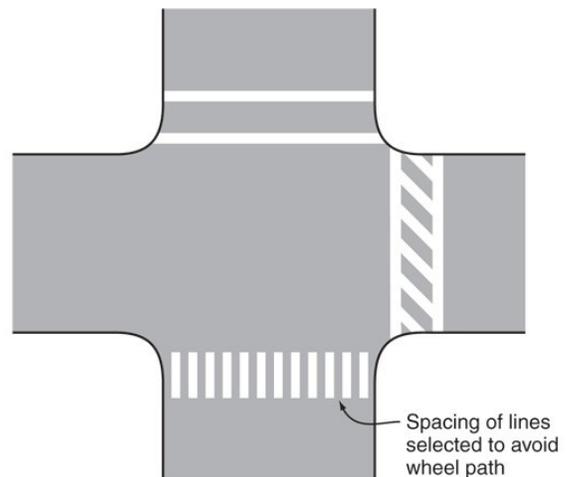


Motorist right turn into pedestrian parallel path

CONSIDERATIONS

- » High Visibility Crosswalk marking locations should be convenient for pedestrian access. They should be designed with curb ramps to allow wheelchair users to cross without leaving the crosswalk
- » Crosswalks are most effective when paired with other countermeasures. Studies have shown that placing crosswalk pavement markings alone in mid-block locations may not increase safety. At a bare minimum signage should be considered.
- » At intersections, all four legs should be marked when possible. Prohibiting crossing on one or more legs may require pedestrians to make multiple crossings to reach their destination, thus increasing their exposure to oncoming vehicles.
- » An example of continental/ladder style pavement markings are shown on the south leg of the image below.

Figure 3B-19. Examples of Crosswalk Markings



Source: MUTCD

Additional Information & Resources

- » Bike Ped Info: http://www.pedbikeinfo.org/cms/downloads/PedestrianLitReview_April2014.pdf#page=12&zoom=100,69,623
- » Manual on Uniform Traffic Control Chapter 3
- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)
- » NDDOT Traffic Operations Manual: <https://www.dot.nd.gov/divisions/programming/docs/trafficops.pdf>
- » FHWA: <https://www.fhwa.dot.gov/publications/research/safety/pedbike/10067/>

PARKING RESTRICTIONS AT CROSSING LOCATIONS



Moorhead, Minnesota

Parking restrictions are a way of improving sight lines at intersections and crossing locations by removing parking that could obstruct views between pedestrians and motorists. Removing parking spaces is especially beneficial at the edges of the crosswalks where pedestrians start or finish their crossing. Generally, vehicles should not be parked within 25 feet of an intersection to provide a minimum line of sight.

SAFETY BENEFITS

22% Reduction in injury crashes.

28% Reduction in non-injury crashes.

 Proven Safety Measure

ESTIMATED COST



\$200-\$500 per zone

Costs can vary depending on the physical means used to achieve this countermeasure and the length of the no-parking zone. Sign installation, striping removal, and delineators are common methods used that have minimal cost.

MODAL IMPACT

 **MOTORIST** » Better visibility of the crossing area and raised awareness of a crossing pedestrian.

 **BICYCLIST** » For bicyclists traveling on a bike facility adjacent to street parking, the removal of parking reduces the risk of a “dooring” crash where a parked vehicle obstructs the bike lane with their door as they attempt to enter or exit the vehicle.

 **PEDESTRIAN** » More visible to motorists.
» Make smarter crossing decisions with a better view of oncoming traffic.

 **LARGE TRUCKS** » None, typically sight lines with large vehicles are not a concern.

➔ CONSIDERATIONS

- » The removal of on-street parking could increase motorist speeds. Additional traffic calming measures can be used to combat the increase speed effect of parking removal.
- » The AASHTO “Green Book” provides more guidance on parking setbacks related to the speed of the roadway. The recommended length of the no-parking zone increases with roadway speeds.
- » It may be necessary to implement physical barriers that prevent motorists from parking or stopping in restricted areas. Common measures include pavement markings, curb extensions, or vertical delineators.

➔ APPLICABLE CONTEXT

Parking Removal/Daylighting is applicable anywhere parked vehicles have the potential to block sight lines at crossings. This countermeasure is effective at locations that have high volumes of pedestrians and vehicle-pedestrian conflicts. Children and persons in wheelchairs experience higher risk from parked cars impacting sight lines. Therefore, this countermeasure is highly relevant near schools, senior living facilities, and both senior and youth activity centers.

➔ MITIGATED CRASH TYPES



Motorist failed to yield to pedestrian



Pedestrian failed to yield



Bicyclist crossing path with uncontrolled motorist



Pedestrian dash

➔ COMPLEMENTARY COUNTERMEASURES

Required

- » No-Parking Signs to denote the length of the no-parking zone

Optional

- » Bulb-outs
- » Curb Ramps
- » High-visibility Crosswalk
- » Warning Signs (MUTCD W11-1, W1-2, W11-15, or S1-1)
- » Lighting
- » Advance Stop/Yield Lines
- » Rectangular Rapid Flash Beacon (RRFB)
- » Pedestrian Hybrid Beacon (PHB)/ High Intensity Activated Crosswalk Beacon (HAWK)
- » Gateway Treatments
- » All Traffic Calming Countermeasures

Additional Information & Resources

- » Crash Modification Factors Clearinghouse: <http://www.cmfclearinghouse.org/detail.cfm?facid=4575>
- » Crash Modification Factors Clearinghouse: <http://www.cmfclearinghouse.org/detail.cfm?facid=4574>
- » National Association of Transportation Officials (NACTO): <https://nacto.org/publication/urban-street-design-guide/intersection-design-elements/visibility-sight-distance/#footnotes>
- » The American Association of State Highway and Transportation Officials (AASHTO) A Policy on Geometric Design of Highways and Streets “Green Book” (2018)
- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)

LIGHTING



Cornelius, North Carolina

source: pedbikeimages / Dan Burden

Appropriate quality and placement of lighting can enhance an environment and increase comfort and safety. Without sufficient lighting, motorists may not be able to see pedestrians in time to stop. Illumination at crosswalks and along the roadway can help increase visibility for pedestrians and bicyclists, particularly at approaches to crossings. Studies show that increasing or adding lighting to crosswalks, road segments, and intersections improves pedestrian and bicyclist safety by reducing crashes, increasing yielding and compliance with traffic control devices, and improving visibility.

➔ SAFETY BENEFITS

59% Reduction in vehicle pedestrian injury crashes.

32% Reduction in night time crashes.



Proven Safety Measure

➔ ESTIMATED COST



\$2,000-\$25,000

Cost can vary greatly depending on the design needs for the location. An engineering or feasibility study is needed to more accurately predict cost.

➔ MODAL IMPACT



MOTORIST » Improves overall safety, especially in night time conditions.



BICYCLIST » Improves visibility to motorists
» Benefit increases with the use of reflective gear.



PEDESTRIAN » Improves visibility to motorists
» Benefit increases with the use of reflective gear.



LARGE TRUCKS » Improves overall safety, especially in night time conditions.

→ APPLICABLE CONTEXT

This countermeasure can be beneficial in a wide variety of circumstances. The NDDOT Traffic Operations Manual has a lighting warrant policy to determine when lighting should be installed based on factors like the presence of curb and gutter, land use, and traffic volumes.

→ COMPLEMENTARY COUNTERMEASURES

Optional

- » All other pedestrian countermeasures

→ MITIGATED CRASH TYPES



Lighting can improve safety in many situations and has been found to reduce motorist, bicycle, and pedestrian crashes. Injury severity is also decreased with improved lighting.

→ CONSIDERATIONS

- » Lighting should be installed on both sides of arterial streets in commercial districts.
- » Lighting design should account for uniform lighting levels and glare.
- » Safety is not limited to the absence or presence of lighting at a crossing. The content of the lighting design can also enhance the safety benefits as a countermeasure. The type of luminaire, vertical mounting distance, and pole layout are examples of design decisions that can improve the pedestrian experience. An example of pole layout designed with special consideration for pedestrian crossing is shown in the images below.

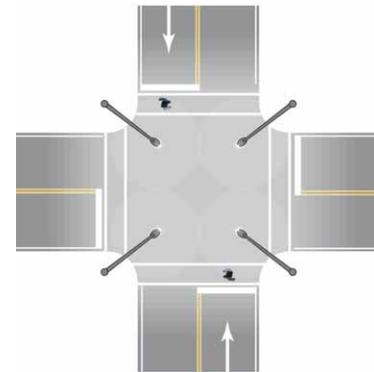


Figure 13. Drawing. Traditional intersection lighting layout.

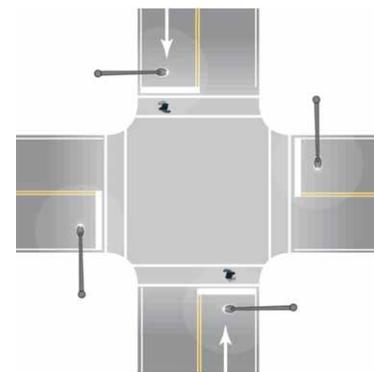


Figure 14. Drawing. New design for intersection lighting layout for crosswalks.

Source: FHWA

Additional Information & Resources

- » Crash Modification Factors Clearinghouse: <http://www.cmfclearinghouse.org/detail.cfm?facid=441>
- » Federal Highway Administration (FHWA): <https://www.fhwa.dot.gov/publications/research/safety/08053/08053.pdf>
- » North Dakota Lighting Policy: <https://www.dot.nd.gov/divisions/programming/docs/lighting-warrant-policy.pdf>
- » AASHTO Roadway Lighting Design Guide (2007)
- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)

IN-ROADWAY SIGNS



Kalamazoo, Michigan

source: Michigan DOT

In-roadway signs (MUTCD R1-6 or R1-6a) are typically placed on the left and right side of all travel lanes at uncontrolled crosswalks. This requires all motorists to drive between two signs creating a “gateway feeling” in which there is a perceived narrowing of the road at an uncontrolled crosswalk. The signs may be placed on lane lines or in the gutter of the roadway by the curb. Gateway treatments increase motorist awareness of pedestrian crossing, reduce approach speeds, and improve yielding rates.

SAFETY BENEFITS

55% Increase in motorists yielding to pedestrians.

5 mph Reduction in vehicle speeds, which reduces crash severity.

ESTIMATED COST

\$

\$900-\$1,500

Source: NCHRP (926)

MODAL IMPACT



MOTORIST » Reduces travel speeds and alerts motorists to pedestrian activity.



BICYCLIST » Impacts could be similar to motorists or pedestrians depending on the location and direction of bicycle travel.



PEDESTRIAN » Better visibility for crossing pedestrian.
» Reduced motorist speeds can increase pedestrian safety.



LARGE TRUCKS » Similar impact to motorists. With a larger vehicle size the potential benefits are even greater for increased pedestrian visibility.

➔ CONSIDERATIONS

- » Signs should be placed on both sides of all travel lanes. They may be located on a center line, a median, crossing island, on a lane line, within a gutter, or near the curb at the edge of the street to create the gateway effect.
- » The sign should be placed at the crosswalk, but neither the sign nor the sign base should be within the crosswalk or the on the crosswalk lines.
- » These signs may need to be removed in winter for snow removal operations.
- » This countermeasure becomes more effective the narrower the gap is between the signs.
- » A rubberized curb sign base may increase the longevity of the device.

➔ APPLICABLE CONTEXT

In-roadway signs are applicable at uncontrolled crossings with a posted speed limit of 35 miles per hour or less and average daily traffic volumes less than 12,000 vehicles per day. Alternative methods should be considered along higher speed roadways.



Source: MUTCD

➔ MITIGATED CRASH TYPES



Motorist failed to yield to pedestrian



Pedestrian failed to yield



Bicyclist crossing path with uncontrolled motorist



Pedestrian dash

➔ COMPLEMENTARY COUNTERMEASURES

Required

- » High Visibility Crosswalk
- » Curb Ramps
- » Advance Stop/Yield Lines

Optional

- » Bulb-outs
- » Lighting
- » Raised Median/Crossing Island
- » Rapid Rectangular Flashing Beacon (RRFB)
- » Pedestrian Hybrid Beacon (PHB)/ High Intensity Activated Crosswalk Beacon (HAWK)
- » Raised Crosswalk
- » Parking Removal

Additional Information & Resources

- » Center for Transportation Studies University of Minnesota: <https://conservancy.umn.edu/bitstream/handle/11299/189957/CTS%2017-05.pdf?sequence=1&isAllowed=y>
- » Michigan Department of Transportation: http://aii.transportation.org/documents/User%20Guide_2018_0503_Final_UPDATED%20CDM%20Edgeline%20Clarification.pdf
- » Manual on Uniform Traffic Control Chapter 2
- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)

CURB RADIUS REDUCTION



New York City, New York

source: NACTO

The radius of a street corner impacts motorist turning speeds and pedestrian crossing distance. A large curb radius typically results in high-speed turning movements putting pedestrians at a higher risk of being struck by fast right turning vehicles. Reducing the corner radius can improve pedestrian safety by requiring motorists to reduce speeds, and shortening pedestrian crossing distances which thereby improves signal timing. Additionally, a smaller radius provides a larger pedestrian waiting areas at corners, improves sight distance, and allows for greater flexibility of curb placement. Curb radius reduction is similar to the bulb-outs countermeasure.

SAFETY BENEFITS

Undetermined

There is limited information that quantifies the effectiveness of a curb radius reduction. One case study support this countermeasure's ability to slow vehicle right turns speeds by up to 40%. Crash severity typically lessens with speed reductions. Studies have also reported an increase in yield rates to pedestrians with this countermeasure.

ESTIMATED COST

\$\$

\$15,000-\$40,000
per intersection

Source: FHWA Pedsafe

MODAL IMPACT



MOTORIST » Better visibility of the crossing area and raised awareness of a crossing pedestrian.



BICYCLIST » Reduced motorist turning speeds could greatly reduce right turn into bicyclist parallel path crashes, which is a common and injury-prone crash type.



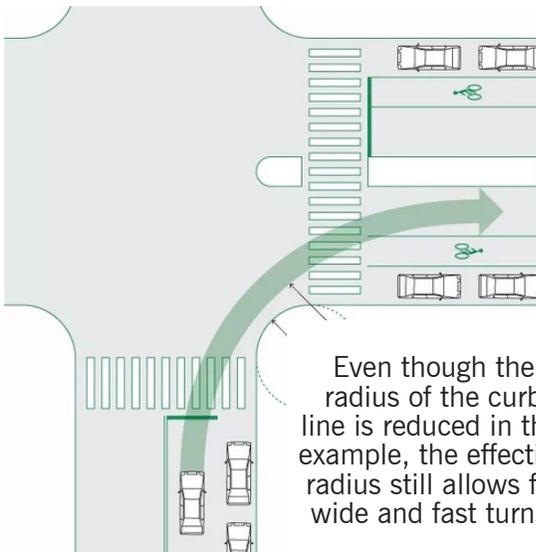
PEDESTRIAN » Able to be seen better with this countermeasure and lower speeds reduce crash severity.
» Larger waiting area and shorter crossing distance.



LARGE TRUCKS » Will make turns more difficult and negatively impact emergency vehicle response times. Should not be used where large vehicles are common.

➔ CONSIDERATIONS

- » A truck apron can be used to provide a curb radius reduction targeted to slow smaller vehicles while accommodating the needs of larger vehicles.
- » All curb radius geometries should be designed to prevent turning vehicles from tracking over the curb which could injure people waiting on the corner.
- » Bulb-outs are similar in function but more commonly used by states and local jurisdictions than curb radius reductions because they do not impact vehicular movements as significantly.
- » Designers often determine corner radii based on the curb geometry only and overlook the effective radius. Effective radius takes into account elements like additional through lanes, bike lanes, and parking. As a result, drivers may still turn as wide as possible to maintain travel speeds if there is physical space available.



Source: NACTO

➔ APPLICABLE CONTEXT

This countermeasure is applicable in urban areas with low heavy vehicle volumes. Intersections that have a skew are candidate locations, especially corners with larger turning angles.

➔ MITIGATED CRASH TYPES



Motorist right turn
into pedestrian
parallel path



Motorist right turn
into bicyclist
parallel path

➔ COMPLEMENTARY COUNTERMEASURES

Required

- » Curb Ramps
- » High Visibility Crosswalk

Optional

- » Raised Median/Crossing island
- » Parking Removal
- » Lighting

Additional Information & Resources

- » National Association of Transportation Officials (NACTO): <https://nacto.org/publication/urban-street-design-guide/intersection-design-elements/corner-radii/#footnotes>
- » FHWA: http://www.pedbikesafe.org/bikesafe/countermeasures_detail.cfm?CM_NUM=16
- » FHWA: http://www.pedbikesafe.org/PEDSAFE/countermeasures_detail.cfm?CM_NUM=28
- » NCHRP(498) Application of Pedestrian Crossing Treatments for Streets and Highways (2016)
- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)
- » Alta Planning: https://altago.com/wp-content/uploads/Corner-Design-for-All-Users_Alta_Sept-2020.pdf

ROAD DIET



Mandan, North Dakota

A road diet is a width reduction of the motorist portion of a roadway cross section. This is commonly achieved by removing a through lane or narrowing vehicle lanes to create space for pedestrian and bicyclist safety treatments and/or parking. In addition to safety treatments like raised medians and bike lanes, road diets typically serve as a traffic calming measure to reduce motorist travel speed. The most common road diet configuration involves converting a four-lane road into three lanes, with one travel lane in each direction and a center left turn lane, often supplemented with painted or raised center islands.

SAFETY BENEFITS

29% Reduction in total crashes.



Proven Safety Measure

ESTIMATED COST

\$\$\$

\$1,500-\$40,000 *per mile*

Costs can vary greatly depending on the desired cross section elements. Re-striping can be very low cost while raised medians and separated bike lanes can increase costs drastically.

MODAL IMPACT



MOTORIST » Reduces motorist speed but may reduce capacity.



BICYCLIST » Can include dedicated space for travel and fewer conflict points with motorists.
» Reduced motorist speeds create a safer environment for bicyclists.



PEDESTRIAN » Shorter crossing distances and fewer conflict points with motorists.
» Additional pedestrian countermeasures that accompany road diets may increase overall access and mobility.



LARGE TRUCKS » Reduces motorist speed but may reduce capacity. Narrower lanes could make navigation more difficult for larger trucks.

➔ CONSIDERATIONS

- » Many different roadway configurations are considered road diets. There are many site specific factors that play a role in determining the most effective cross section reduction. Traffic mix, left turn volumes, access density, existing roadway width and drainage, roadway alignment and sight distances, crash history, and land use are some examples of factors to be considered.
- » Signal modifications may be needed at certain locations which can increase the cost of this countermeasure significantly, like realigning signal heads, which may require new mast arms, or new signal heads for new turn lane configuration.

➔ APPLICABLE CONTEXT

Road Diets are applicable on both urban and rural roads that prioritize bicycle and pedestrian travel. A good candidate location will have extra capacity and predictable traffic growth. A traffic engineering analysis or assessment should be completed to ensure that removal of lanes does not create congestion on the roadway.

➔ COMPLEMENTARY COUNTERMEASURES

Optional

- » Raised Median/Crossing Island
- » All Other Crossing Treatments
- » Bike Lane

➔ MITIGATED CRASH TYPES



Motorist failed to yield to pedestrian



Pedestrian failed to yield



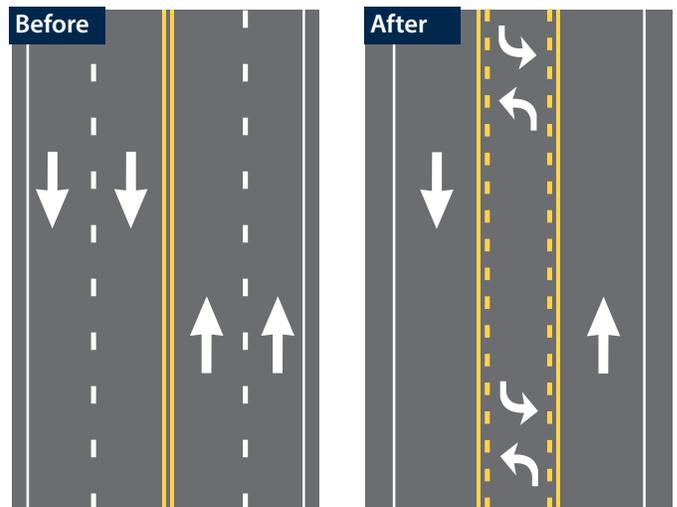
Pedestrian dash



Bicyclist crossing path with uncontrolled motorist



Bicyclist ride through/out-stop sign



Source: FHWA

Additional Information & Resources

- » Crash Modification Factors Clearinghouse: <http://www.cmfclearinghouse.org/detail.cfm?facid=199>
- » Federal Highway Administration (FHWA): https://safety.fhwa.dot.gov/road_diets/
- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)

CONTINUOUS RAISED MEDIAN/ HARDENED CENTERLINES



Bismarck, North Dakota

Continuous raised medians and hardened centerlines are roadway design treatments that provide access management and separate opposing directions of motorist travel. They can be extended across an intersection or driveway, creating a continuous median that restricts motorist movements ultimately reducing the number of potential conflict points. They can also partially extend through an intersection to reduce speed of left turn movements as long as they do not encroach on crosswalk space.

SAFETY BENEFITS

46% Reduction in total crashes.

31% Reduction in vehicle-pedestrian crashes.



Proven Safety Measure

ESTIMATED COST

\$\$\$

\$2,000-\$40,000 per mile

Costs can vary greatly depending on the desired cross section elements. Temporary curbing and flexible delineators can be very low cost while raised medians can increase costs drastically.

MODAL IMPACT



MOTORIST

- » Access management could encourage better driver behavior and fewer conflict points.
- » Change in travel patterns could create capacity issues for adjacent roadways.



BICYCLIST

- » Access can be maintained for bicycles offering mobility while reducing conflicts with motorists.
- » Increased right turns out of driveways could create issues if crossing a bi-directional bike lane and shared use path since right turning motorists may forget to look to their right before making the turn.



PEDESTRIAN

- » Access can be maintained for bicycles offering mobility while reducing conflicts with motorists.
- » Refuge islands allow pedestrians to cross one direction of traffic at a time.



LARGE TRUCKS

- » The required turning radius of hardened centerlines makes navigating this countermeasure difficult for heavy trucks.

➔ APPLICABLE CONTEXT

This countermeasure is applicable at any intersection or mid block location where restricting left turn movements exhibit safety concerns. Examples of left turn driver behavior that could be mitigated include failing to yield, high speed turns, cutting across centerlines, or inappropriate gap selection.

➔ COMPLEMENTARY COUNTERMEASURES

Required

- » Crossing Signing (R1-6 or similar)
- » High Visibility Crosswalk
- » Advance Stop/Yield Lines

Optional

- » All Traffic Calming Countermeasures

➔ MITIGATED CRASH TYPES



Motorist failed to yield to pedestrian



Bicyclist crossing path with uncontrolled motorist



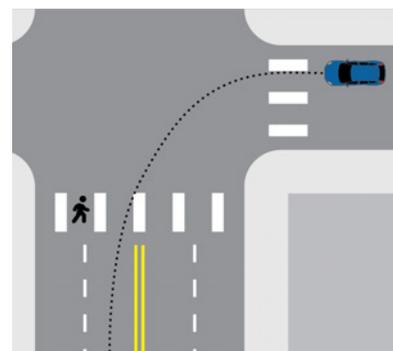
Motorist left turn into pedestrian parallel path



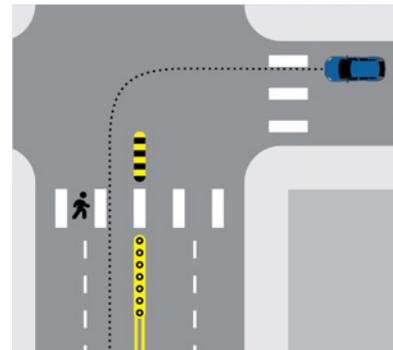
Motorist left turn into bicyclist opposite direction

➔ CONSIDERATIONS

- » Crossing islands greater than 6 feet in width should be considered where pedestrian or bicycle volumes are higher.
- » Landscaping should not obstruct visibility between pedestrians and approaching motorists. Fences, railings, and curbs can orient pedestrians to face the direction of oncoming traffic.
- » If installing at mid-block locations, consider accompanying this treatment with an active warning beacon.
- » This access management strategy, could lead to increased through speeds. Additional traffic calming measures can be used to combat the increase speed effect.
- » When not continuous, ideally the physical barrier extends past the crosswalk, but no vertical elements should land within the crosswalk. (see example below)



Without Hardened Center Line



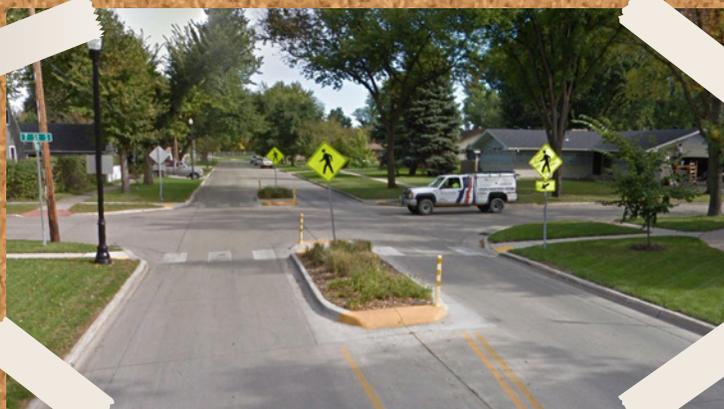
With Hardened Center Line

Source: Insurance Institute for Highway Safety (IIHS)

Additional Information & Resources

- » Crash Modification Factors Clearinghouse: http://www.cmfclearinghouse.org/study_detail.cfm?stid=487
- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)

CROSSING ISLANDS



Fargo, North Dakota

Source: Google Earth

Crossing islands are roadway treatments that provide space for pedestrians to wait between traffic lanes. They can simplify crossing and improve safety for pedestrians and bicyclists by allowing them to cross each direction of traffic separately. They are particularly beneficial at uncontrolled crossings, large signalized crossings, or complex intersections. Crossing islands that extend up to or beyond crosswalks can also slow left-turning motorists, providing the same traffic calming benefits as hardened centerlines or medians.

SAFETY BENEFITS

46% Reduction in total crashes.

8 mph Reduction in vehicle speeds.



Proven Safety Measure

ESTIMATED COST



\$2,000-\$40,000 per island

Costs can vary greatly depending on the desired elements and size/length. Temporary curbing and flexible delineators can be very low cost while decorative elements can increase costs drastically.

MODAL IMPACT



MOTORIST

- » Reduced speed and higher yielding rate to pedestrians.
- » Tight turning radius can reduce throughput at signals requiring long phasing.



BICYCLIST

- » Impacts could be similar to motorists or pedestrians depending on the location and direction of bicycle travel.



PEDESTRIAN

- » Better pedestrian visibility.
- » Two stage crossing that is safer and easier.



LARGE TRUCKS

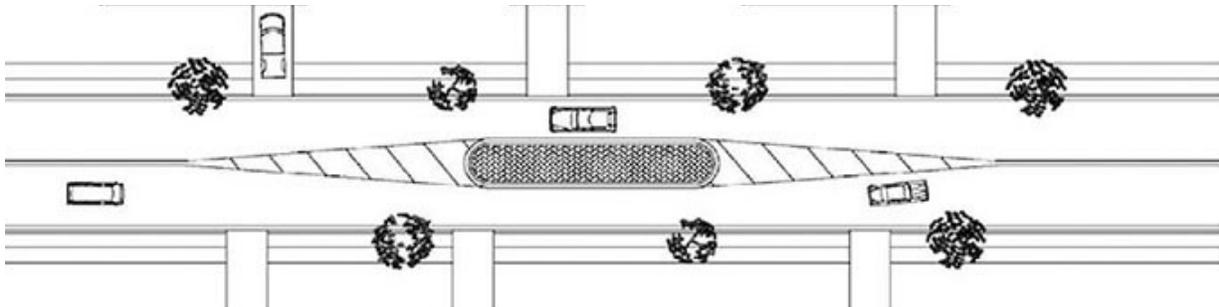
- » Reduced speed and higher yielding rate to pedestrians.
- » Tight turning radius can reduce throughput at signals requiring long phasing.

➔ CONSIDERATIONS

- » Crossing islands should be a minimum width of 6 feet to meet accessibility requirements. For bicyclists refuge and to large groups of pedestrians, the minimum should be increased to 8 feet.
- » Crossing islands can be designed with a Z-crossing to require pedestrians to face oncoming traffic which may further increase visibility.
- » Landscaping should not obstruct visibility between pedestrians and motorists.
- » Consider accompanying this treatment with an active warning beacon at mid-block locations.

➔ APPLICABLE CONTEXT

Crossing islands should be considered anywhere space is available, but especially on roads with medium/high speeds and volumes. Roads that have two or more lanes of through traffic and speeds above 30 miles per hour would benefit most from this countermeasure. They are common at intersections and mid block crossings.



Source: Delaware Department of Transportation

➔ MITIGATED CRASH TYPES



Motorist failed to yield to pedestrian



Pedestrian failed to yield



Pedestrian dash



Bicyclist crossing path with uncontrolled motorist



Bicyclist ride through/out-stop sign

➔ COMPLEMENTARY COUNTERMEASURES

Required

- » Crossing Signing (R1-6 or similar)
- » High Visibility Crosswalk
- » Curb Ramps
- » Advance Stop/Yield Lines

Optional

- » Bulb-outs
- » Rapid Rectangular Flashing Beacon (RRFB)
- » Pedestrian Hybrid Beacon (PHB)/ High Intensity Activated Crosswalk Beacon (HAWK)
- » Raised Crosswalk
- » Crossing Barriers
- » Parking Removal
- » Gateway Treatment
- » All Traffic Calming Countermeasures

Additional Information & Resources

- » Crash Modification Factors Clearinghouse: <http://www.cmfclearinghouse.org/detail.cfm?facid=8799>
- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)

CROSSING BARRIERS



Grand Forks, North Dakota

At some mid block locations, motorists are unlikely to yield to a crossing bicyclist or pedestrian. Certain locations are not designed to provide safe crossings and factors like vehicle volume and speed create risk that pedestrians may not recognize or take into consideration when deciding to cross. While it is generally preferred to create safe crossings, it may be necessary to consider the installation of a continuous barrier or fencing to channelize pedestrians to a safer crossing as signs are not typically effective.

SAFETY BENEFITS

Undetermined

There is limited information that quantifies the effectiveness of median barriers. Case studies indicate that this countermeasure increases pedestrian safety by limiting crossings at unsafe locations. Barriers can limit the amount of risk and exposure pedestrians experience when crossing against motorists.

ESTIMATED COST



Dependent

Costs vary depending on the type of barrier and existing infrastructure. There must be a raised median for this countermeasure and barriers, especially fencing, may increase in price with aesthetic design.

MODAL IMPACT



MOTORIST » Prevents unexpected pedestrian crossings and may serve as a traffic calming measure.



BICYCLIST » Increases general safety.
» May increase travel time disproportionately compared to other modes of travel.



PEDESTRIAN » Removes pedestrians from high risk crossing situations.
» May create dedicated crossing locations with high quality crossing facilities.
» Restricts mobility and access and may increase travel time.



LARGE TRUCKS » Prevents unexpected pedestrian crossings and may serve as a traffic calming measure.

→ APPLICABLE CONTEXT

Pedestrian crossing barriers should be used in locations with extremely unsafe crossing conditions that have a history of risky behavior and crashes. This countermeasure should be used only if the problem is not solvable by other treatments. One common application of this countermeasure is on college campuses where students may be more prone to risky crossing behavior. Another common application is near facilities that hold special events such as sports complexes or performing arts venues. Large volumes of pedestrians looking to avoid congestion may also increase risky crossing behavior.

→ CONSIDERATIONS

- » Wayfinding and signage should be provided to help pedestrians find alternative appropriate crossing locations.
- » People may try to climb or bypass barriers if forced to travel too far out of their way. This only adds risk to an already dangerous crossing.
- » This treatment may require out of direction travel and increase travel time for pedestrians.
- » Consideration should be given to the design of the fencing to ensure that the risk to vehicles is limited upon impact.
- » Pedestrian barriers are often used in conjunction with an enhanced crossing nearby to consolidate crossing to the safest possible location.
- » Requires regular maintenance to ensure the integrity of the barrier as well as cleaning up trash that may accumulate along the median.
- » Fence design should take into account winter conditions, so as to not cause snow drifts in adjacent lanes.

→ MITIGATED CRASH TYPES



Motorist failed to yield to pedestrian



Pedestrian failed to yield



Bicyclist crossing path with uncontrolled motorist



Pedestrian dash

→ COMPLEMENTARY COUNTERMEASURES

Required

- » Curb Ramps

Optional

- » Bulb-outs
- » Lighting
- » Continuous Raised Median
- » Crossing Island
- » Traffic Signals
- » Rapid Rectangular Flashing Beacon (RRFB)
- » Pedestrian Hybrid Beacon (PHB)/ High Intensity Activated Crosswalk Beacon (HAWK)

Additional Information & Resources

- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)

IN PAVEMENT LIGHTED CROSSWALKS



Image Source: TAPCO

In-pavement lighted crosswalks can be very effective in areas with high pedestrian activity such as schools, commercial districts, or areas that have experienced high vehicle/pedestrian collisions. The crosswalks consist of bright strobe lights, used on airport runways, embedded in the pavement that flash when activated by a pedestrian or through detection. In-pavement lighted crosswalks can be highly effective at night. They can also be used with pedestrian crossing signals and appropriate signage.

SAFETY BENEFITS

9-20 ft Increase in stopping distance.

ESTIMATED COST

\$\$

\$27,000-\$50,000

Source: Moorhead Traffic Calming Manual

MODAL IMPACT



MOTORIST » Alerts motorist to the presence of a crosswalk
» May result in better yielding to pedestrians.



BICYCLIST » May increase safety if used at bicycle crossing.



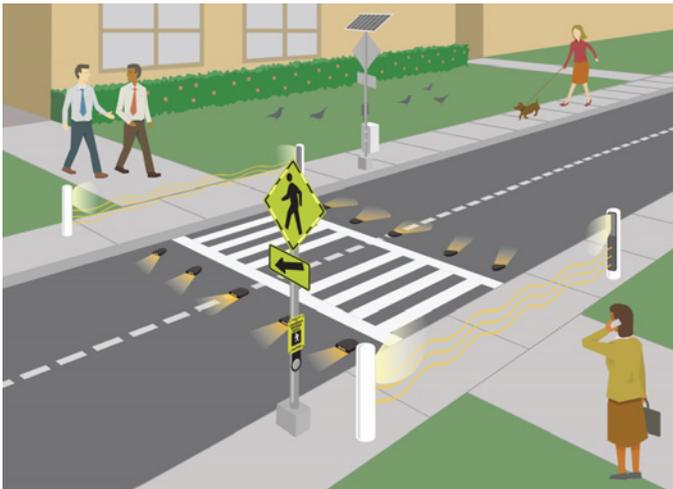
PEDESTRIAN » May increase safety by increasing visibility to motorists.



LARGE TRUCKS » Alerts motorist to the presence of a crosswalk
» May result in better yielding to pedestrians.

➔ CONSIDERATIONS

- » Primarily improves pedestrian conditions in low light, benefits reduced in poor visibility or daylight conditions.
- » There are maintenance considerations since the whole system is likely to need to be replaced for resurfacing or utility repairs.
- » Generally the lights are only visible to the first car in a platoon.
- » May become blocked in the winter due to packed snow and ice.



Source: Light Guard Systems

➔ MITIGATED CRASH TYPES



Motorist failed
To yield to
Pedestrian



Bicyclist crossing
path with
uncontrolled motorist



Other -
Reduction in
Crash Severity

➔ APPLICABLE CONTEXT

Lighted crosswalks are applicable in areas with high pedestrian activity.

Embedded in the pavement to outline the crosswalk and oriented to face oncoming traffic, In-Road Warning Lights (IRWL) flash in unison to alert drivers of pedestrians actively crossing the road.



Source: TAPCO

➔ COMPLEMENTARY COUNTERMEASURES

Required

- » High Visibility Crosswalk

Optional

- » Road Diet
- » Gateway Treatments
- » Raised Median/Crossing Islands
- » Rectangular Rapid Flash Beacons
- » Pedestrian Hybrid Beacon
- » Raised Crosswalk
- » Pedestrian Detection

Additional Information & Resources

- » FHWA: http://www.pedbikeinfo.org/cms/downloads/PedestrianLitReview_April2014.pdf#page=34&zoom=100,69,350
- » "Motorist Actions at a Crosswalk With an In Pavement Flashing Light System" Karkee et al., 2006: <https://pubmed.ncbi.nlm.nih.gov/21128195/>
- » Tapco Product Line: <https://www.tapconet.com/product/in-road-warning-light-system>
- » Light Guard Systems: <https://www.lightguardsystems.com/tag/irwl/>

RECTANGULAR RAPID FLASHING BEACON (RRFB)



Lincoln, North Dakota

Rectangular Rapid Flashing Beacons (RRFBs) are placed on both sides of an uncontrolled crosswalk, below a pedestrian crossing sign, and above an arrow pointing at the crosswalk. The beacons differ from standard flashing beacons by using a rapid flash frequency (approximately 190 times per minute), brighter light intensity, and ability to aim the LED lighting. RRFBs can be passively or pedestrian actuated, and feature an irregular, eye-catching flash pattern to call attention to the presence of pedestrians. RRFBs require a power source, however there are solar powered options so no connection to existing power is required.

SAFETY BENEFITS

47% Reduction in pedestrian crashes.

56% Increase in vehicle yield rates to pedestrians.



Proven Safety Measure

ESTIMATED COST

\$\$

\$40,000

Source: NDDOT Historical Bid Price

MODAL IMPACT



MOTORIST

- » Reduces conflicts with pedestrians and possibly reduces rear end crashes.
- » May increase delay.



BICYCLIST

- » Increases safety especially at roadway crossings of regional bikeways where this countermeasure is commonly applied.
- » May decrease delay.



PEDESTRIAN

- » Better visibility and increased motorist yielding and stopping distance.
- » May decrease delay.



LARGE
TRUCKS

- » Reduces conflicts with pedestrians and possibly reduces rear end crashes.
- » May increase delay.

→ APPLICABLE CONTEXT

Rectangular rapid flash beacons (RRFBs) are applicable on roadways with low to medium traffic volumes and a posted speed limit of 35 miles per hour or lower. RRFBs are good for two lane roadways, but less suited for multilane roadways unless an overhead configuration is considered effective with engineering judgment.

→ CONSIDERATIONS

- » RRFBs should not be used in conjunction with YIELD, STOP, or traffic signal control.
- » If multiple RRFBs are needed in close proximity, consider redesigning the roadway to address systemic safety challenges.
- » Other treatments may be more appropriate in locations with sight distance constraints.
- » RRFBs typically draw power from standalone solar panel units, but may also be wired to a traditional power source.
- » RRFBs are a lower cost option compared to traffic signals and PHBs/HAWKs.

→ MITIGATED CRASH TYPES



Motorist failed to yield to pedestrian



Pedestrian failed to yield



Bicyclist crossing path with uncontrolled motorist



Pedestrian dash

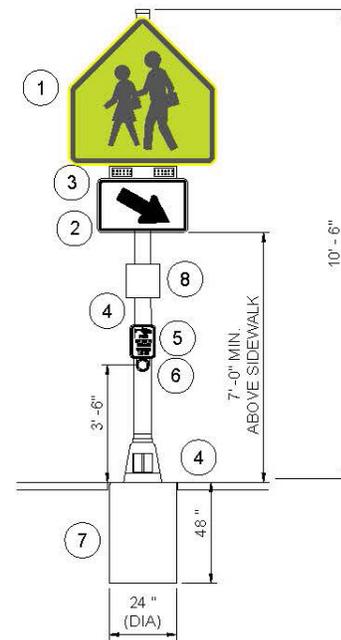
→ COMPLEMENTARY COUNTERMEASURES

Required

- » High Visibility Crosswalk
- » Curb Ramps
- » Advance Stop/Yield Lines
- » Appropriate Signing
- » Pedestrian Actuation (active or passive)

Optional

- » Bulb-outs
- » Raised Crosswalk
- » Parking Removal
- » Gateway Treatment
- » Lighting
- » Crossing Island



PEDESTAL MOUNTED RRFB ASSEMBLY DETAIL

(NOT TO SCALE)
(SOME DETAILS MAY VARY)

Source: Washington State Department of Transportation

Additional Information & Resources

- » Crash Modification Factors Clearinghouse: <http://www.cmfclearinghouse.org/detail.cfm?facid=9024>
- » NCBI: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3177346/>
- » Manual on Uniform Traffic Control Interim Approval 21
- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)

PEDESTRIAN HYBRID BEACON (PHB)



Grand Forks, North Dakota

Pedestrian Hybrid Beacons (PHBs), also called High Intensity Activated Crosswalk Systems (HAWKs), are signals installed at unsignalized major street crossing locations to improve pedestrian safety. PHBs may be used in locations where side street volumes do not warrant a conventional traffic signal, or in locations where a conventional signal may encourage additional traffic on the minor street. PHBs typically include overhead beacons with three sections facing both directions on the major street, overhead signs labeled “CROSSWALK STOP ON RED”, a marked crosswalk on the major street, and countdown pedestrian signal heads. The MUTCD has warrants for PHBs that account for pedestrian volumes, crossing distances, vehicular volumes, and roadway speeds.

SAFETY BENEFITS

39% Reduction in total crashes.

69% Reduction in pedestrian crashes.



Proven Safety Measure

ESTIMATED COST

\$\$\$

\$100,000

Source: NDDOT Historical Bid Price

MODAL IMPACT



MOTORIST

- » Reduces conflicts with pedestrians and possibly reduces rear end crashes.
- » May increase delay.



BICYCLIST

- » Increase safety, especially at roadway crossings of regional bikeways where this countermeasure is commonly applied. May also decrease delay.



PEDESTRIAN

- » Better visibility and raised motorist awareness.
- » May decrease delay.



LARGE
TRUCKS

- » Reduces conflicts with pedestrians and possibly reduces rear end crashes.
- » May increase delay.

→ COMPLEMENTARY COUNTERMEASURES

Required

- » High Visibility Crosswalk
- » Curb Ramps
- » Advance Stop/Yield Lines
- » Appropriate Signing
- » Pedestrian Push Button Actuation
- » Pedestrian Countdown Signals

Optional

- » Bulb-outs
- » Raised Crosswalk
- » Parking Removal
- » Gateway Treatment
- » Lighting
- » Crossing island

→ MITIGATED CRASH TYPES



Motorist failed to yield to pedestrian



Pedestrian failed to yield



Pedestrian dash



Bicyclist crossing path with uncontrolled motorist



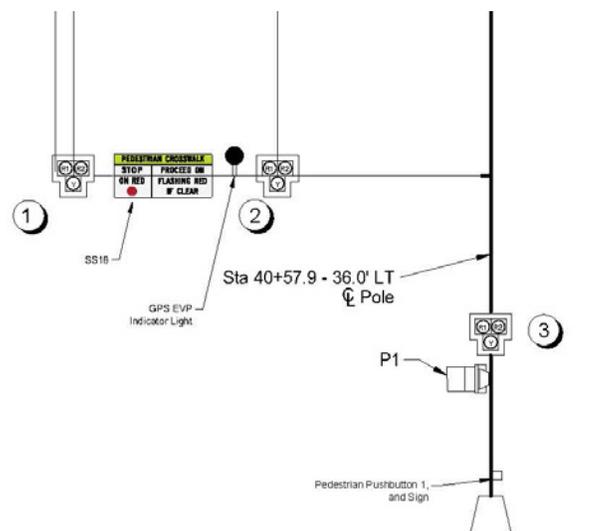
Bicyclist ride through/out-stop sign

→ APPLICABLE CONTEXT

The MUTCD has warrants for PHBs that explain where this countermeasure is appropriate. Crossings that experience long pedestrian delay and areas near schools parks and senior centers are good candidates for this treatment. This countermeasure is most common at mid-block locations and should not be placed near four-leg intersections. PHBs may be placed adjacent to a three-leg intersection as long as all turning movements that would conflict with the crosswalk can see the flashing beacons.

→ CONSIDERATIONS

- » PHBs may be effective at reducing multiple threat crashes. Review advance stop/yield lines countermeasure.
- » PHBs may be appropriate where traffic signals are unwarranted.
- » The preferred design is to place the beacon over the crosswalk, rather than on the side of the road.
- » PHBs should be placed outside of the functional area of signalized intersections and outside of turn lanes.



Source: University Avenue Grand Forks, ND

Additional Information & Resources

- » Crash Modification Factors Clearinghouse: <http://www.cmfclearinghouse.org/detail.cfm?facid=2911>
- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)

ALL WALK PHASE



Los Angeles, California

source: LA Great Streets

An all walk phase, also known as a pedestrian scramble or exclusive pedestrian phase, is a phase at signalized intersections which stops vehicle traffic in all directions and allows pedestrians to cross in any fashion, including diagonally. This low cost treatment can increase pedestrian safety by separating pedestrians from vehicles and may improve the efficiency of intersections. It is particularly advantageous in situations where other intersection treatments are cost prohibitive or unable to be implemented due to insufficient right of way.

SAFETY BENEFITS

51% Reduction in pedestrian crashes.

ESTIMATED COST

\$

\$1,500

Source: NCHRP (926)

MODAL IMPACT



MOTORIST

- » Removes nearly all conflicts with pedestrians.
- » Increases delay for all motorists.



BICYCLIST

- » May create confusion of right of way with pedestrians during the phase.
- » Should reduce some conflicts with motorists.



PEDESTRIAN

- » Removes nearly all conflicts with motorists.
- » May reduce travel time by allowing persons to cross diagonally.



LARGE TRUCKS

- » Removes nearly all conflicts with pedestrians.
- » Increases delay for all motorists.

➔ CONSIDERATIONS

- » This countermeasure can cause a large amount of additional motorist delay because the cycle length needs to increase to accommodate the dedicated pedestrian phase.
- » Crosswalks will need to be repainted to include a diagonal crossing pattern and pedestrian signs will need to be installed to clarify the all walk phase.
- » Pedestrians may have to queue longer than normal while waiting for the dedicated all walk phase. Sidewalk spaces must be sufficient to handle the anticipated number of pedestrians waiting to cross.
- » Signal equipment may need to be upgraded in order to be re-timed with the additional phase and remain in coordination with other nearby signals.
- » This countermeasure has been used for a long time in the United States, but is still not common. Many sources recommend this countermeasure for very specific and extreme cases.

➔ APPLICABLE CONTEXT

All walk phases are applicable in dense urban areas or downtown settings. All walk phases should be used where pedestrian volumes are high and vehicle volumes are low to moderate. Additionally this countermeasure is useful where there is a high exposure of pedestrians to turning motorists. All walk phases have been implemented in Grand Forks, North Dakota.



Grand Forks, North Dakota

➔ MITIGATED CRASH TYPES



Motorist failed to yield to pedestrian



Pedestrian failed to yield



Pedestrian dash



Motorist left turn into pedestrian parallel path



Motorist right turn into pedestrian parallel path

➔ COMPLEMENTARY COUNTERMEASURES

Required

- » Appropriate Signing
- » High Visibility Crosswalk
- » Curb Ramps
- » Pedestrian Countdown Signal
- » Pedestrian Detection
- » Traffic Signal

Optional

- » Bulb-outs
- » Lighting
- » No Right Turn on Red Sign

Additional Information & Resources

- » Crash Modification Factors Clearinghouse: <http://www.cmfclearinghouse.org/detail.cfm?facid=4117>
- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)

PEDESTRIAN COUNTDOWN SIGNALS



Bismarck, North Dakota

Pedestrian countdown signals indicate to pedestrians how much time is left in a crossing phase, and prohibits pedestrian crossings when conflicting traffic may impact pedestrian safety. Ideally, every signalized intersection with pedestrian walk indications should have a pedestrian countdown signal head. Countdown signals are indications designed to begin counting down at the beginning of the clearance interval and can be on fixed time, push-button operation, or use passive pedestrian detection. The MUTCD requires countdown pedestrian indications for all newly installed traffic signals where pedestrian walk indications are installed.

SAFETY BENEFITS

55% Reduction in pedestrian crashes.



Proven Safety Measure

ESTIMATED COST



\$750 per module

Source: NCHRP(926)

MODAL IMPACT



MOTORIST

- » Improves safety and increases awareness of the signal phase.
- » Minor delays can be expected to incorporate appropriate pedestrian signal timing, especially at large signalized intersections.



BICYCLIST

- » Impacts could be similar to motorists or pedestrians depending on the location and direction of bicycle travel.



PEDESTRIAN

- » More informative about the signal phase timing than traditional “walk/don’t-walk” indications.



LARGE
TRUCKS

- » Similar impact to motorists.

→ APPLICABLE CONTEXT

Pedestrian countdown timers are required any time a new pedestrian walk indication is installed.

→ COMPLEMENTARY COUNTERMEASURES

Required

- » Curb Ramps
- » High Visibility Crosswalk

Optional

- » Bulb-outs
- » Raised Crosswalk
- » Reduce Corner Radius
- » Lighting
- » Parking Removal
- » Pedestrian Actuation

→ MITIGATED CRASH TYPES



Pedestrian failed to yield



Pedestrian dash



Motorist left turn into pedestrian parallel path

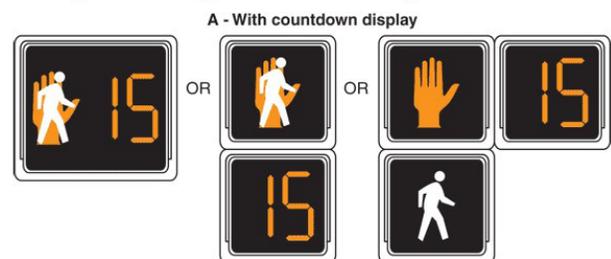


Motorist right turn into pedestrian parallel path

→ CONSIDERATIONS

- » Pedestrian countdown signals should be recognizable to pedestrians at all distances from the beginning of the crosswalk to a point 10 feet from the end of the controlled crosswalk during both day and night.
- » Quick feedback to a pedestrian pushbutton should be programmed into the system; excessive delay encourages noncompliance.
- » Supplemental nonvisual guidance for pedestrians with sensory restrictions should be provided.
- » The total of the walk interval and pedestrian clearance time should allow a pedestrian entering the crosswalk at the beginning of the walk indication enough time to travel to the end of the crosswalk while walking at a speed of 3 feet per second.

Figure 4E-1. Typical Pedestrian Signal Indications



Source: MUTCD

Additional Information & Resources

- » Crash Modification Factors Clearinghouse: <http://www.cmfclearinghouse.org/detail.cfm?facid=5273>
- » Manual on Uniform Traffic Control Chapter 4
- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)

LEADING PEDESTRIAN/BIKE INTERVAL



Chicago, Illinois

source: Bike Uptown (Chicago) / Arline Welty

Leading pedestrian intervals (LPIs) provide pedestrians a head start when crossing at a signalized intersection. LPIs can be easily programmed into existing signals to give pedestrians the WALK signal 3 to 7 seconds before motorists are allowed to proceed through the intersection. This extra time provides pedestrians with an opportunity to establish their presence in the crosswalk before motorists start turning and provides additional crossing time for those who need it. LPIs can be provided automatically with each phase or provided only when actuated (actively or passively). Leading Bicycle Intervals (LBIs) have the same principles and can be applied to bicycle signals in the same manner.

SAFETY BENEFITS

60% Reduction in pedestrian crashes.



Proven Safety Measure

ESTIMATED COST



Minimal

If pedestrian infrastructure is already in place there are little to no costs associated with this treatment

MODAL IMPACT



MOTORIST » Allows motorists to identify crossing pedestrians faster and easier.
» May increase delay.



BICYCLIST » Increases safety by improving visibility to motorists.



PEDESTRIAN » Increases safety by improving visibility to motorists.



LARGE TRUCKS » Similar impact to motorists.

→ APPLICABLE CONTEXT

Leading pedestrian intervals (LPIs) are applicable at signalized intersections with medium to high levels of turning motorists and crossing pedestrians. This countermeasure is also relevant in areas where the typical walking speed of a pedestrian may be slower than 3 feet per second like schools, parks, and senior facilities.

This treatment may be beneficial at locations with low pedestrian demand where signals are semi-actuated or fully actuated. Short minimum green times result in motorists expecting a limited amount of time to enter a main road, resulting in conflicts with pedestrians when they are present.

Leading Bicycle Intervals (LBIs) are applicable on highly used bicycle routes where infrastructure already exists or is planned.

→ CONSIDERATIONS

- » LPIs may be less effective when used at intersections without right turn on red light restrictions.
- » The LPI should be accompanied by an audible noise to inform visually-impaired pedestrians that it is safe to cross.
- » If an intersection has such high pedestrian volumes that motorists are unable to turn across the crosswalk, the green interval for the parallel concurrent vehicle traffic can be set to extend beyond the pedestrian interval to provide turning drivers with sufficient green time to make their turns.
- » LBIs are highly effective in at locations with separated bike lanes, contraflow bike lanes, and transitions from cycle tracks to on street bike lanes.
- » Select intersections in Grand Forks, North Dakota have implemented LPIs.

→ MITIGATED CRASH TYPES



Motorist right turn into pedestrian parallel path



Motorist right turn into bicyclist parallel path



Motorist left turn into pedestrian parallel path



Motorist left turn into bicyclist opposite direction

→ COMPLEMENTARY COUNTERMEASURES

Required

- » Curb Ramps
- » High Visibility Crosswalk
- » Pedestrian Detection
- » Bicycle Signal (LBIs)

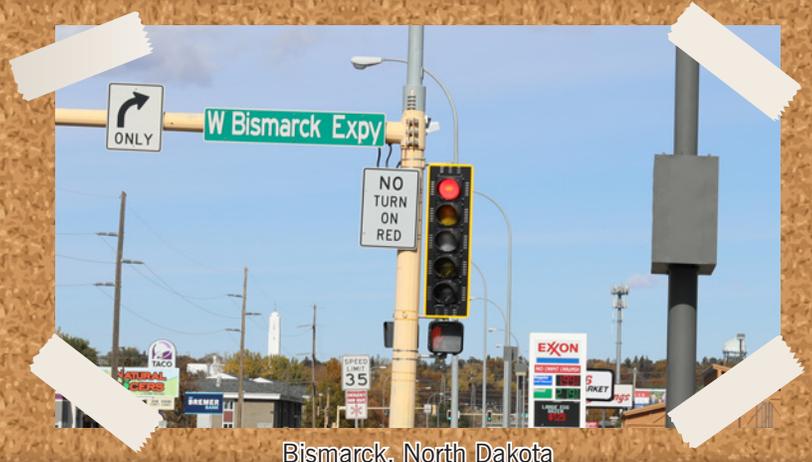
Optional

- » No Turn on Red Signs
- » Bulb-outs
- » Raised Crosswalk
- » Reduce Corner Radius
- » Lighting
- » Parking Removal
- » Bicycle Detection (LBIs)
- » Bike Boxes
- » Bicycle Lane Extension Through Intersection

Additional Information & Resources

- » Crash Modification Factors Clearinghouse
<http://www.cmfclearinghouse.org/detail.cfm?facid=9891>
<http://www.cmfclearinghouse.org/detail.cfm?facid=9918>
- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)

TURN RESTRICTIONS



Bismarck, North Dakota

Turn restrictions can enhance safety at intersections by prohibiting turning maneuvers that are considered high risk or have a crash history. Eliminating turning movements can be accomplished through physical infrastructure (channelization), signing, and traffic signal indications. At unsignalized locations channelization is almost exclusively used to restrict turns. Signalized intersections more commonly use signing and signal elements. Where channelization is not used, this strategy can be applied during certain periods of the day. The most common type of turn restriction for signalized intersections is to restrict right turns on red with a posted sign. Left turns may be completely prohibited or restricted to a protected only phase for a certain time of day or when a pedestrian calls for a walk indication (known as a Pedestrian Omit Flashing Yellow Arrow (POOFYA)).

SAFETY BENEFITS

30% Reduction in right angle crashes (No-Turn on Red Signs)

20% Reduction in rear end crashes (No-Turn on Red Signs)

28% Reduction in pedestrian crashes (protected left turn phases)

ESTIMATED COST



\$200 per sign

Source: NCHRP (926)

Dynamic right turn signs and may cost up to \$3,000. Other signal work may cost up to \$50,000.

MODAL IMPACT



MOTORIST » Reduced conflicts with other motorists, pedestrians, and bicyclists.
» Possible reduced mobility and increased delay.



BICYCLIST » Increased safety from reduced conflicts with motorists.



PEDESTRIAN » Increased safety from reduced conflicts with motorist during walk phase.



LARGE TRUCKS » Reduced conflicts with other motorists, pedestrians, and bicyclists.
» Possible reduced mobility and increased delay.

→ APPLICABLE CONTEXT

Turn restrictions have varying crash reduction results based on the application of the countermeasure. Therefore, in order to achieve a safety benefit this countermeasure should only be applied where specific conflicts with turns create high risk situations.



Source: MUTCD

Grand Forks, North Dakota

→ CONSIDERATIONS

- » Dynamic signs can be used to restrict turns during certain times of day or during certain signal phases; for example, vehicle right turns may be restricted during a bike signal phase or during specific peak hours.
- » A common concern that comes up when restricting right turns on red is that this can lead to higher right turn on green conflicts with pedestrians and motorists traveling in a parallel direction. The use of a leading pedestrian interval (or leading bicycle interval) or all walk phase can address this issue.

→ MITIGATED CRASH TYPES



Motorist left turn into pedestrian parallel path



Motorist left turn into bicyclist opposite direction



Motorist failed to yield to pedestrian



Motorist right turn into pedestrian parallel path.
With all walk phase only.

Otherwise this crash type may increase



Motorist right turn into bicyclist parallel path.
With dedicated bike phase only.

Otherwise this crash type may increase

→ COMPLEMENTARY COUNTERMEASURES

Optional

- » Leading Pedestrian Interval
- » Leading Bicycle Interval
- » Bicycle Lane Extension Through Intersection
- » Bicycle Signal
- » Lighting
- » All Walk Phase

Additional Information & Resources

- » National Association of Transportation Officials (NACTO): <https://nacto.org/publication/transit-street-design-guide/intersections/signals-operations/turn-restrictions/>
- » Federal Highway Administration (FHWA): https://safety.fhwa.dot.gov/intersection/other_topics/fhwasa08008/sa3_restrict_eliminate_turns.pdf
- » Manual on Uniform Traffic Control Chapter 2
- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)

BICYCLE LANE EXTENSION THROUGH INTERSECTION



Missoula, Montana

Image Source: NACTO

Bicycle lane extension pavement markings through intersections are intended to provide bicyclists with a clear, highly visible pathway through an intersection and create a safer bicycling environment. They help to alert motorists to the presence of bicycle through-traffic and encourage turning motorists to yield. The pavement within the bicycle lane extension can include green color. The color may be applied with paint, durable liquid pavement markings, thermoplastic, or colored asphalt.

SAFETY BENEFITS

20% Increase in motorist yielding.

10% Reduction in total crashes.

19% Reduction in bicycle crashes.

ESTIMATED COST



\$200-\$1,500

source: NCHRP (926)

MODAL IMPACT



MOTORIST » Increased awareness of bicyclists and clarification of right of way.



BICYCLIST » Reduction of conflicts with motorists and increased safety due to driver awareness.
» Helps reduce right turn into bicyclist parallel path crashes which often result in injury.



PEDESTRIAN » May increase motorist awareness of adjacent pedestrian crossing.



LARGE TRUCKS » Increased awareness of bicyclists and clarification of right of way.

→ COMPLEMENTARY COUNTERMEASURES

Required

- » Appropriate Signing
- » Appropriate Pavement Markings

Optional

- » Passive Bicycle Detection
- » Leading Bike Interval
- » Bike Signals
- » No Turn on Red Signs
- » Bike Boxes
- » Two Stage Bicycle Turn Queue Boxes
- » Mixing Zones

→ APPLICABLE CONTEXT

This countermeasure is applicable at locations with bicycle lanes where it is desired to delineate the bicycle crossing, where turning motorists cross through moving bicyclists, and at wide or complex intersections where the bicyclist path is unclear. This may be especially effective along major bike routes and regional trails.

→ CONSIDERATIONS

- » Long term maintenance cost should be considered prior to installation. Local weather conditions, marking placement, and marking material will affect pavement marking durability.
- » Since the effectiveness of markings depends entirely on their visibility, maintaining markings should be a high priority.
- » Different types of markings may increase visibility within conflict areas or across entire intersections. Examples are in the image below.

→ MITIGATED CRASH TYPES



Motorist left turn into bicyclist opposite direction



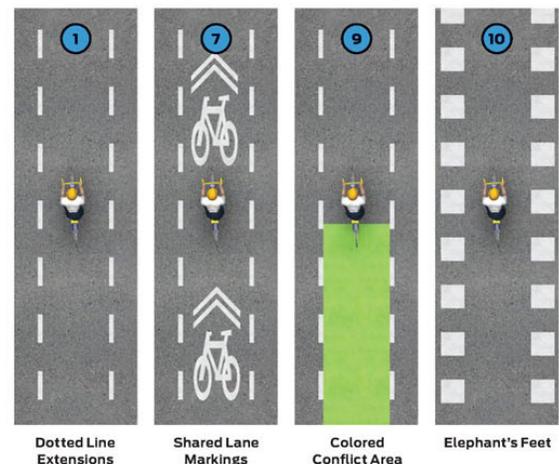
Motorist right turn into bicyclist parallel path



Bicyclist crossing path with uncontrolled motorist



Bicyclist ride through/out signalized intersection



Dotted Line Extensions

Shared Lane Markings

Colored Conflict Area

Elephant's Feet

Source: NACTO

Additional Information & Resources

- » National Association of Transportation Officials (NACTO):
<https://nacto.org/wp-content/uploads/2010/08/Safety-effects-of-blue-cycle-crossings.pdf>
<https://nacto.org/wp-content/uploads/2010/08/Evaluation-of-Blue-Bike-Lane-Treatment.pdf>
<https://nacto.org/publication/urban-bikeway-design-guide/intersection-treatments/intersection-crossing-markings/>
- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)

BICYCLE SIGNALS



Saint Paul, Minnesota

Image Source: Google Earth

Bicycle signal heads are similar to conventional traffic signals. However, rather than red, yellow and green “balls,” the signal heads use red, yellow, and green bike icons. These lights are actuated in the same way as traditional traffic lights. Bicycle signals are necessary to indicate a leading or protected phase for bicycle movements. This may sometimes require an additional phase be added to the traffic signal cycle.

SAFETY BENEFITS

Undetermined

Currently there is limited information that quantifies the effectiveness of passive bicycle detection. Improved detection for bicyclists has deterred red light running and other unsafe behaviors when installed. This reduces delay for bicycles at signalized intersections and increases confidence that they would be detected and therefore a creates greater willingness to wait through the red.

ESTIMATED COST



\$5,000-\$10,000

Source: NCHRP (926)

MODAL IMPACT



MOTORIST » Increases safety and interactions with bicyclists.
» May increase delay depending on signal timing.



BICYCLIST » Increased bicycle signal compliance.
» Ensures bicyclists needs are served during the signal cycle and reduces delay.



PEDESTRIAN » None



LARGE TRUCKS » Increases safety and interactions with bicyclists.
» May increase delay depending on signal timing.

→ COMPLEMENTARY COUNTERMEASURES

Required

- » Appropriate Signing
- » Appropriate Pavement Markings
- » Bike Lanes

Optional

- » Passive Bicycle Detection
- » Leading Bike Interval
- » Bike Boxes
- » Bicycle Lane Extension Through Intersection
- » Two Stage Bicycle Turn Queue Boxes

→ APPLICABLE CONTEXT

This treatment is generally better suited for spot treatments at intersections that are complicated for bicyclists to navigate, intersect a primary bicycle route, and have high bicycle volumes. An exception to this is where agencies want to create a “green wave” effect by timing bicycle signals along a corridor to allow bicyclists to move through intersections at a consistent speed.

→ CONSIDERATIONS

- » This treatment has been given interim approval to use by FHWA if used for protected bicycle phases, but is not included in the 2009 MUTCD. FHWA requires an agency to request permission to install a bicycle signal to apply a leading phase.
- » The addition of separated or exclusive bicycle signal phases can increase delay for all users at the intersection, which may decrease compliance. As such, each intersection should be studied carefully to balance the safety and operational needs of pedestrians, bicyclists, and motorists.
- » The signal should be installed with actuation and appropriate detection for bicyclists.
- » Consider bicyclists’ movements when selecting minimum green times and clearance intervals due to slower speeds and start-up times.

→ MITIGATED CRASH TYPES



Motorist left turn into bicyclist opposite direction



Motorist right turn into bicyclist parallel path



Bicyclist ride through/out signalized intersection

Additional Information & Resources

- » National Association of Transportation Officials (NACTO): <https://nacto.org/publication/urban-bikeway-design-guide/bicycle-signals/bicycle-signal-heads/>
- » Bike Safe: http://pedbikesafe.org/bikesafe/countermeasures_detail.cfm?CM_NUM=55
- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)

PASSIVE BICYCLE DETECTION



Portland, Oregon

Image Source: NACTO

At signalized intersections that require users to be detected to actuate a signal, detection should be designed to accommodate bicyclists. Passive detection (i.e., when the signal system automatically detects the presence of the user) is considered best practice where feasible. Loop detectors, commonly used for motorist detection, can also be used to detect bicyclists. Other passive detection devices include video and microwave detection. Bicycle detection devices can be used to call a phase or to prolong the phase to allow a bicyclist to clear an intersection. Pavement markings and/or signs should be used to notify bicyclists of the proper bicycle detection location.

SAFETY BENEFITS

Undetermined

Currently there is limited information that quantifies the effectiveness of passive bicycle detection. Improved detection for bicyclists has deterred red light running and other unsafe behaviors when installed. This reduces delay for bicycles at signalized intersections and increases confidence that they will be detected and therefore creates greater willingness to wait through the red.

ESTIMATED COST



\$1,000-\$9,000

source: NCHRP (926)

MODAL IMPACT



MOTORIST

» Improves safety and interactions with bicycles by improving compliance with traffic signals.



BICYCLIST

» Increased bicycle signal compliance.
» Ensures bicyclists needs are served during the signal cycle and reduces delay.



PEDESTRIAN

» None



LARGE TRUCKS

» Improves safety and interactions with bicycles by improving compliance with traffic signals.

→ COMPLEMENTARY COUNTERMEASURES

Required

- » Appropriate Signing
- » Appropriate Pavement Markings
- » Bike Lanes

Optional

- » Bicycle Signals
- » Leading Bike Interval
- » Bike Boxes
- » Bicycle Lane Extension Through Intersection
- » Two Stage Bicycle Turn Queue Boxes

→ APPLICABLE CONTEXT

Passive bicycle detection is applicable at signalized intersections that are designed or optimized in a way that all users must be detected to actuate the appropriate signal phase. This countermeasure is particularly important at locations where the minimum green has been established to serve motorists and may not be long enough to serve bicyclists.

→ CONSIDERATIONS

- » Combining passive bicycle detection with detection confirmation lights or active detection (buttons) may improve compliance by assuring bicyclists that they have been detected.
- » It may be appropriate to install advanced bicycle detection on the approach to the intersection to extend the phase, or to prompt the phase and allow for continuous bicycle through movements.
- » It is important that the design of loop detectors consider the amount of metal in typical bicycles. Certain types of loop configurations are better at detecting bicyclists than others.
- » Signal timing should be adjusted to account for the unique operating characteristics of bicycles.
- » Detection should be located in the most conspicuous and convenient location.
- » Supplement detection with appropriate signs and pavement markings to inform bicyclists where to wait.

→ MITIGATED CRASH TYPES



Motorist left turn into bicyclist opposite direction



Motorist right turn into bicyclist parallel path



Bicyclist ride through/out signalized intersection

Additional Information & Resources

- » Bike Ped Safe: http://pedbikesafe.org/bikesafe/countermeasures_detail.cfm?CM_NUM=36
- » Manual on Uniform Traffic Control Chapter 4
- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)

TWO STAGE BICYCLE TURN QUEUE BOXES



Portland, Oregon

Image Source: NACTO

A two stage queue box (also known as a Copenhagen Left or jug handle turn) is an area set aside for bicyclists at a signalized intersection outside of the traveled path of motor vehicles. When using a two stage bicycle turn box to make a left turn, a bicyclist would proceed on a green signal indication to the turn box on the right hand side of the travel lanes, and then turn left within the turn box and wait for the appropriate signal indication on the cross street to proceed. In addition to mitigating conflicts inherent in merging across traffic to turn, two stage bicycle turn boxes reduce conflicts between bicycles and pedestrians and separate queued bicyclists waiting to turn from through bicyclists moving on the green signal.

SAFETY BENEFITS

Undetermined

Currently there is limited information that quantifies the effectiveness of bike boxes. Studies indicate that cyclists are able to make more comfortable left turns and conflict points are reduced between motorists and other bicyclists.

ESTIMATED COST



\$1,000 per box

source: NCHRP (926)

MODAL IMPACT



MOTORIST

- » Clarifies right of way and improves yield rates to bicyclists.
- » Restricts right turns on red and may increase delay.



BICYCLIST

- » Increases safety and visibility to motorists but may increase delay.
- » Improves mobility by allowing a head start against motorists.



PEDESTRIAN

- » May increase safety by reducing vehicle encroachment on the crosswalk.



LARGE TRUCKS

- » Clarifies right of way and improves yield rates to bicyclists.
- » Restricts right turns on red and may increase delay.

→ COMPLEMENTARY COUNTERMEASURES

Required

- » Appropriate Signing
- » Appropriate Pavement Markings
- » Bike Lanes
- » No Turn on Red Signs

Optional

- » Bicycle Signals
- » Leading Bike Interval
- » Bike Boxes
- » Passive Bicycle Detection
- » Bicycle Lane Extension Through Intersection

→ CONSIDERATIONS

- » While two stage turns may increase bicyclist comfort in many locations, this configuration typically results in increased delay for bicyclists. Bicyclists now need to receive two separate green signal indications to turn.
- » The queue box shall be placed in a protected area. Typically this is within an on street parking lane or between the bicycle lane and the pedestrian crossing.
- » Colored paving inside of the queuing area should be used to further define the bicycle space.
- » Markings across intersections should be used to define through bicyclist positioning.
- » At mid-block turning locations, the queue box may be integrated into the sidewalk space. This configuration is also known as a “jug handle.”

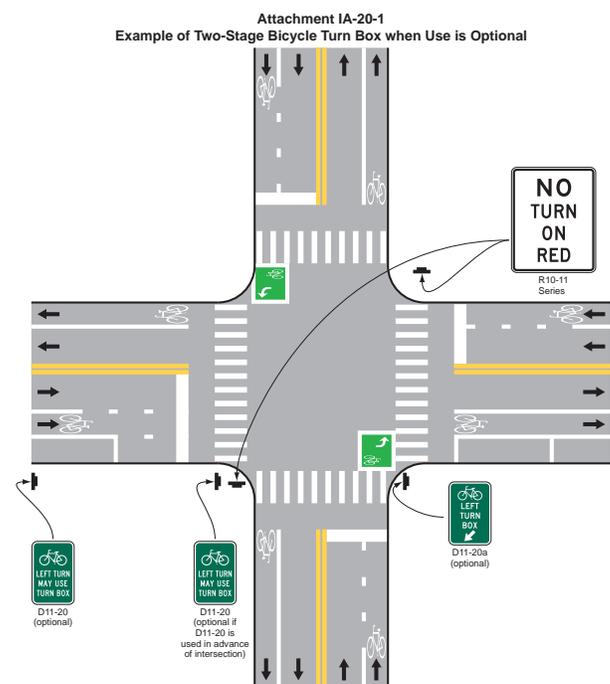
→ APPLICABLE CONTEXT

This countermeasure may be useful at locations where bicyclists would have to merge across multiple lanes of traffic, would have to wait in a shared travel lane with motorists to turn, or at locations with separated bike lanes or side paths where it is not possible for bicyclists to merge into motor vehicle lanes in advance of the intersection. An agency should request permission to experiment from FHWA to use this treatment as it is not approved for use.

→ MITIGATED CRASH TYPES



Motorist right turn into bicyclist parallel path



Source: FHWA

Additional Information & Resources

- » National Association of Transportation Officials (NACTO): <https://nacto.org/publication/urban-bikeway-design-guide/intersection-treatments/two-stage-turn-queue-boxes/>
- » Manual on Uniform Traffic Control Chapter Interim Approval IA-20: https://mutcd.fhwa.dot.gov/resources/interim_approval/ia20/index.htm
- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)

BIKE BOXES



Milwaukee, Wisconsin

Image Source: Urban Milwaukee News

Bike boxes provide space for bicyclists to position themselves in front of vehicles while stopped at a signalized intersection. This treatment provides a predictable place for bicyclists to stop and wait at a signal, allowing them to get out ahead of traffic at the onset of a green signal. Bike boxes are intended to reduce the likelihood of a right turn into bicyclist parallel path collisions at the onset of a green light. In addition to increasing the visibility and predictability of bicyclists, bike boxes provide priority for bicyclists by allowing them to come to the front of the queue.

SAFETY BENEFITS

Undetermined

Currently there is limited information that quantifies the effectiveness of bike boxes. Many studies conclude that cyclists are able to position themselves in front of the traffic thus reducing the risk of conflict with right turning vehicles. Additionally it has been observed that motorists give bicyclists the right-of-way more often with the presence of a bicycle box.

ESTIMATED COST



\$5,000 per box

source: NCHRP(926)

MODAL IMPACT



MOTORIST

- » Clarifies right-of-way and improves yield rates to bicyclists.
- » Restricts right turns on red and may increase delay.



BICYCLIST

- » Increases safety and visibility to motorists.
- » Improves mobility by allowing a head start against motorists and may decreased delay.



PEDESTRIAN

- » May increase safety by reducing vehicle encroachment on the crosswalk.



LARGE TRUCKS

- » Clarifies right-of-way and improves yield rates to bicyclists.
- » Restricts right turns on red and may increase delay.

→ APPLICABLE CONTEXT

Bike boxes are applicable at signalized intersections with medium to high volumes of bicyclists and motor vehicles. This countermeasure can be highly effective where there are large amounts of queuing bicyclists, heavy vehicles, and combination of turning motorists and straight traveling bicyclists.

→ COMPLEMENTARY COUNTERMEASURES

Required

- » Appropriate Signing
- » Appropriate Pavement Markings
- » Bike Lanes
- » No Turn on Red Signs

Optional

- » Bicycle Signals
- » Leading Bike Interval
- » Two Stage Bicycle Turn Queue Boxes
- » Passive Bicycle Detection
- » Bicycle Lane Extension Through Intersection

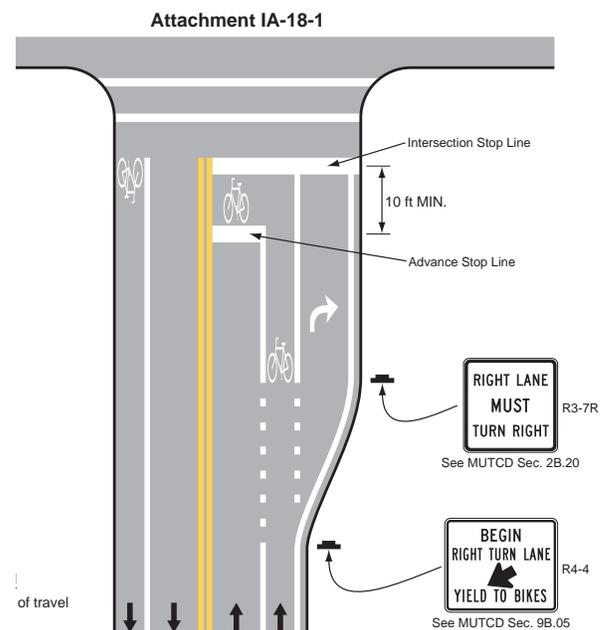
→ MITIGATED CRASH TYPES



Motorist right turn into bicyclist parallel path

→ CONSIDERATIONS

- » This treatment has been given interim approval to use by FHWA, but is not included in the 2009 MUTCD.
- » A box formed by transverse lines shall be used to hold queuing bicyclists, typically 10-16 feet deep. Deeper boxes show less encroachment by motor vehicles.
- » Boxes may be disregarded by motorists if not commonly filled by bicyclists and properly signed.
- » Bike boxes that extend across the entire approach can greatly ease the transition for left turning bicyclists.
- » Stop lines shall be used to indicate the point behind which motor vehicles are required to stop (up to 7 feet behind the bike box).
- » Colored pavement should be used as a background color within the bike box to encourage compliance by motorists



Source: FHWA

Additional Information & Resources

- » National Association of Transportation Officials (NACTO): <https://nacto.org/publication/urban-bikeway-design-guide/intersection-treatments/bike-boxes/>
- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)

MIXING ZONE TREATMENTS



Billings, Montana

Image Source: NACTO

Mixing zones are locations within intersections where bicyclists transition into a shared motor vehicle turn lane from a bicycle lane. This design is intended to reduce the speed of turning vehicles and allow bicyclists to avoid being on the turning side of a vehicle which could result in a right turn into bicyclist parallel path crashes. The shared lane requires turning motorists to enter or cross the bicyclist's travel path, mixing bicycles with motor vehicles. A key feature of a mixing zone is the provision of a constrained merging location where motorists merge across the bicycle lane. Mixing zones are often used in situations where right of way is limited and it is infeasible or cost-prohibitive to build a protected intersection or maintain a continuous bicycle lane. Mixing zones should encourage motorists to yield to bicyclists, reduce motor vehicle speed within the shared turn lane, and reduce the risk crashes.

SAFETY BENEFITS

27% Reduction in bicycle injury crashes.

ESTIMATED COST

\$

\$500-\$2,000

source: NCHRP(926)

MODAL IMPACT



MOTORIST » Increased awareness of bicyclists. Some confusion of right of way may lead to unpredictable interactions between motorists and bicyclists.



BICYCLIST » Increased safety and improved visibility to motorists. Some confusion of right of way may elevate stress level when compared to dedicated facilities.



PEDESTRIAN » None



LARGE TRUCKS » Similar impact to motorists. With a larger vehicle size sharing the space with a bicyclist becomes more risky.

→ APPLICABLE CONTEXT

Mixing Zones are typically a compromise at intersections with roadway bike infrastructure that is constrained by right of way. This treatment may not be appropriate at intersections with very high peak automobile right-turn demand.

→ COMPLEMENTARY COUNTERMEASURES

Required

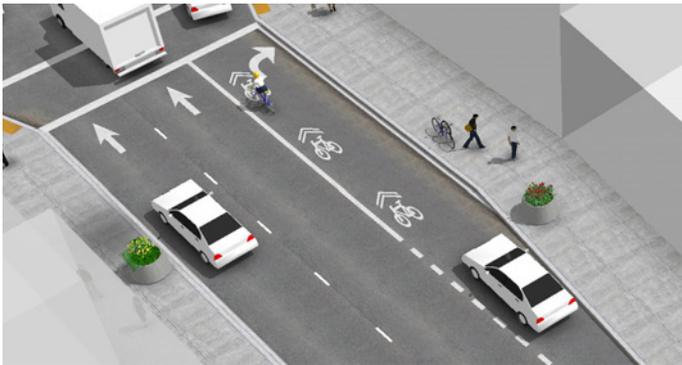
- » Appropriate Signing
- » Appropriate Pavement Markings
- » Bike Lanes

Optional

- » Colored/Textured Pavement

→ CONSIDERATIONS

- » Guides bicyclists to ride in part of the turning lane, which tends to have lower speed traffic than the adjacent through lane, allowing higher speed through traffic to pass unimpeded.
- » It is usually not clear who has the right-of-way between turning drivers and people bicycling through the intersection. This lack of clarity may lead to additional traffic conflicts, stress, and assertive driving and bicycling behaviors.
- » The shared space in advance of intersection can increase bicyclist stress levels. The design creates unpredictable bicycle movements.
- » Reduces motor vehicle speed within the right turn lane.
- » Some form of bicycle marking shall be used to clarify bicyclist positioning within the combined lane



→ MITIGATED CRASH TYPES



Motorist right turn into bicyclist parallel path



Source: NACTO

Additional Information & Resources

- » National Association of Transportation Officials (NACTO): <https://nacto.org/publication/urban-bikeway-design-guide/intersection-treatments/combined-bike-laneturn-lane/>
- » New York City Department of Transportation: <https://www1.nyc.gov/html/dot/downloads/pdf/cycling-at-a-crossroads-2018.pdf>
- » NCHRP (926) Guidance to Improve Pedestrian and Bicyclist Safety at Intersections (2020)

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