SAFER ROADS SAVE LIVES

TRAFFIC CONTROL DEVICE INNOVATIONS TO IMPROVE PEDESTRIAN AND BICYCLE SAFETY AT SIGNALIZED INTERSECTIONS

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Overview

Reducing traffic fatalities is a top priority for transportation agencies at all levels of government throughout the United States. In 2016, a total of 37,987 individuals were killed in motor vehicle crashes, including 5,987 pedestrians and 840 bicyclists. To meet this challenge, agencies are continuously exploring new methods to reduce conflicts between motorists and non-motorists. Crossing signalized intersections can be especially problematic to pedestrians and bicyclists due to the large number of conflict points, high traffic volumes and speeds, and long walking times required to traverse a crosswalk.

This publication presents eight case studies of innovative traffic control devices designed to improve pedestrian and bicycle safety at signalized intersections. These case studies describe strategies adopted by transportation agencies to improve the ability of non-motorists to travel safely through signalized intersections by raising the visibility of pedestrians and bicyclists to motorists and maintaining the physical separation between motorists and non-motorists. This publication also describes several emerging technology applications designed to improve pedestrian and bicyclist safety. These emerging technologies include the latest research and development of materials, systems, and products to improve communication between motorists and non-motorists in real time.

Safe travel through signalized intersections requires the diligence and cooperation of both motorists and non-motorists. No device can eliminate all human error, attention lapses, or imprudent behaviors. However, effectively designed, and properly installed and operated infrastructure can contribute greatly to reducing risks associated with vehicle and non-vehicle conflicts, especially at signalized intersections.

The materials presented will hopefully spur thinking to continue the development of new methods as well as the innovative application of more traditional approaches to addressing signalized intersection safety. ■

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Introduction

The elimination of highway fatalities is among the highest priorities for the nation's transportation agencies. Agencies under the U.S. Department of Transportation (USDOT) have adopted a vision committed to the elimination of all highway fatalities within 30 years, and many states and local governments have adopted similar visions striving for the elimination of traffic fatalities. While most fatal crashes involve only motorized modes, a significant number also involve non-motorized modes including walking and bicycling.

Table 1 presents the annual number of motor vehicle, pedestrian, and bicyclist fatalities over the 10-year period from 2007 to 2016. In 2016, 5,987 pedestrians and 840 bicyclists were killed in motor vehicle crashes, and an additional 70,000 pedestrians and 45,000 bicyclists were injured.[1] Pedestrian fatalities accounted for 16 percent of all fatalities, and bicyclist fatalities represented 2 percent of all fatalities in 2016. The 5,987 pedestrian fatalities in 2016 were a 9 percent increase from 5,495 pedestrian fatalities in 2015. The 840 bicyclist fatalities in 2016 were a 3 percent increase over the 818 fatalities in 2015 and a 15 percent increase over the 729 fatalities in 2014.

Between 2010 and 2015, the most common pedestrian action prior to pedestrian fatalities was failure to yield the right of way (30.6 percent); followed by in the roadway improperly (e.g., standing, lying, working) (18.8 percent); not visible (18.6 percent); improper crossing of roadway or intersection (17.7 percent); and dart/dash (16.4 percent). The most common bicyclist action prior to bicyclist fatalities was failure to yield right of way (34.9 percent); no improper action (25.7 percent); and not visible (12.1 percent).[2] These statistics suggest that controlling the right of way and effectively directing motorist and nonmotorist actions is critical to improving safety at signalized intersections.

The act of safely crossing a roadway as a motorist, pedestrian, or bicyclist requires the successful execution of several steps. Upon approaching a signalized intersection, motorists, pedestrians, and bicyclists must assess the conditions and determine the availability of supporting infrastructure, including signs, signals, and markings, designed to direct where, when, and how to safely cross the intersection. This infrastructure is designed to reduce the risk of a conflict between motorists and non-motorists by gaining attention, providing guidance, and directing behavior required to avoid collisions.

Table 2 presents a summary of various pedestrian and safety-improvement strategies that can be applied at signalized intersections. Motorist and non-motorist conflicts at signalized intersections are managed by installing crosswalk markings; regulatory or warning signs; and pedestrian or bicycle traffic signals. In addition, pedestrian and bicycle conflicts with motorized vehicles are controlled through traffic signal timing strategies such as leading pedestrian or bicycle intervals, exclusive pedestrian or bicycle phases, and extended walk times. Curb extensions, barriers, and islands can be used to restrict movements, reduce walking distances or to provide shelter for pedestrians and bicyclists crossing particularly wide or complex roadways.

Table 1.
Total Fatalities, Pedestrian Fatalities, and Bicyclist Fatalities, 2007-2016

Year	Total Fatalities	Pedestrian Fatalities		Bicyclist Fatalities	
		Fatalities	%	Fatalities	%
2007	41,259	4,699	11%	701	2%
2008	37,423	4,414	12%	718	2%
2009	33,883	4,109	12%	628	2%
2010	32,999	4,302	13%	623	2%
2011	32,479	4,457	14%	682	2%
2012	33,782	4,818	14%	734	2%
2013	32,893	4,779	15%	749	2%
2014	32,744	4,910	15%	729	2%
2015	35,485	5,495	15%	818	2%
2016	37,461	5,987	16%	840	2%

[1] National Highway Traffic Safety Administration. *Traffic Safety Fact Sheets 2015.*
[2] National Highway Traffic Safety Administration. *Pedestrian and Bicyclist Data Analysis.* March 2018.

Table 2.
Strategies to Improve Pedestrian and Bicycle Safety at Signalized Intersections

Strategy	Examples
Traffic Signal Enhancements	• Automatic pedestrian detectors • Providing larger traffic signals to ensure visibility • Placing signals so that motorists waiting at a red light can't see the other signals and anticipate the green • Installing countdown signals to provide pedestrians with information about the amount of time remaining in a crossing interval
Traffic Signing	• Provide motorists with advance warning of an upcoming pedestrian crossing or that they are entering a traffic-calmed area alerting them to modify their speed
Pavement Marking	• Install striping in a pedestrian crosswalk • Highlight pedestrian and bicycle lanes
Intersection Median Barriers	• Shortened version of a raised curb median extends through the intersection to prevent cross-street through movements and left-turning movements to cross streets from the main street • Crossing islands. Cut-throughs must be incorporated into the design for pedestrian and bicyclist use

Ultimately, safe travel through signalized intersections requires the diligence and cooperation of both motorists and non-motorists. No device can eliminate all human error, attention lapses, or imprudent behaviors. However, effectively designed and properly installed and operated infrastructure can contribute greatly to reducing risk associated with vehicle and non-vehicle conflicts. Safety researchers, traffic engineers, device makers, and deployers continue to evolve infrastructure to advance the goal of safety for all travel by alerting travelers to potential risks; guiding travelers through protected pathways; and directing travelers where, when, and how to use or yield the right of way.

The discussions presented in this publication are not meant to be exhaustive. Rather, the goal is to provide examples that will spur thinking, discussions, and innovative applications to assist in developing strategies to address the critical need to reduce pedestrian and bicyclist fatalities. ■

Slow Left-Turn Wedge – City of New York

Introduction

The New York City Department of Transportation (NYC DOT) conducted the Left-Turn Pedestrian and Bicycle Crash Study to advance New York City's Vision Zero[3] initiative. Analysis of city-wide crash data indicated that left turns account for more than twice as many pedestrian and bicyclist fatalities as right turns, and more than three times as many serious injuries and fatalities. Furthermore, data analysis revealed that 80 percent of the locations experiencing a left-turn pedestrian or bicycle injury had a signalized approach and 70 percent involved a one-way street. In addition, injuries to pedestrians and bicyclists typically occurred where the:

- Vehicle was coming from the minor approach;
- Receiving street was 60 feet or wider;
- Vehicle was coming from a one-way street; and
- Receiving street was a two-way street.

Left turns are more dangerous than right turns, as left turns can be taken at a wider radius, which leads to higher speeds and greater pedestrian exposure. In addition, when executing a left turn, the driver's visibility is partially obscured by parked cars and the vehicle's A pillar (or the first pillar of the car that holds the windshield). Finally, left turns are more complicated than right turns and require more mental and physical effort ("driver workload") than right turns.

Left-Turn Traffic Calming

To address left-turn pedestrian and bicycle crashes, city traffic engineers evaluated several strategies, including: left-turn restrictions; installing left-turn bays and protected bicycle lanes; and modifying signal timing and phasing to include left-turn-only phases and leading pedestrian intervals (LPI).

Analysis of crash data after deployment of these strategies demonstrated their effectiveness in reducing left-turn pedestrian and bicycle crashes:

- Left-turn restrictions reduced left-turn bicycle and pedestrian injuries by 41 percent, and total injuries fell by 21 percent;
- Installation of left-turn bays reduced left-turn pedestrian injuries by 24 percent and total pedestrian injuries by 9 percent;
- Protected bicycle lanes reduced left-turn pedestrians and bicyclists killed or severely injured by 53 percent and total pedestrians and bicyclists killed or severely injured by 20 percent;
- Left-turn pedestrian and bicyclist injuries were reduced by 33 percent, and total pedestrian and bicyclist injuries were reduced by 25 percent when exclusive left-turn phases were added to traffic signal phasing;
- Left-turn pedestrian and bicycle injuries declined by 14 percent, and left-turn pedestrians and bicyclists killed or severely injured declined by 56 percent when LPIs were added to traffic signal phasing.

Slow Left-Turn Wedge

Another left-turn traffic calming method implemented by city traffic engineers was a slow left-turn wedge. Figure 1 portrays a slow turn wedge installation at a one-way to one-way street intersection. The design uses pavement markings and plastic delineators to restrict parking 10 feet from the curb and to outline the turning radius.

When combined with near-curb parking removal, the left-turn wedge improves the drivers' sight lines of pedestrians waiting at intersection curbs and pedestrians' sight lines of approaching cars, allowing pedestrians to make eye contact with drivers from the sidewalk. The use of a guiding radius tightens and calms the left turn, and modifying the turning angle from cross street onto receiving roadway creates safer, slower left turns with no change in traffic capacity.

Figure 1. One-way to one-way parking removal and slow turn wedge treatment (Photo Credit: New York City DOT)

[3] New York City Department of Transportation. *Left Turn Pedestrian and Bicyclist Crash Study.* August 2016.

Figure 2 presents a slow turn treatment for a one-way to two-way street movement. This treatment adds rubber curb with delineators on receiving two-way street centerline to plastic delineators and pavement striping on the exiting leg of the one-way street. The treatment consists of six pieces of rubber curb and bollards installed on the centerline starting from the crosswalk. The hardened centerline and guiding radius tighten and calm left turns for vehicles entering the two-way street.

Where left-turn traffic calming treatments have been implemented, median left-turn speeds have decreased by 19.9 percent. Average left-turn speeds have decreased by 20.5 percent. Eighty-fifth percentile left-turn speeds have decreased by 16.7 percent, and maximum left-turn speeds have decreased by 11.7 percent. Preliminary results show a 20 percent reduction in pedestrian injuries at these locations.

The cost of this treatment can range from several hundred to several thousand dollars. Maintenance costs include replacement of plastic bollards that may be struck by vehicles. A mountable rubber speed bump can be placed at the base of the hardened lane separator instead of concrete.

References

New York City Department of Transportation. *Left Turn Pedestrian and Bicyclist Crash Study.* August 2016. ■

Figure 2. One-way to two-way treatment (Photo Credit: Imagery @2018 Google)

Leading Pedestrian Interval Plus (LPI+) – City of Charlotte, North Carolina

Introduction

Adoption of a leading pedestrian interval (LPI) is a signal timing technique that can be considered at intersections with high pedestrian crossing volumes and a high volume of conflicting turning vehicles during the permissive phase of the signal cycle. As shown in Figure 3, LPI allows pedestrians to proceed into the crosswalk prior to any vehicles, making pedestrians more visible to drivers. LPIs are typically applied where both pedestrian volumes and turning volumes are high enough to warrant an additional dedicated interval for pedestrian-only traffic. However, implementation of an LPI may also be considered at suburban intersections with lower pedestrian volume but a clear conflict with turning vehicles. Where a bikeway on the through movement conflicts with turning traffic, incorporation of a leading bicycle interval (LBI) along with the LPI can be considered. An LBI clears the intersection of all cyclists quickly and can help prevent right-hook collisions, which occur when right-turning vehicles collide with bicyclists traveling straight through the intersection.

From the Manual on Uniform Traffic Control Devices (MUTCD):

> "If a leading pedestrian interval is used, it should be at least 3 seconds in duration and should be timed to allow pedestrians to cross at least one lane of traffic or, in the case of a large corner radius, to travel far enough for pedestrians to establish their position ahead of the turning traffic before the turning traffic is released. If a leading pedestrian interval is used, consideration should be given to prohibiting turns across the crosswalk during the leading pedestrian interval."[4]

LPIs have been shown to reduce pedestrian-vehicle collisions as much as 60 percent at treated intersections[5] and typically require adjustments to existing signal timing that are relatively low-cost compared with other countermeasures.

LPIs should give pedestrians a minimum head start of three to seven seconds, depending on the overall crossing distance. Intervals of up to 10 seconds may be appropriate where pedestrian volumes are high or the crossing distance is long. The installation of curb extensions, which increase the visibility of pedestrians, can increase the effectiveness of LPIs.[6]

Figure 3. LPI provides head start for pedestrians (Photo Credit: *Improving Walkability at Signalized Intersections with Signal Control Strategies*)

City of Charlotte, North Carolina

The city of Charlotte, North Carolina, advanced the concept of LPIs by employing a concept called "LPI+." The city has installed flashing yellow arrows (FYAs) at several intersections to hold right-turning traffic during 5- to 10-second LPIs. Charlotte tested the LPI+ concept by installing three right-turn FYAs at the intersection of Fairview Road and Sharon Road along with LED blank-out signs capable of displaying two messages at each approach: "No Turn on Red" and "Yield to Pedestrians" (Figure 4).

When a pedestrian activates a push button to cross the street, the blank-out displays a "No Turn on Red" display to two different approaches. One display is to the conflicting right-turn movement that will be stopped during the LPI with the FYA signal head. The other display is to the approach the pedestrian is crossing. This is to stop vehicles from encroaching in the crosswalk as they try to make right turns on red (Figure 5). The "No Turn on Red" continues to display along with a red indication for the right-turn lane until the "walk + flashing don't walk" time is completed. This gives a completely protected crossing for the pedestrian.

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[4] Federal Highway Administration. *Manual on Uniform Traffic Control Devices*. Section 4E.06 ¶22 and 23. 2009.

[5] A.C. Fayish and Frank Gross, "Safety effectiveness of leading pedestrian intervals evaluated by a before–after study with comparison groups," *Transportation Research Record No. 2198* (2010): 15–22.

[6] National Association of City Transportation Officials. *Urban Street Design Guide*.

Figure 4. Sharon Road approach at intersection of Fairview Road and Sharon Road (Photo Credit: Imagery @2018 Google)

Figure 5. Right-turn signal at Fairview Road approach (Photo Credit: Imagery @2018 Google)

During the peak hours, however, the right-turn volume increases to the point that it is not reasonable to hold this movement for the length of the "Walk + Flashing Don't Walk" phase. During the peak hours, the blank-out signs still turn on when a pedestrian pushes the button. However, now a leading pedestrian interval of 10 seconds is used. At the end of the 10 seconds, the blank-out sign facing the right-turn vehicles changes its display to "Yield to Pedestrians," and the signal-head display changes from red to FYA. The blank-out facing the approach the pedestrian is crossing continues to display "No Turn on Red" until the pedestrian crossing has timed out.

The significance of this is three-fold[7]:

- The LPI+ concept requires a complete change in the way that we design and operate signalized intersection/pedestrian crossings. LPI+ is used to create a completely protected crossing with push-button activation, not just to help pedestrians enter the crosswalk. The completely protected crossing will be the normal situation, and the engineer will drop back to an LPI only when the effect on traffic is devastating to capacity;
- LPI+ creates an improved crossing environment. A fully protected crosswalk at the same time stopping vehicles from encroaching in that crosswalk is the pedestrian gold standard. This was achieved here with moderate costs, some controller database changes, and slight traffic signal cabinet modifications;
- LPI+ can be incorporated into any new traffic signal installation. The additional cost of the blank-out signs adds approximately $12,000 to the overall cost of the intersection. The modifications to cabinet and controller are a matter of implementing the ideas that the city has created. In a changing traffic engineering world where modes of travel other than the vehicle are receiving ever-increasing attention, this idea moves beyond lip service and puts that emphasis on the street.

The city is working toward making LPI+ the standard installation for all new traffic signals and has also created a priority list for retrofits of existing intersections.

References

Federal Highway Administration. *Manual on Uniform Traffic Control Devices.* Section 4E.06 ¶22 and 23. 2009.

A.C. Fayish and Frank Gross, "Safety effectiveness of leading pedestrian intervals evaluated by a before–after study with comparison groups," *Transportation Research Record No. 2198* (2010): 15–22.

National Association of City Transportation Officials. *Urban Street Design Guide.* ■

[7] http://ncsite.org/2016/09/16poy-lpiplus/

Exclusive Pedestrian Phase (Pedestrian Scramble) – City of Dunwoody, Georgia

Introduction

An exclusive pedestrian phase or "pedestrian scramble" (Figure 6) has been used to enhance the safety and mobility of pedestrians at signalized intersections by allowing pedestrians to cross in any direction, including diagonally, without coming into conflict with turning vehicles.[8] Scramble pedestrian crosswalk signal phasing is useful at intersections with heavy pedestrian traffic and vehicle turning volumes as it serves to reduce vehicle-pedestrian conflicts by providing exclusive phases for pedestrians and, sometimes, for motorists. The scramble phase is generally displayed as a red signal in all directions for vehicles in conjunction with the "Walk" display in all directions for pedestrians and restrictions to "right-turn on red."

The advantages of introducing scramble crossings include the following:

- Promotion of pedestrian priority and the relief of pedestrian congestion on more traditional orthogonal crossings and footways, particularly where pedestrian volumes are very high;
- Reduction of walk distances and times, particularly where pedestrians would otherwise use two orthogonal crossings to reach their intended destination and can now complete their journey through the junction by making a single diagonal crossing movement;
- Potential improvements in safety by reducing conflicts between pedestrians and vehicles.

Since there are no pedestrian-vehicle conflict points with a pedestrian scramble phase, the presence of this phasing is associated with significantly lower pedestrian collisions, particularly for locations that have moderate-to-high pedestrian volumes.

Bechtel et al.[9] studied one intersection in the Chinatown neighborhood of Oakland, California, and found a 50 percent reduction in pedestrian-vehicle conflicts when a pedestrian scramble was introduced. Kattan et al.[10] studied a pedestrian scramble at two intersections in downtown Calgary, Alberta. They measured the number of pedestrian-vehicle conflicts and pedestrian violations (crossing against signal) and found that the pedestrian scramble decreased the number of pedestrian-vehicle conflicts occurring at the intersection but increased the number of violations after the implementation.

The potential drawbacks of scramble crossings for pedestrians include the following:

- Increased delays to vehicles, particularly where an "All Red" signal stage must be introduced, and pedestrians fail to clear the intersection at the end of the crossing periods leading to potential additional delays to vehicles;
- In some instances, scramble phasing has proven to be unsuccessful due to reductions in capacity for vehicular movements because of the longer cycle length required;
- There may be reluctance on the part of many pedestrians to obey the "Don't Walk" indications during the vehicle phases, which results in confusion among both drivers and pedestrians;
- This treatment may affect the ability to synchronize timing at adjacent traffic signals.

Figure 6. Pedestrian scramble Los Angeles, California (Photo Credit: Hollywood Great Streets)

Figure 7. Typical pedestrian scramble signing (Photo Credit: Pedestrian Scramble Crossings – A Tale of Two Cities)

[8] City of Los Angeles. *Complete Streets Design Guide.*

[9] Bechtel, A.K., K.E. MacLeod, and D.R. Ragland (2003) *Oakland Chinatown Pedestrian Scramble: An Evaluation.*

[10] Kattan, L., S. Acharjee, and R. Tay. Pedestrian Scramble Operations. *Transportation Research Record: Journal of the Transportation Research Board.* 2140, 2009, pp. 79-84.

Exclusive pedestrian phases are applicable at intersections with a high frequency of turning vehicles and high pedestrian volumes (e.g., 1,200 pedestrian crossings per day) and are ideally suited to intersections that have shorter crossings and where sight distances and unique roadway geometries are problematic. They are especially applicable in areas with vulnerable groups such as schools, senior housing communities, and parks or hospitals.

Although an exclusive pedestrian phase enables crossings in all directions, pedestrians must wait a little longer for their next walk signal while vehicles traveling through the intersection complete their signal phase. The tradeoff to safer, multidirectional crossings afforded by an exclusive pedestrian phase is increased wait times for all intersection users. This treatment may potentially confuse visually impaired pedestrians who rely on traffic sounds to decide when and where to cross.

Figure 8. Diagonal crosswalk at intersection of North Shallowford and Dunwoody Park (Photo Credit: Imagery @2018 Google)

City of Dunwoody, Georgia

The city of Dunwoody, Georgia, installed a pedestrian scramble at the intersection of North Shallowford Road and Dunwoody Park (Figure 8). The city decided to introduce a pedestrian-only phase to protect pedestrians and bicycle users traveling on a city-designated recreational trail connecting the park to surrounding neighborhoods. In addition to the protected phase, the city also installed a brick finish on a diagonal crossing to highlight a path through the intersection. The total cost of the installation was approximately $10,000.

"We wanted to do something for trail users coming through. This is a better experience for trail users, especially for those on bikes — a way to enhance the trail experience," said City of Dunwoody Public Works Director Michael Smith.[11]

While a pedestrian scramble is normally associated with large cities, the Dunwoody experience demonstrates that fully protected pedestrian phases and diagonal crosswalks can play a role in smaller communities.

References

LADOT. *Signal Treatment Toolbox adapted from Steps to a Walkable Community: A Guide for Citizens, Planners, and Engineers.*

Rajnath Bissessar, City of Toronto and Craig Tonder, City of Calgary. *Pedestrian Scramble Crossings – A Tale of Two Cities.* ■

[11] https://www.reporternewspapers.net/2016/04/21/dunwoodys-new-crosswalk-scramble-crosswalk-puts-pedestrians-first/

Bicycle Detection – City of Pasadena, California

Introduction

Requiring a bicyclist to dismount and push the pedestrian push button (if present) or wait for a vehicle to approach the detector zone to call the phase can frustrate a bicyclist at actuated traffic signals. Inconvenienced or delayed bicyclists can grow impatient and decide to cross the intersection illegally, thereby exposing themselves to a heightened safety risk. The implementation of passive bicycle detection systems can reduce the level of impatience and irritation by ensuring that the presence of a bicycle is detected in an accurate and timely fashion. Effective detection: (1) accurately detects bicyclists; and (2) provides clear guidance to bicyclists on how to actuate detection (Figure 9).

Several technologies are available to perform bicycle detection at actuated signals including:

- Loop – Induction loop embedded in the pavement (Figure 10);
- Video – Video detection aimed at bicyclist approaches and calibrated to detect bicyclists;
- Microwave – Miniature microwave radar that picks up nonbackground targets.

Among the benefits of passive bicycle detection are included the following[12]:

- Improves efficiency and reduces delay for bicycle travel;
- Enables the implementation of signal timing plans that incorporate the different physical and performance characteristics of bicycles and vehicles;
- Increases convenience and safety of bicycling and helps establish bicycling as a legitimate mode of transportation on streets;
- Discourages red-light running by bicyclists without causing excessive delay to motorists;
- Can be used to prolong the green phase to provide adequate time for bicyclists to clear the intersection.

Bicycle detection systems can be applied in several locations, including:

- In the travel lane on intersection approaches without bike lanes where actuation is required;
- At intersections with bicycle signal heads and/or bicycle-specific phasing that are actuated;
- In bike lanes on intersection approaches that are actuated;
- In left-turn lanes with actuated left-turn signals where bicyclists may also turn left;
- To increase the green signal phase on intersection approaches whose combined minimum green plus yellow plus all-red is insufficient for bicyclists to clear the intersection when starting on a green signal. Advanced bicyclist detection can be applied to extend the green phase or to call the signal;
- At clearly marked locations to designate where a bicyclist should wait.

Figure 9. Bicycle Detection Advisory Sign

Figure 10. In-pavement bicycle loop detector (Photo Credit: City of Scottsdale Trails Subcommittee)

[12] National Association of City Transportation Officials. *Urban Bikeway Design Guide.*

City of Pasadena, California

The state of California enacted Assembly Bill 1581 in 2007, which stated:

"Upon the first placement of the traffic-actuated signal or replacement of the loop detector of a traffic-actuated signal, the traffic-actuated signal shall, to the extent feasible and in conformance with professional traffic engineering practice, be installed and maintained so as to detect lawful bicycle or motorcycle traffic on the roadway."

In response to this legislation, the city of Pasadena, California, implemented a major upgrade to traffic signals to incorporate bicycle detection. The new video-based bicycle detection and differentiation capability is helping the Pasadena Department of Transportation (DOT) implement new traffic signal timing strategies, including phase timings for bicycles such as bike minimum green, which adjusts green light extension to provide safe crossing time for bicycles and returns signal timing to normal when bicycles are not detected. Pasadena is looking to increase this bicycle detection and differentiation capability to additional intersections – up to 30 more intersections.

Currently, the city of Pasadena DOT operates more than 340 traffic signals in its Transportation Management Center (TMC) via a highly sophisticated traffic control system (TCS) that automates and adapts to all motorized and non-motorized moving traffic occurring within city streets, thus providing the most logical and efficient mobility strategies 24 hours a day to maintain the city's traffic signal network.

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City of Pasadena. *Pasadena Bicycle Transportation Action Plan.* Aug. 17, 2015. ■

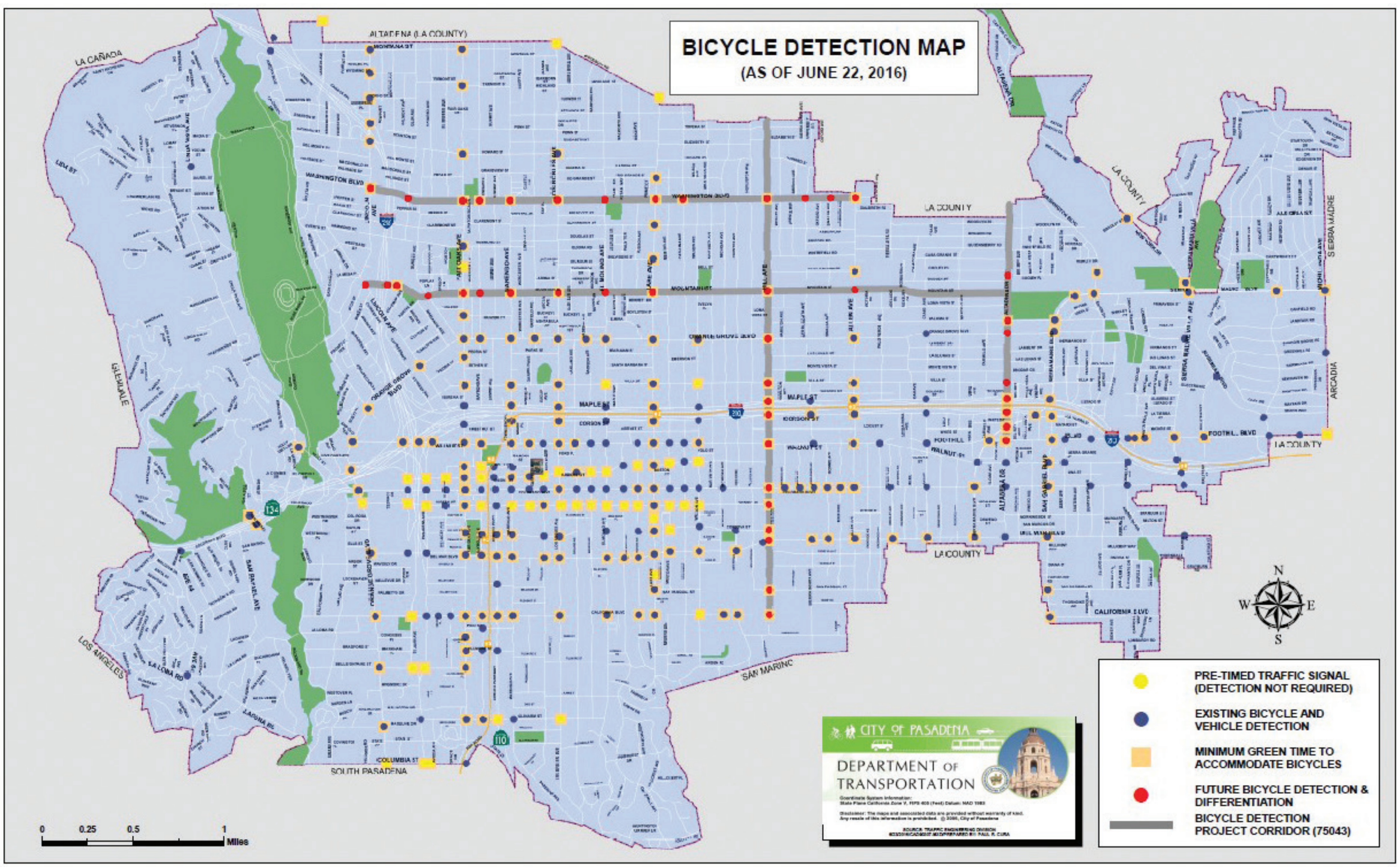

Figure 11. Pasadena Bicycle Detection Map (Photo Credit: City of Pasadena)

Bike Boxes – City of Portland, Oregon

Introduction

A bike box is a designated area at the head of a traffic lane at a signalized intersection that provides bicyclists with a safe and visible way to get ahead of queuing traffic during the red signal phase (Figure 12).

Typical applications for bike boxes include:

- At signalized intersections with high volumes of bicycles and/or motor vehicles, especially those with frequent bicyclist left turns and/or motorist right turns;
- Where there may be right- or left-turning conflicts between bicyclists and motorists;
- Where there is a desire to better accommodate left-turning bicycle traffic;
- Where a left turn is required to follow a designated bike route, access a shared-use path, or when the bicycle lane moves to the left side of the street.

Figure 12. Bike box construction (Photo Credit: NE Georgia Regional Commission)

Figure 13. Bike box at signalized intersection (Photo Credit: Oregon Transportation Research and Education Consortium (OTREC))

Among the advantages of bike boxes include the following:

- Reduces signal delay for bicyclists;
- Facilitates bicyclist left-turn positioning at intersections during red signal indication. This only applies to bike boxes that extend across the entire intersection;
- Facilitates the transition from a right-side bike lane to a left-side bike lane during red signal indication. This only applies to bike boxes that extend across the entire intersection;
- Helps prevent "right-hook" conflicts with turning vehicles at the start of the green indication.

Bike boxes typically are installed only where bike lanes exist and leading up to the bike box is a 25- to 50-foot-long marked ingress area that connects the bike lane to the bike box. A bicycle symbol is placed in the center of the bike box area to alert motorists and bicyclists that the area is reserved for use by bicyclists. A stop bar is installed in front of the bike box and behind any crosswalk (Figure 13). The bike box extends across all approach lanes and is typically 10 to 16 feet deep. A "Wait Here" message can also be painted on the pavement behind the stop bar to reiterate to motorists where they should queue when the traffic signal is red.

An R10-6A (Stop Here on Red) sign can be installed near the stop bar to define the location where motorized vehicles should stop. When issues exist where right-turning vehicles often conflict with bicyclists, it is common for an R10-11 (No Turn on Red) sign to be installed to restrict right turns on red, allowing bicyclists to safely enter the bike box area without fear of right-turning vehicles causing right-hook crashes with bicyclists. Using bike boxes to put bicyclists in front of traffic, along with enforcement of the no-turn-on-red regulation, can reduce the chance of right-hook crashes.

Thermoplastic markings typically have a life cycle of three to five years when the manufacturer guidelines are followed to ensure the application process is done correctly. Application after significant wear must be done by removing the thermoplastic and reapplying.

An evaluation of bike boxes conducted by Portland State University researchers concluded that after controlling for volumes, the number of bicycle-vehicle conflicts decreased and yielding behavior increased at intersections with bike boxes. In addition, user perceptions of safety increased. Specifically, approximately 42 percent of motorists who are not cyclists felt driving through the intersections was safer with the bike boxes and 77 percent of cyclists felt bicycling through the intersections was safer with the bike boxes.[13]

[13] Dill, J., C. Monsere, and N. McNeil. *Evaluation of Bike Boxes at Signalized Intersections*. Portland State University. January 2011.

City of Portland, Oregon

Two Portland bicyclists were killed in right-hook collisions in October 2007. In both collisions, large trucks were stopped at red lights and proceeded with right turns when the light turned green. Neither saw the cyclists riding through the intersection in the bike lane. The accidents catalyzed Portland to act to address this safety issue. In total, Portland currently has 15 signalized intersections with bike boxes and plans to install an additional dozen.

References

National Association of City Transportation Officials. *NACTO Urban Bikeway Design Guide*, 2011.

Hickman, Tristan. *Using Bike Boxes to Make Bicyclists Visible and Keep Them Safe.* Ayers Associates. ■

Figure 14. Bike box images (Photo Credit: NATCO)

Toucan Bikeway Crossing – City of Fort Collins, Colorado

Introduction

Toucan (two can cross the roadway) traffic signals provide safe and comfortable crossings for pedestrians and bicyclists and are typically placed at locations of heavy bicycle and pedestrian crossing activity such as where neighborhood byways cross major streets (Figure 15). Examples of Toucan crossings can be found in Palo Alto, California, Berkeley, California, Tucson, Arizona, and Salt Lake City, Utah. Each varies in dimensions, signal layout, signal style, signage, and grading.

The Toucan design is a variation of the pedestrian-focused hybrid beacon and does not yet have MUTCD approval.

Toucan traffic signals can be activated through passive detection or by using push buttons. The system typically uses a standard signal for motorists on the major street being crossed and can use a bicycle signal and a center-oriented crossing. Pedestrians are provided with a standard "Walk" indication and have a separate, adjacent crosswalk. Clearance time depends on who activates the signal (i.e., pedestrians get longer time to cross the street, bicyclists shorter time). Fundamental to a Toucan is the restriction of through motor vehicle movements, as vehicles on the minor street are forced to turn right.

When no bicycle or pedestrian traffic is present on the minor roadway, a mainline red-yellow-green signal head gives a green indication to mainline vehicular traffic. When a call is placed by minor roadway pedestrian/bicycle traffic, mainline traffic is given a yellow, then a red indication, and the bicycle/pedestrian traffic is given a “walking man” and/or green bicycle signal indication.

Toucan crossings are configured with a “pork chop” or other similar channelizing median at each minor leg to restrict minor roadway vehicular movements to right-out and to consolidate the bicycles/pedestrians to one crossing.

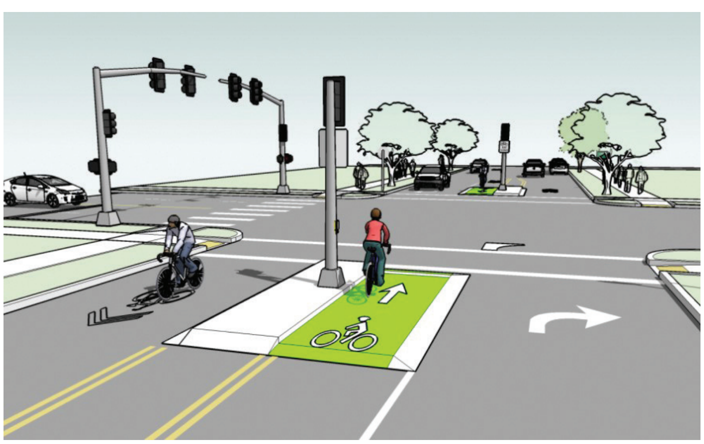

Figure 15. Toucan crossing (Photo Credit: Alta Planning)

Fort Collins, Colorado

Planners in Fort Collins, Colorado, developed a five-mile-long bicycle route on low-volume local streets that incorporated Toucan crossings at several intersections with higher-traffic-volume roadways. The final design of the crossing provided bicycle-specific signals with push buttons in six-inch raised center medians, with a two-inch raised through bike lane storage area and a “painted pork chop” median. The plowable features of the median allow for a year-round maintenance solution while still delineating the bike lane. The painted median provides flexibility for the city to observe vehicle compliance and add channelizing modifications if necessitated (Figure 16).

A bicyclist riding down the middle of the lane on the low-traffic street crosses a Toucan by pulling to the center island and pushing the bike-specific button there. It works like any sidewalk-activated button, except that the green light for crossing bike traffic doesn’t need to last quite as long as one for a walking button.

The typical Toucan crossing costs between $100,000 and $150,000, which is approximately one-half of the cost of a conventional traffic signal that controls all four legs of an intersection.

References

City of Fort Collins. *Pitkin Bikeway Construction Plans.* ■

Figure 16. Toucan crossing in Fort Collins, Colorado
(Photo Credit: City of Fort Collins)

Protected Intersection – Salt Lake City, Utah

Introduction

Communities throughout the nation have developed systems of dedicated bikeways that separate bicycle users from motorists. However, the protected lanes can lose their benefits when they cross a signalized intersection. To address this challenge, a concept called a "protected intersection" was developed to provide bicyclists with a safe path through the intersection.[14] The concept is modeled after a Dutch intersection design. The design elements accommodate left, through, and right-turn movements for bicyclists that minimize or eliminate conflicts with turning vehicles. The four main elements include (Table 3 and Figure 17):

- A corner refuge island;
- A forward stop bar for bicyclists;
- A setback bike and pedestrian crossing; and
- Bicycle-friendly signal phasing.

When combined, these design elements create a safe, clear experience for motorists and non-motorists using the street. Signals control movements, refuge islands create protected spaces, and proper positioning of crossings and conflict points provides everyone with the time and space necessary to react to potential risks.

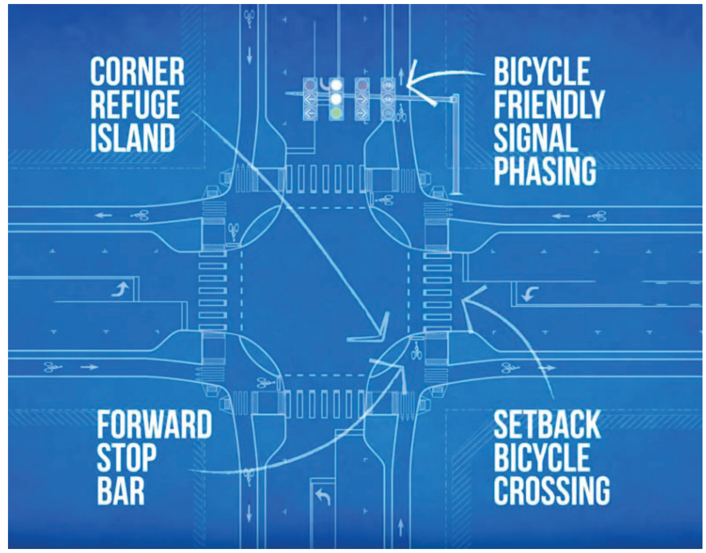

Figure 17. Design elements of protected intersections (Photo Credit: Alta Planning)

Table 3.
Design Elements for Fully Protected Intersection

Design Element	Description
Corner refugee island	The island physically separates bicyclists as they make right turns and provides a secure refuge for those waiting at a red signal protected from moving cars.
Forward stop bar for bicyclists	The forward stop location makes bicyclists visible to drivers waiting during red light signal indication; the physical distance ahead of cars gives bicyclists an effective head start when the light turns green, and the distance of the road that bicyclists need to cross is greatly reduced.
Setback bike and pedestrian crossing	The bike lane bends away from the intersection and drivers turn 90 degrees to face the bike lane before they even cross it making people on bikes highly visible and out of the driver's blind spot.
Bicycle-friendly signal phasing	The use of bicycle specific signals and bicycle-friendly signal phasing. Just as important the physical design of intersections is the use of signals to control how and when different people can proceed.

[14] Nick Falbo of Alta Planning + Design proposed the concept in a presentation submitted as part of the "*2014 Cameron Rian Hays Outside the Box Competition.*"

Salt Lake City

Salt Lake City transportation officials incorporated a protected intersection as part of a larger project to construct a new cycle track on a major thoroughfare that would cross an existing protected bike lane at the intersection of 200 West and 300 South.

A protected intersection was the most practical and functional design. "It provided a solution for the two intersecting bike lanes," says Salt Lake City Transportation Director Robin Hutcheson. "Also, the location has high pedestrian traffic, and the design improved pedestrian safety."

Salt Lake City streets are wide, allowing higher speeds. The protected intersection narrows the space and reduces the number of lanes, slowing cars down. This was a plus: At 7,000 cars per day, the low-volume intersection was operating below traffic capacity. "We accomplished this innovative design with a very minimal additional cost margin," Hutcheson said.[15]

The protected intersection design provides protection to both pedestrians and bicyclists. Pedestrians are provided with separate crosswalks and islands to wait for changes in signal indications.

References

Alta Planning + Design. *Evolution of the Protected Intersection.* 2015. ■

Figure 18. Protected intersection design in Salt Lake City, Utah (Photo Credit: Imagery @2018 Google)

[15] https://www.pwmag.com/roadways/traffic-control-lighting/protected-intersections_o

Innovative Intersection Lighting Design for Pedestrians – Florida Department of Transportation

Introduction

Poor night lighting can make it difficult for drivers to identify the presence of pedestrians using crosswalks at signalized intersections. However, numerous studies have demonstrated that nighttime fatal crashes can be reduced up to 60 percent with the installation of roadway lighting.

- Elvik and Vaa found a 64 percent reduction of fatal crashes, 28 percent reduction in injury crashes, and 17 percent reduction in property-damage-only crashes after lighting was installed;[16]
- Per Ole Wanvik showed a 28 percent reduction in injury crashes, 60 percent reduction in fatal crashes, and 45 percent reduction in injury crashes involving pedestrians;[17]
- Minnesota Local Road Research Board (2006) before-and-after study found that 44 percent of the intersections showed a reduction in the number of nighttime crashes;[18]
- Lipinski and Wortman showed a 45 percent reduction in the night crash rate at rural at-grade intersections;[19]
- Walker and Roberts found a 52 percent reduction in nighttime crashes at 47 intersections in a six-year before-and-after study.[20]

Enhanced lighting offers several benefits including:

- Improves view of roadway geometry and adjacent environment;
- Increases sight distance to improve response to hazards and decision points;
- Eliminates dark spots and improves the mutual view of motorists and pedestrians;
- Provides clearer view during police, emergency, construction, and maintenance activities or events.

Florida Department of Transportation (FDOT)

In response to an increasing trend in pedestrian and bicycle fatalities and injuries, the Florida Department of Transportation (FDOT) has undertaken several initiatives to improve safety at signalized intersections. These initiatives include conducting research as well as increasing funding for the purpose of improving lighting at signalized intersections throughout the state.

FDOT conducted field test deployment of retrofitting LED lighting at a signalized intersection to evaluate the impact of improved lighting on pedestrian visibility.[21] The test also examined several technical questions including:

- How to mount the fixtures;
- Where to mount the fixtures;
- How much additional pedestrian visibility is provided.

Figure 19 portrays the before-and-after lighting conditions for a pedestrian dressed in dark clothing after installation of an LED lamp on a signal mast arm at the test intersection. The level of illumination provided increases in the after condition, and the visibility of the pedestrian in the crosswalk has also improved.

In addition to conducting research to improve lighting, FDOT has also targeted funding to retrofit high crash locations with improved lighting standards.[22] Table 4 summarizes the district funding allocation of the five-year, $100 million FDOT intersection lighting retrofit program. The program was initiated to "catch" signalized intersections on high-crash corridors that would not be upgraded via standard practice (i.e., signal reconstruction). The current plan is to upgrade or install intersection lighting at approximately 2,500 intersections statewide within the next few years. Moving forward, all signal reconstructions in urbanized areas with pedestrian facilities will have intersection lighting as a matter of course.

References

Florida Pedestrian and Bicycle Strategic Safety Plan. Updated May 2017. ■

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[16] Elvik, R. and T. Vaa. *Handbook of Road Safety Measures*, Oxford, United Kingdom, 2004.

[17] Wanvik, P. *Road Lighting and Traffic Safety*, Norwegian University of Science and Technology, 2009.

[18] Isebrands, H. et. al. *Safety Impacts of Street Lighting at Isolated Rural Intersections*, Minnesota Department of Transportation, Part II, MN/RC-2006-35, September 2006.

[19] Lipinski, M. and R.H. Wortman. "Effect of Illumination on Rural At-Grade Intersection Crashes." *Report 611. Transportation Research Record*, 1976. pp 25–27.

[20] Roberts, S.E. and F.W. Walker. "Influence of Lighting on Accident Frequency at Highway Intersections." *Report 562. Transportation Research Record*, 1976, pp 73-77.

[21] *Innovative Intersection Lighting Design For Pedestrians presentation at 2017 Design Training Expo* prepared by Justin R. Reck, FDOT, Jennifer McKinney, FDOT, Richard Endrzejewski, PE, Element Engineering Group and Danny Hendrickson, P.E., PTOE, ICON Consultant Group.

[22] *Intersection Lighting Retrofits presentation at 2017 Design Training Expo* prepared by Humberto Castillero, P.E., PTOE, and Ed Cashman, P.E.

Figure 19. Before and after LED installation for pedestrian dressed in dark clothing (Photo Credit: Innovative Intersection Light Design for Pedestrian Presentation)

Table 4.
Allocation of FDOT Lighting Retrofit Funding[23]

District	$100M Allocation	Number of Intersections	Average B/C Ratios
1	$ 7,344,283	187	40.5
2	$ 9,792,377	249	38.4
3	$ 6,383,638	163	37.9
4	$ 20,514,410	522	40.0
5	$ 17,260,614	440	41.0
6	$ 23,613,263	601	46.8
7	$ 15,091,416	384	46.2
Total	**$ 100,000,000**	**2,546**	**41.5**

[23] *Improving Pedestrian Safety with Engineering and Technology presentation at FSITE Winter Workshop*, February 9, 2018, prepared by Trey Tillander and Alan El-Urfali, State Traffic Engineering and Operations Office.

Advanced Technology Applications

Introduction

Rapid advances in communications and computing technology have provided the opportunity to explore advanced applications to address pedestrian and bicycle safety. While many of these concepts are in the research and development stage, others will be available shortly for widespread deployment. Summarized here are several examples of these emerging technologies.

Variable Pedestrian Clearance Interval System – City of Minneapolis, Minnesota

The Minnesota Department of Transportation (MnDOT) sponsored a research project designed to test the feasibility of detecting pedestrians to extend crossing times across a major arterial. The variable pedestrian clearance interval (VPCI) project utilized automated pedestrian detection via video-based pedestrian detection sensors to identify pedestrians in the crosswalk and then adjust pedestrian signal phasing. Video camera sensors installed at the signal pole at each end of the crosswalk provided a means to identify pedestrian presence (Figure 20). The system was programmed for a minimum pedestrian countdown time. However, when a pedestrian was detected within the crosswalk by the cameras, the “Flashing Don't Walk” time was extended to accommodate these pedestrians. If the minimum countdown was reached, and no pedestrians were detected within the crosswalk, the “Flashing Don't Walk” time could be skipped altogether.[24]

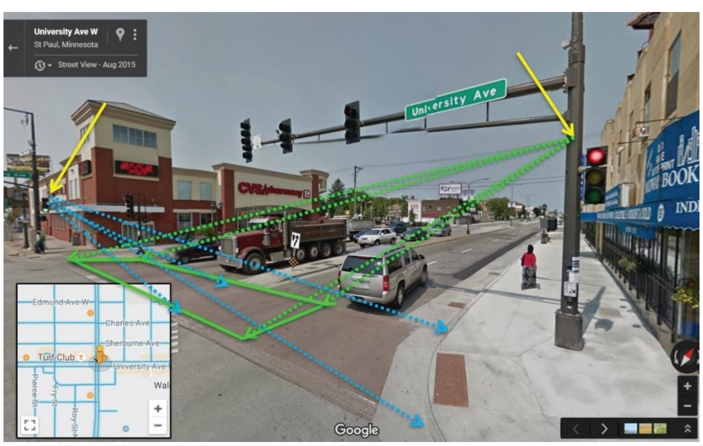

Figure 20. VPCI camera coverage (Photo Credit: VCPI Presentation MnDOT Fall Forum)

Vehicle-to-Pedestrian Connected Vehicle Infrastructure

Pedestrian detection systems can be implemented in vehicles, in the infrastructure, or with pedestrians themselves to provide warnings to drivers, pedestrians, or both:

In-Vehicle Systems: In-vehicle warning systems are becoming more and more commonplace (e.g., blind spot warning, forward collision warning). The current field of vehicle-to-vehicle (V2V) communications is providing the development of even more advanced warning systems (e.g., intersection movement assist, left turn assist). In-vehicle warnings to the presence of a pedestrian in the roadway might be logical.

Handheld Devices (for pedestrians): Perhaps the simplest and most apparent warning system for pedestrians is a handheld device. Pedestrians are provided with a device that warns them about the approach or presence of a vehicle as they enter an intersection.

Infrastructure-Based Sensor Systems

Embedded sensors in the infrastructure can communicate the presence of pedestrians or vehicles. For example, the SAFE STRIP project seeks to examine the feasibility of incorporating micro and nano sensors into marker or tape strips that are mounted on the road surface to measure real-time data and provide information directly to the driver. For example, one use case under exploration consists of incorporating sensors in marker strips on zebra crossings to indicate the presence of a pedestrian to a crosswalk (Figure 21). Both equipped vehicles and nonequipped vehicles could receive this warning message, either by direct communication between the sensors and the vehicle or via a service provider. In this case, the service provider receives the warning information by means of a roadside unit (RSU).

Bicycle Infrastructure – Copenhagen, DK[25]

Copenhagen, Denmark (DK) can be described as the “city of cyclists” – due to its longstanding cycling tradition. The following statistics underscore the importance of bicycling in the city:

- 62 percent of residents use a bicycle daily;
- 41 percent of all work trips are accomplished by bike;
- There are five times more bikes than motor vehicles in the city;
- The city contains 375 kilometers of exclusive bikeways.

[24] ITS Mn / NCITE Joint ITS Technical Committee Presentation. Aug. 7, 2018.

[25] Ruggieri, Gianluca. *The State of the Art of Copenhagen’s Cycling Infrastructure and Possible Application in Other Urban Context.* Master’s degree thesis in urban planning and policy design. Politecnico Di Milano.

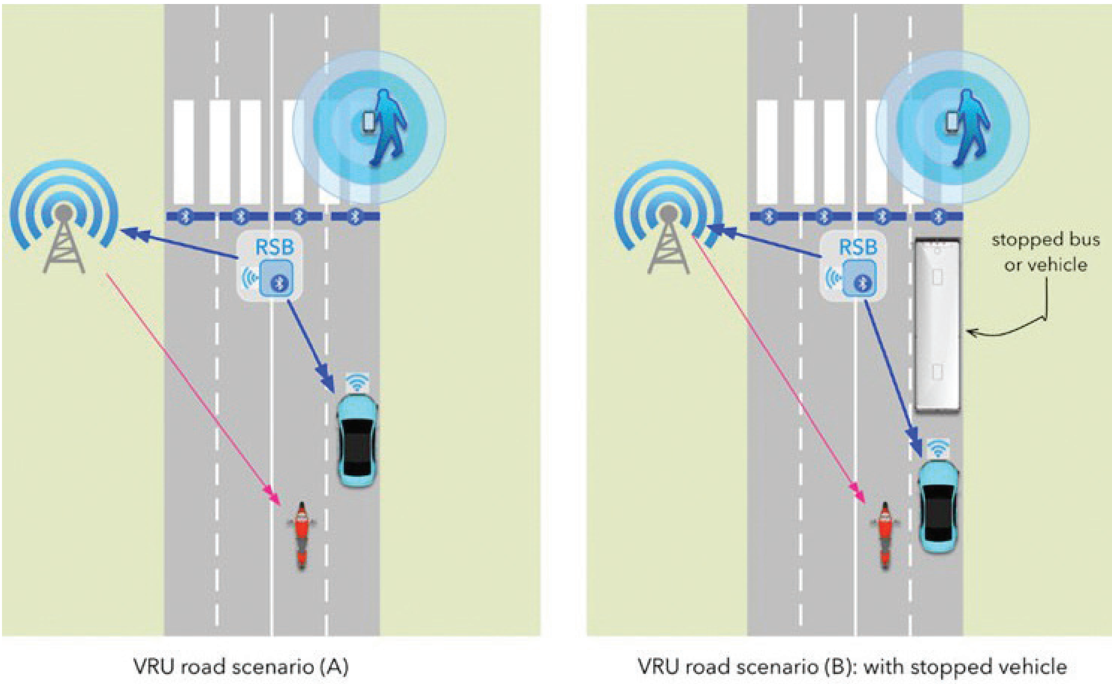

Figure 21. SAFE STRIP pedestrian crosswalk scenarios (Photo Credit: SAFE STRIP Use Cases and Application Scenarios)

Figure 22. Bicycle counter (Photo Credit: Gianluca Ruggieri)

Figure 23. Illuminated bike path (Photo Credit: Gianluca Ruggieri)

Between 2005 and 2016, Copenhagen invested over $200 million in cycling-related infrastructure. Their fatality rates are lower than most of the world, despite cycling accounting for 26 percent of all trips under five kilometers and 16 percent of all trips regardless of the distance.

To support the bicycle traveler, the city has deployed several supporting technologies, including bicycle counters (Figure 22) and illuminated bike paths (Figure 23) using LED markers (Figure 24).

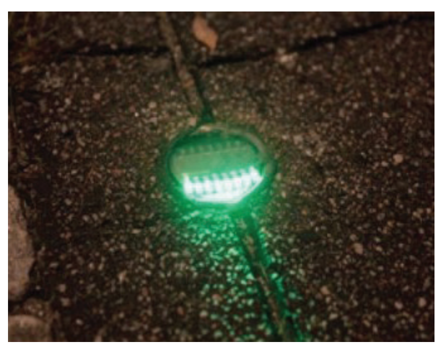

Figure 24. LED marker (Photo Credit: Gianluca Ruggieri)

Variable message signs for bicycles provide dynamic information to cyclists based on real-time sensor data. Upstream at a signalized intersection, the system places cameras on traffic lights that determine throughput and cyclist traffic (Figure 25). That data are processed and filtered into an LED message board, which displays a basic safety message for downstream riders approaching the intersection (Figure 26).

Sensor data are used to prioritize cyclists in intersections, and bicycle counters placed in key locations are used to communicate to cyclists and other road users (Figure 27). Bicycle counters (or bicycle barometers) are basic sensors that count the number of cyclists moving though a location (Figure 28). Pavement markings and signals also played a major role in cyclist safety in Copenhagen. Each intersection had its own cyclist signals used in the same manner as for automobile drivers (Figure 29). Large blue lanes at every intersection reminded drivers that cyclists are always present (Figure 30). Bike lanes were clearly delineated and marked with pedicyclist icons throughout the city. ■

Figure 25. Bicycle surveillance

Figure 26. Bicycle LED sign

Figure 27. Bicycle sensor

Figure 28. Bicycle counter

Figure 29. Bicycle signal

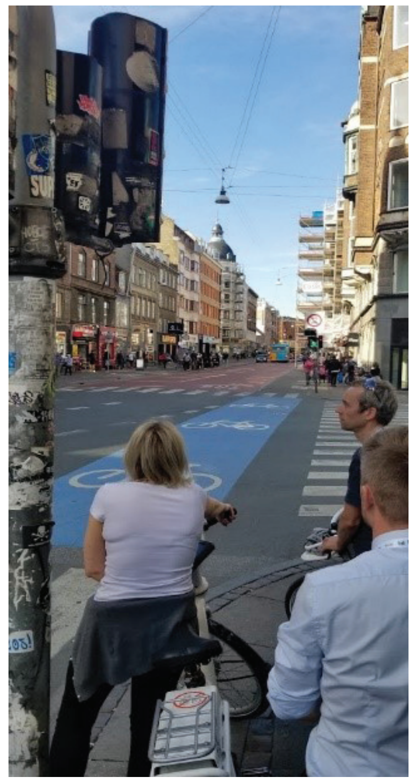

Figure 30. Bicycle markings

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