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Understanding and Using New Pedestrian and Bicycle Facilities

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16. Abstract

Research has explored the benefits of innovative pedestrian and bicycle facilities, but it is unclear how pedestrians and bicyclists learn to properly use them. This report provides information on new pedestrian and bicycle treatments and (1) the behavior and knowledge of pedestrians, bicyclists, and drivers traversing through, on, and around the new facilities, and (2) law enforcement activity around the facilities. A systematic literature review as well as a review of current practices in outreach was conducted.

Generally, road users use new transportation facilities safely, if not entirely as intended. Confusion can occur when expectations differ from reality, such as when movement patterns are changed. Pedestrians and bicyclists express positive attitudes (e.g., reduced delays, improved routes, increased safety) about new facilities, and motorists share these sentiments unless they perceive inconveniences or unexpected behaviors. Little published research has explored education strategies for specific facilities. It appears that the general practice is to use established signage rather than experimenting with a potentially more effective method, such as intuitive design principles or media campaigns. Just one study identified evaluated the effects of enforcement activities. Enforcement—whether by visible patrol, citations, sting operations, or otherwise—is likely to positively influence compliance among all road users, but the research community has yet to document this mechanism. The review of current practices in outreach was intended to supplement the literature review, which identified gaps in knowledge about what might be effective at improving the understanding and use of facilities. A small number of studies into broader educational campaigns indicate that multimode communication to a highly localized audience is the most successful strategy for improving safety through behavioral change. More research is needed to quantify the success of the educational campaigns.

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List of Acronyms

AASHTO	American Association of State Highway Transportation Officials
ABL	advisory bike lane
CDC	Centers for Disease Control and Prevention
CMF	crash modification factor
DelDOT	Delaware Department of Transportation
FHWA	Federal Highway Administration
HSRC	Highway Safety Research Center (at the University of North Carolina)
ITE	Institute of Transportation Engineers
LPI	leading pedestrian interval
MnDOT	Minnesota Department of Transportation
MUTCD	Manual on Uniform Traffic Control Devices
NACTO	National Association of Transportation Officials
NHI	National Highway Institute
NYSDOT	New York State Department of Transportation
PBCAT	Pedestrian and Bicycle Crash Analysis Tool
PBIC	Pedestrian and Bicycle Information Center
PSA	public service announcement
RRFB	rectangular rapid-flashing beacon
RSA	road safety audit
RTOR	permitted right turns on red
TTC	time-to-collision
VDOT	Virginia Department of Transportation

Executive Summary

Research has explored the benefits of innovative pedestrian and bicycle facilities, such as leading pedestrian intervals, rectangular rapid-flashing beacons, and contraflow bike lanes. However, these facilities are new to many road users. The report provides information on new pedestrian and bicycle treatments and (1) the behavior and knowledge of pedestrians, bicyclists, and drivers traversing through, on, and around the new facilities, and (2) law enforcement activity around the facilities, so that the National Highway Traffic Safety Administration can develop and improve countermeasure programs to help reduce the number of pedestrian and bicyclist injuries and fatalities. To meet this goal, the research team conducted a systematic literature review of treatments and their impacts as well as a review of current outreach practices.

A total of 114 articles on 17 facilities were reviewed, organized by primary road-user type. Facilities used primarily by bicyclists include bike boxes, two-stage turn boxes, bicycle signals and detectors, advisory bike lanes, buffered bike lanes, and contraflow bike lanes. Facilities used primarily by pedestrians include leading pedestrian intervals, offset crossings, pedestrian scrambles, "puffin" crossings,[1] raised crosswalks, rectangular rapid-flashing beacons, and refuge islands. Facilities used by both pedestrian and bicyclist road users include protected intersections, roundabouts, shared-use paths, and pedestrian and bicyclist wayfinding signage.

Findings on each facility are organized into various components: use, compliance, and safety; attitudes, beliefs, and perceptions; education strategies; and knowledge and comprehension. Generally, road users navigate new transportation facilities safely, if not entirely as intended. For example, motorists may not always yield when they should, but pedestrians and bicyclists take precautions to avoid injury regardless. Confusion can occur when expectations differ from reality, such as when movement patterns are changed by bike boxes or two-stage left-turn boxes. Pedestrians and bicyclists express positive attitudes about pedestrian and bicycle facilities. Motorists share these sentiments unless they perceive inconveniences or unexpected behaviors such as bicyclists riding in buffered or contraflow lanes.[2]

Little published research has explored education strategies for specific facilities. Some facilities are more interactive than others and some road users may require guidance. It appears that the general practice is to use established signage to help direct behavior. Experimenting with new and potentially more effective methods to communicate with road users, such as intuitive design principles or media campaigns, is occurring continuously. Only one identified study evaluated the effects of enforcement activities. Enforcement for proper facility use—whether by visible patrols, citations, safety and compliance operations, or otherwise—is likely to positively influence compliance among all road users. Law enforcement officers may claim this, but the research community has yet to document it.

The review of current practices in public outreach was intended to supplement the literature review, which identified gaps in knowledge about what might be effective at improving the understanding and use of facilities. There are considerable efforts by practitioners, enforcement, and others to improve access and safety through education, even if those efforts are not

[1] The name comes from the phrase "pedestrian user-friendly intelligent," a type of pedestrian crossing used in the United Kingdom. Some British sources capitalize it, some do not.
[2] In transport engineering nomenclature, a lane in which traffic flows in the opposite direction of the surrounding lanes is called a counterflow lane or contraflow lane.

scientifically evaluated. The review includes a sampling of public agencies and advocacy groups at various levels – national, State, and local.

Local agencies and advocacy groups are responsible for much of the educational outreach to the public regarding pedestrian and bicycle facilities. Larger organizations, such as professional associations, Federal agencies, and national advocacy groups, tend to deliver more broad, general safety messages (e.g., safe habits, proper equipment use) or technical specifications and implementation guidelines. While these are important for planners, more localized organizations seem better positioned to deliver relevant messages to prospective users. Although little research directly evaluated education surrounding specific facilities, the team identified a small number of studies into broader educational campaigns. These studies indicate that multimode (e.g., social media, online advertising, cell phone, print, PSAs) communication to a highly localized audience is the most successful strategy for improving safety through behavioral change. More research is needed to quantify the success of the educational campaigns.

Introduction

Improving road users' understanding of pedestrian and bicyclist facilities has the potential to improve safety. In 2020 pedestrians accounted for 6,516 fatalities and bicyclists for 938 fatalities in motor vehicle crashes (Stewart, 2022). Elements to be considered for effective pedestrian and bicycle safety programs are infrastructure and engineering countermeasures as well as education and enforcement. The intent of this document is to synthesize information about how people understand and use infrastructure with the aim of developing better ways to communicate with the public about new facilities to ultimately improve safety.

Research has explored the benefits of innovative pedestrian and bicycle facilities, such as leading pedestrian intervals, rectangular rapid-flashing beacons, and contraflow bike lanes. However, these facilities are new to many road users. Evaluations of pedestrian and bicycle facilities tend to study safety (e.g., crashes) and operational (e.g., delay) metrics rather than user understanding. A literature review of bicycle-related facilities highlighted evaluations from 41 different treatments but provided little information on user comprehension and proper use (Mead et al., 2014).

This report provides information on new pedestrian and bicycle treatments and (1) the behavior and knowledge of pedestrians, bicyclists, and drivers traversing through, on, and around the new facilities, and (2) law enforcement activities around the facilities, so that NHTSA can develop and improve countermeasure programs to help reduce the number of pedestrian and bicyclist injuries and fatalities.

This report is organized as follows. First, the *Literature Review Methodology* section provides an overview of the literature discovery and review process. The scope of the investigation is defined, and information is presented to describe the search terms used, sources considered, and document screening method. The *Literature Review Findings* section then synthesizes the findings related to each facility, organized by the primary road user (bicyclist, pedestrian, or both). Facilities in each subsection are arbitrarily ordered. The *Current Practices in Outreach* section describes a sample of material developed to improve road user understanding and use of specific facilities at the national, State, and local levels as well as describing lessons learned from other pedestrian and bicycle safety campaigns. Finally, the *Conclusions* section summarizes the overall findings.

Literature Review Methodology

This section provides an overview of the literature discovery and review process. The scope of the investigation is defined, and information is presented to describe the search terms used, sources considered, and document screening method.

Scope of the Investigation

Transportation research covers a broad range of topics. The goal of this report is to document use, understanding, and enforcement of new pedestrian and bicyclist facilities. This narrows the scope of the literature review considerably. The research team thus focused on the use of certain facilities and excluded all documents pertaining to facility design principles, such as signal timing optimization, materials, economics, and computer vision algorithms. Automated driving systems and electric bikes are also beyond the scope, as are more established, traditional pedestrian and bicyclist facilities such as generic crosswalks and bike lanes. The review primarily covers research over the 15-year-period 2006 to 2020, but seminal sources prior to this period are cited. Both U.S.-based and international research (if available in English) are included. Table 1 lists facilities on which research was sought as they are ordered in subsequent sections. Each respective section, where appropriate, also includes a photo or diagram of the facility.

Findings on each facility are organized into various components, summarized in Table 2. Use, compliance, and safety pertain to specific behaviors and outcomes. These vary by facility and include bicyclist speed and distance from curbs, waiting positions, and signal compliance; pedestrian pushbutton use, scanning behaviors, and walking patterns; and motorist speeds, positions relative to facilities, and yielding behaviors. Safety outcomes generally include conflicts, injuries, and crashes. Attitudes, beliefs, and perceptions describe what road users think of facilities and other road users. These may include motorists' attitudes toward bicyclists and vice versa, beliefs about the intent of a facility, and perceptions of safety. Education strategies include public outreach, and informational signs or flyers. Knowledge and comprehension refer to how road users understand various aspects of the facility, including its intent, who has the right-of-way; and where to walk, ride, or drive. Use and compliance help gauge level of understanding of how to use the facility. If someone uses the facility and uses it correctly, this demonstrates an understanding of how to use the facility.

Table 1. List of Facilities and Synonymous Terms

Terms Used in This Report	Synonymous Terms
Bike Box	Advanced stop box
	Advanced stop line
	Bicycle storage box
Two-Stage Turn Box	Left turn box
	Turn box
	Two-stage turn queue box
	Two-phase left-turn box
	Two-stage bicycle turn box
	Two-step crossing for left-turn bicycle
Bicycle Signals and Detectors	(No other terms identified)
Advisory Bike Lane	Advisory bike lane
	Advisory shoulder
	Dashed bicycle lane
	Non-compulsory bicycle lane
	Suggestion lane
Buffered Bike Lane	Bike lanes plus buffer
	Buffered bicycle lane
	Buffer-separated preferential lane
	Separated bicycle paths, by lane markings
Contraflow Bike Lane	Counter-flow bike lanes
	Limited one-way streets
Leading Pedestrian Intervals	Pedestrian head start
Offset Crossing	Danish offset
	Staggered crossing
	Z-crossing
Pedestrian and Bicyclist Wayfinding	Wayshowing
Pedestrian Scramble	Barnes Dance[3]
	Diagonal crossing
	Exclusive pedestrian phase
Puffin Crossing	(No other terms identified)
Raised Crosswalk	(No other terms identified)
Rectangular Rapid-Flashing Beacon	(No other terms identified)
Refuge Island	Crossing islands
	Safety islands
Protected Intersection	(No other terms identified)
Roundabout	(No other terms identified)
Shared-Use Path	Multi-use path
	Shared path

[3] According to several sources, the term "Barnes Dance" commemorates traffic engineer Henry Barnes while also alluding to a barn dance. He first introduced it in Denver, Colorado in the late 1940s, when the "pedestrian scramble" was being tested in Kansas City and Vancouver. When Barnes became traffic commissioner of New York City in 1962, his first action 10 days after he took office was to install the first pedestrian scramble at the intersection of Vanderbilt Avenue and 42nd Street, to great acclaim. In his autobiography Barnes wrote that a City Hall reporter, John Buchanan, first coined the phrase by writing that "Barnes has made the people so happy they're dancing in the streets." See "Where was the First Walk/Don't Walk Sign Installed?" www.fhwa.dot.gov/infrastructure/barnes.cfm and www.bloomberg.com/news/articles/2012-12-18/a-brief-history-of-the-barnes-dance

Table 2. Researched Facility Components

Component	Examples
Use, compliance, and safety	**Bicyclist** speed, distance from curb, waiting position, signal compliance **Pedestrian** pushbutton use, scanning behaviors, walking patterns **Motorist** speed, position relative to facility, yielding behaviors Conflicts, injuries, crashes
Attitudes, beliefs, and perceptions	Road users' attitudes toward others, beliefs about the intent of a facility, perceptions of safety
Education strategies	Public outreach, informational signs, flyers, pavement coloring
Knowledge and comprehension	Intended use of a facility, right-of-way, where to walk, ride, or drive

Information Sources and Search Terms

The research team cast a wide net to identify as many potentially relevant documents as possible. Five main information sources were used: the Transport Research International Documentation database, Scopus, Google Scholar, DeepDyve, and the International Association of Chiefs of Police online network. TRID provides records (but not necessarily access) to a plethora of transportation research from across the globe. Scopus and Google Scholar search through journals such as *Accident Analysis and Prevention* and *Transportation Research Part F: Traffic Psychology and Behaviour.* DeepDyve served as a secondary source for the full text versions of previously identified documents. The IACP was searched for relevant resources pertaining to enforcement.

To account for different spelling and naming conventions, facility and concept synonyms were used. These terms were combined with Boolean operators "AND" and "OR." For example, the search string for bike boxes was:

((("bike" OR "bicycle") AND "box") OR "bike box" OR "advanced stop")
AND
(compliance OR behavior OR education OR enforcement OR understanding)

Search results were downloaded as text and XML files from each respective information source. These records included titles, abstracts, URLs and other bibliographic information. Results from each information source were combined into a spreadsheet and screened for duplicates. This process identified 6,163 potentially relevant documents, which were then screened as described in the proceeding section. During the review stage, additional relevant documents were identified and added to the queue.

Document Screening Method

The research team developed an automated screening and scoring process, but this proved problematic and was replaced by a manual review of titles and abstracts. Many documents could be excluded by simply reading titles; for more ambiguous cases, the research team read the abstracts. This process identified 389 sources that were likely to be relevant to the present review. During the review process, a number of sources were deemed irrelevant and a number of new sources were identified. This process ultimately resulted in 136 relevant documents. As shown in Table 3, 7 of these were excluded for methodological concerns and the full text of 15 documents could not be obtained (were unavailable in the searched databases). This literature review synthesizes the relevant findings of the remaining 114 documents.

Table 3. Results of Document Screening and Review Process

Facility	Identified	Not Obtained	Excluded	Reviewed
Bike Boxes	10	0	1	9
Two-Stage Turn Boxes	3	0	1	2
Bicycle Signals and Detectors	7	2	1	4
Advisory Bike Lanes	6	0	3	3
Buffered Bike Lanes	9	0	1	8
Contraflow Bike Lanes	8	0	0	8
Leading Pedestrian Intervals	5	0	0	5
Offset Crossings	3	1	0	2
Pedestrian Scrambles	6	1	0	5
Puffin Crossings	12	4	0	8
Raised Crosswalks	4	0	0	4
Rectangular Rapid-Flashing Beacons	24	2	0	22
Refuge Islands	16	3	0	13
Protected Intersections	3	0	0	3
Roundabouts	5	0	0	5
Shared-Use Paths	12	2	0	10
Pedestrian and Bicyclist Wayfinding	3	0	0	3
Total	136	15	7	114

Literature Review Findings

This section provides a synthesis of the findings from the literature review. Findings are organized by facility and grouped by the primary road user.

Following the description of each facility, the sources reviewed and present findings in terms of use, compliance, and safety; attitudes, beliefs, and perceptions; education strategies; knowledge and comprehension; and gaps in the literature are presented along with a summary of the findings and general conclusions.

Primarily Bicyclist Facilities

Bike Boxes

The *bike box* (as referenced here and in most of the literature) is also known as the *advanced stop box* (Newman, 2002), *advanced stop line* (Allen et al., 2005; Atkins, 2005) and the *bicycle storage box* (Johnson et al., 2010). The National Association of City Transportation Officials defines a bike box as "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" (NACTO, 2014, p. 49). A variety of configurations exist (Atkins, 2005) but bike boxes are most often directly fed by approaching cycle lanes (Newman, 2002). A bicycle logo typically appears in the box with the words "WAIT HERE" directed at motorists, appearing on the pavement just before the box (Hunter, 2000). A typical example is shown in Figure 1.

Figure 1. Bike Box in Portland, Oregon (NACTO, 2014)

Bike boxes are intended to improve bicyclists' safety by making them more visible, directly in front of drivers (Hunter, 2000; Loskorn et al., 2013). This also removes them from the paths of turning motor vehicles, thereby reducing the risk of right-hook crashes, or left-hook crashes in countries where motorized traffic drives on the left (Hunter, 2000; Dill et al., 2012; Loskorn et al., 2013). Upon approach to a bike box, motorists are expected to drive in their own marked lane, "without stopping in the box, or driving along the cycle lane" while bicyclists "use the box area as a reservoir at a red signal, allowing more bicyclists to accumulate ahead of the stopped traffic" (Newman, 2002, p. 5). Bicyclists have the right-of-way when in the box; the box is not meant to be used on a green traffic signal (Hunter, 2000).

There is some disagreement regarding the origin of bike boxes. Atkins (2005) claims that they were first introduced in Oxford in 1986 whereas Johnson et al. (2010) assert that they originated in the Netherlands. In addition to these countries, bike boxes also appear in Australia (Johnson et al., 2010), Canada (Casello, 2017), and several American cities including Austin, Texas (Loskorn et al., 2013); Portland, Oregon (Dill et al., 2012); and Eugene, Oregon (Hunter, 2000).

Sources

The research team identified and obtained 10 relevant studies for this review. Half of these studies originated in the U.S., with the other half originating from New Zealand, the U.K., Australia, and Canada.

- Hunter (2000) conducted a before-after analysis and a complementary survey at one intersection in Eugene, Oregon. Notably, this was the only reviewed source that included an extensive educational component consisting of a press release, stories in the local and University of Oregon student newspapers, and an instructional sign board placed near the intersection.
- Newman (2002) describes a number of configuration alternatives, but fails to provide any quantitative analysis.
- Allen et al. (2005) conducted an observational study involving 12 sites with bike boxes and video footage of over 6,000 bicyclists.
- Atkins (2005) describes general usage and vehicle encroachment patterns at 10 sites in London.
- Having emerged as an issue central to bike boxes, Johnson et al. (2010) evaluated bicyclist and driver compliance.
- Casello (2017) also focused on compliance, distinguishing between "rule compliance" and "facility compliance."
- Dill et al. (2012) conducted a before-after analysis of 10 bike boxes in Portland, Oregon, in which 7 of the sites employed green pavement coloring.
- Loskorn et al. (2013) then drilled deeper into the effect of the green coloring in a before-after analysis in Austin, Texas.
- Finally, Fournier et al. (2020) shifted attention to the driver in a driving simulator experiment.
- One of the 10 sources reviewed is excluded from this review due to potential issues concerning generalizability. Ohlms and Kweon (2018) captured 96 hours of video footage of bicyclists passing through one complex intersection in Charlottesville, Virginia. The T intersection involved an additional approach just before the junction, while another leg splits into two upon exiting the intersection. In sum, the intersection is more akin to one with five legs rather than a standard T configuration. Furthermore, both bike boxes and two-stage left turns were installed, confounding the effects of one another. Researchers also noted that a nearby university launched a bikeshare program

during the study, potentially introducing many inexperienced bicyclists into the analysis, but failed to address or quantify this risk. These factors contribute to a unique environment that may not generalize to other bike boxes, thus prompting the exclusion from the review.

Table 4 provides a chronological overview of these sources and the road users and components present in the literature.

Table 4. Overview of Sources Relevant to Bike Boxes

Source	**Bicyclists**	**Motorists**	**Pedestrians**	**Use, Comprehension, Safety**	**Attitudes, Beliefs, Perceptions**	**Education Strategies**	**Knowledge, Comprehension**
Hunter, 2000	✓	✓		✓		✓	✓
Newman, 2002	✓	✓			✓		
Allen et al., 2005	✓	✓		✓		✓	
Atkins, 2005	✓			✓	✓		
Johnson et al., 2010	✓	✓		✓	✓		
Dill et al., 2012	✓	✓		✓	✓	✓	✓
Loskorn et al., 2013	✓	✓		✓		✓	✓
Casello et al., 2017	✓			✓			
Fournier et al., 2020		✓		✓	✓		✓

Note: A ✓ indicates that the source does address this road user or component.

Use, Compliance, and Safety

The literature describes how bicyclists use bike boxes primarily in terms of where in the box they stop. Compliance on the part of both the cyclist and the driver is studied extensively. As expected, safety is a direct consequence of compliance, but proved difficult to analyze quantitatively. Several studies also examined the effects of pavement coloring.

Bike boxes provide value to bicyclists only when the signal at an intersection is red. When the signal is green, bicyclists should proceed without altering their behavior, whether they were riding in bike lanes or traffic lanes. Hunter (2000) observed 16% of *all* cyclists passing through the intersection use the box; among those who did stop (in compliance with a red signal), 29% used the box. The survey component of the same study found that 31% of respondents indicated that they had used the box.

Compliant use of bike boxes requires different actions from bicyclists and motorists. Johnson et al. (2010) define bicyclist compliance as “entering the [bike box] with at least one wheel in the box” (p. 70) and motorist compliance as “stopping before the [bike box, with] the front wheels of the vehicle stopping before the white line” (p. 70). There are, of course, other components of compliant use of bike boxes. Casello (2017) draws a distinction between “facility compliance” and “rule compliance.” The former coincides with Johnson et al.’s definition while the latter relates to the legal requirements of road users, namely cyclists heeding traffic signals and motorists yielding to cyclists. The following section discusses compliance as proper use among cyclists and motorists, followed by a presentation of findings related to rule compliance.

Bicyclists are meant to approach the intersection and use the bike box to maneuver *directly in front of traffic* and then proceed when the signal turns green (Hunter, 2000). Dill et al. (2012) named three zones where bicyclists can stop in relation to a bike box: Area A is the intended space, located directly in front of vehicular traffic; Area B is the space immediately to the right of Area A, in the bike lane but longitudinally in line with the bike box; and Area C is the feeder bike lane itself, bound longitudinally by the vehicular stop bar (Figure 2). This demarcation does not explicitly label a fourth area where many bicyclists were observed stopping: the vehicular traffic lane preceding the bike box. Allen et al. (2005) observed 38% of cyclists encountering red signals stopped in Area A, with others waiting in pedestrian crossings. Atkins (2005) found that 24% stopped in Area A, and 37% stopped in the traffic lane upstream of the stop bar. Dill et al. (2012) noted that only 9% of bicyclists stopped in Area A, with 64% stopping in Area B. Loskorn et al. (2013) studied bike box use before and after filling in the bike box with green pavement coloring; 9% of cyclists stopped in Area A before the color was added compared to 15% after. Casello (2017) reports that more than 65% of bicyclists observed making left turns through bike boxes “did so through the use of the intended design” but do not comment on specific areas.

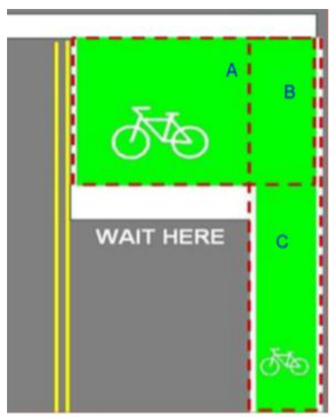


Figure 2. Cyclist Stopping Locations in Bike Boxes (Dill et al., 2012)

Johnson et al. (2010) examined compliance on two variations of the traditional bike box, neither of which included a contiguous bike-lane-into-bike-box configuration. Given three through lanes on a one-way street leading up to an intersection, one alternative placed a bike box at the head of a left-turn lane, while the other placed a bike box at the head of the center (through) lane; 65% of bicyclists complied with the former, while 53% complied with the latter. They note that bicyclists “are required to move from traveling in parallel to the drivers to stop in front of the vehicle” and hypothesize that this “need for variation in behavior may have contributed to non-compliance” (Johnson, 2010, p. 71). These compliance rates may also be higher than others due to the absence of adjacent bike lanes.

Stopping within the bike box means that bicyclists stop *after* the vehicular stop bar and *before* the edge of the pedestrian crossing. Allen et al. (2005) found that bicyclists encroached into the pedestrian crossing area 40% of the time at intersections with bike boxes compared to 54% at control sites. They also note that, at these sites, 12% of motor vehicles encroached into the pedestrian crossing, suggesting that bike boxes may provide a buffer zone that discourages such encroachment. If true, bike boxes may improve safety for pedestrians as well as bicyclists. Dill et al. (2012) observed a 77% motorist encroachment rate into crosswalks, followed by a 73% motorist encroachment rate into bike boxes following implementation. Additionally, the motorist encroachment rate into crosswalks was reduced significantly when compared to the control intersections.

Motorist noncompliance was found to be widespread and problematic. Hunter (2000) observed motor vehicles encroaching into the box in 52% of signal cycles, with 16% being severe, meaning more than half of the motor vehicle was in the box. Hunter adds that encroachment was higher during heavier traffic, among "vehicles near the end of the signal cycle that were unable to get through the signal" and speculate that "motor vehicle encroachments into the box likely diminished the amount of use" (Hunter, 2000, p. 104). Dill et al. (2012) observed that 27% of motorists encroached on the bike box. Fournier et al. (2020) used a driving simulator to explore motorist compliance with bike boxes *in the absence of (simulated) cyclists.* They found that just 24% of participants, acting as motorists, failed to stop behind the bike box, and that "drivers more familiar with bike boxes are less likely to encroach upon them" (Fournier, 2020, p. 9). Loskorn et al. (2013) examined compliance at two sites and observed diverging trends: at one site, stop line encroachment decreased by 12% after installing a bike box; at the other, encroachment increased by 34%.

Measured from the bicyclist's point of view, researchers found that "36 [%] of all [bi]cyclists across the [bike box] sites experienced some form of encroachment by vehicles" (Allen et al., 2005, p. 80). Johnson et al. (2010) observed a motorist compliance rate of 50%, hypothesizing that such low compliance rates could be due to requiring motorists to "stop behind the box, short of their "usual" position in the intersection," (p. 71) a "lack of knowledge of the purpose of the boxes, disregard for the space if no [bi]cyclists are already present, failure to notice the infrastructure or acknowledge the space as legitimate, or failure to accept [bi]cyclists as legitimate road users" (p. 71).

Compliant use of bike boxes requires bicyclists to obey traffic signals. In the Netherlands, a bike box often uses a separate bicyclist-specific signal to give the bicyclist a brief head start, but this is rare in the United States (Dill et al., 2012). Some bicyclists, already in front of a traffic queue and seeing no conflicting traffic, decide to proceed from the bike box against the signal. Hunter (2000) observed a 12% rate of bicyclists violating the signal, and no statistically significant difference before and after the bike box implementation. On the contrary, Allen et al. (2005) reports that 17% of bicyclists violated red lights at bike boxes compared to 13% at control sites (a statistically significant difference). Loskorn et al. (2013) also observed a statistically significant 15% increase in bicyclist signal violations, but only after painting the bike box green.

Dill et al. (2012) analyzed a subset of bicyclist video footage at test sites and one control site to quantify how often right-turning motorists yielded to through bicyclists. These bicyclists were not stopped in the box but traveling straight along the adjacent bike lane. They reported very large increases in the *number* of times motorists yielded to bicyclists, but not the rate. The data provided show that the *rate* of such yielding (adjusted for the number of interactions observed) was 4% at test sites prior to implementation and 20% post-implementation, compared to 3% prior and 1% post at the control site. The 492% increase in yielding rates at test sites is highly statistically significant. The bike box is therefore associated with a sharp increase in motorists yielding to bicyclists.

Several researchers analyzed conflicts as a surrogate safety measure in association with bike boxes. Hunter (2000) defined a conflict as "an interaction such that at least one of the parties had to make a sudden change in speed or direction in order to avoid the other" (p. 104) and found that conflicts were infrequent and conflict rates were similar before (1.3 conflicts per 100 entering bicyclists) and after (1.5) implementation. The survey component of the same study revealed that about half of all respondents had "encountered difficulties" using bike boxes. Bicyclists complained that motor vehicles were in the boxes and that going out in front of cars was "uncomfortable" while motorists "wanted bicycles out of the way so they could ignore the no-turn-on-red signs" (Hunter, 2000, p. 103). Allen et al. (2005) compared sites with and without bike boxes. They found a higher rate of conflicts at sites with bike boxes (1.3% of observed cyclists) than those without (0.6%) but note that the bike boxes "do not appear to have contributed to the conflicts witnessed" and "factors such as junction layout, speed and volume of traffic/traffic flows may be contributory" (p. 47).

Two sources reported safety improvements associated with bike boxes. Dill et al. (2012) observed conflicts and widely fluctuating vehicle and bicyclist counts; statistical models ultimately concluded that bike boxes, whether with or without green pavement coloring, were associated with fewer conflicts. Loskorn et al. (2013) implemented two bike boxes, then later added green pavement coloring, and counted avoidance maneuvers (defined as instances when "a bicyclist rode outside of the lane") (p. 1042) in each phase. At one site, the frequency of avoidance maneuvers increased after the non-colored bike box was installed, though not statistically significantly; and zero instances occurred after the color was added, but there were not enough observations to determine statistical significance. At the other site, the non-colored bike box was associated with a significant decrease in avoidance maneuvers. Avoidance maneuvers then increased with the addition of color but remained lower than before the non-colored bike box was installed.

Pavement coloring can be used to draw road users' attention to changes in pedestrian and bicyclist facilities, helping to convey proper use to road users. Allen et al. (2005) considered the effect of pavement color and found "a lower level of encroachment by cars" (p. 36) at colored bike boxes, but lacked vehicle flow data, and thus concluded that "it cannot be determined whether the use of colour…has an effect" (p. 36). Both bike boxes studied by Johnson et al. (2010) were green, preventing any such comparisons.

Dill et al. (2012) made qualified statements regarding the observed effects of color on vehicular stop bar encroachment and bicyclist stopping location. Counterintuitively, 28% of motor vehicles arriving at a red signal encroached upon green bike boxes compared to 23% at non-colored bike boxes (a statistically significant difference). Pavement coloring is meant to increase conspicuity, so motor vehicles should see the bike box more easily and thus encroach upon it less often, rather than more often, as observed here. The effect of coloring on bicyclist stopping locations was more intuitive: cyclists stopped in the bike box or in the adjacent bike lane (in line with the box) more often in bike boxes with color (75%) than without (66%, a statistically significant difference). Far fewer also waited in the bike lane (upstream of the box) at sites with color (5%) than without (23%, a statistically significant difference). However, they qualified these finding by admitting that "the timing of the installation of the bike boxes resulted in a less than ideal comparison group between the color and no-color locations…Therefore the difference…may be due to other intersection design or use factors” (p. 131).

Loskorn et al. (2013) designed an experiment specifically designed to explore the effects of pavement coloring. Two “skeleton” bike boxes (devoid of color) were installed and observed, then modified by adding green pavement marking (and “No Right Turn on Red” signs). Motorists responded inconsistently while bicyclists’ behaviors conformed much more closely with the intended use as a result.

Motorist behaviors were inconsistent between the two sites regarding stop line encroachment. At one site, stop line encroachment increased by 34% ($p < 0.001$) with the skeleton bike box, then decreased by 10% ($p = 0.002$) after adding color, ending significantly higher than when no bike box was installed. At the other site, encroachment decreased 12% ($p = 0.167$) then increased 16% ($p < 0.001$). They conclude that “no significant conclusions can be made about stop line encroachment because of the inconsistent results from the two sites” (Loskorn et al., 2013, p. 1045). Bike lane encroachments were also inconsistent. At one site, bike lane encroachment did not change significantly across all three configurations (no bike box, skeleton, green), while a significant ($p < 0.01$) decrease was associated with the skeleton bike box and an increase ($p = 0.058$) was associated with the green bike box at the other site.

Across both sites, adding the green was associated with statistically significant ($p < 0.05$) increases in bicyclists stopping in the bike box (from 11% to 18%) and in the adjacent portion of the bike lane (from 31% to 48%), and decreases in bicyclists stopping in the pedestrian crosswalk (from 43% to 29%) and in the vehicle lane upstream of the box (from 10% to 2%).

Attitudes, Beliefs, and Perceptions

Several studies probed bicyclists’ and motorists’ opinions on bike boxes. Overall, bicyclists were more in favor of bike boxes than motorists.

Bicyclists expressed increased perceptions of safety in several studies. In New Zealand, where motorists drive on the left, more than half of bicyclists felt the bike box made them safer when traveling straight or turning left, and “far more” were in favor of bike boxes than opposed when turning right, though specific percentages are not provided (Newman, 2002). Atkins (2005) also reported “improved cyclist perception of safety and comfort” (p. 9-1) but did not provide specifics. Johnson et al. (2010) considered the level of facility compliance among bicyclists as evidence that bicyclists “perceived the boxes to provide a safe space to wait during the red light phase” (p. 71). Only Dill et al. (2012) provided actual response rates: 77% of bicyclists indicated that the bike box made the intersection safer for them as bicyclists, 13% felt no difference, 2% felt it made the intersection more dangerous, and 8% were unsure. When asked about motorists, 81% of respondents felt that bike boxes made motorists more aware of bicyclists, but 35% felt that motorists did not understand the purpose of the boxes.

Motorists were not as supportive of bike boxes. Newman (2002) found that, of the few drivers that commented on the bike box, there were “equal numbers in favour and opposed” (p. 15). Specifically, drivers did not “appear to be too enthusiastic about having [bi]cyclists stacking ahead of them at a red signal, even though they generally understood the purpose of the [bike box]” (p. 19). Dill et al.’s (2012) survey included both motorists who were and were not also bicyclists. The survey revealed that bicyclist-motorists were “generally more positive about the bike boxes” (p. 131). Non-bicyclist-motorists felt that the boxes “made driving in the intersection safer (42% versus 14% more dangerous) and made them more comfortable driving through the intersection (33% versus 16% less comfortable)” (p. 131). In addition, although 42% of motorists found the bike boxes “inconvenient,” 52% felt they increased motorist awareness of bicyclists. Fournier et al. (2020) further explored the relationship between bicycling frequency and infrastructure familiarity among motorists. Statistical tests indicated no significant association, prompting them to conclude that “drivers can be familiar with bicycle infrastructure without being a [bi]cyclist” (p. 7).

Education Strategies

Many strategies are available to communicate the proper use of a facility to road users; however, the use of education-based strategies with bike boxes is limited. Of the studies reviewed, one study included a large public outreach effort, while others merely advocated for more education.

Hunter (2000) stands out from the other sources reviewed as the only study that employed direct and extensive educational efforts. Researchers issued a press release and published stories in the local and University of Oregon student newspapers. An oral survey administered to 661 passing bicyclists soon after the bike box was installed revealed that 59% were “not sure of [its] purpose” (p. 103). This prompted researchers to deploy instructional signs around the intersection.

An instructional sign board was installed on a construction barricade, along with a flashing light to draw attention. Two traffic signs were also mounted: on the right, a sign pointing to the stop bar (the beginning of the bike box) reading “Stop Here on Red;” on the left, a similar sign also pointing to the stop bar with “Except Bicycles” added. The feeder bike lane for this bike box was on the left side of a one-way street with three through lanes (straight, straight or right, right-only), so this configuration intuitively delivers the right message to the right road user group.

Other sources called for similar educational measures but did not include them in their analysis. Such education may reduce misuse of bike boxes, thereby increasing their effectiveness for bicyclists (Allen et al., 2005). Specifically, motorists should be informed of the new stop line and the bike box’s purpose (Loskorn et al., 2013). Fournier et al. (2020) recommended teaching drivers as they acquire a license or through public safety campaigns.

Knowledge and Comprehension

Hunter (2000) surveyed bicyclists soon after the installation of a bike box and found that 59% of respondents were “not sure” of its purpose. This prompted the addition of instructional signs discussed in a previous section. (While signs were added, they were not evaluated separately.)

Dill et al. recruited motorists to complete an online survey and conducted intercept surveys with passing bicyclists. In response to an open-ended question about the purpose of a pictured bike box, 84% of motorists “included an answer that is consistent with the intent of the bike box, such as increasing visibility of [bi]cyclists, increasing safety, having cars stop back or bikes go ahead, minimizing conflict or right-hooks, etc.” These motorists were also shown a diagram and asked what they should do when approaching an intersection with a bike box when the light is red. When the diagrams did not include a bicycle, “94% of respondents chose the correct response – stopping behind the box”. Interestingly, a significantly ($p < 0.05$) smaller proportion chose the correct response when the diagram included a bicyclist in the box. Of the surveyed bicyclists, 97% correctly identified the intent of the bike box, but “35% did not think that most motorists understood the purpose of the boxes” (Dill et al., 2012, p. 129-131).

Loskorn et al. (2013) did not directly probe comprehension, but use patterns among bicyclists suggested that adding the green pavement markings increased their understanding of the bike box.

Results from Fournier et al.'s (2020) driving simulator experiment indicate that motorists (participants) were "not very familiar with bike boxes" (p. 5), but greater familiarity was associated with a lower likelihood of encroaching upon them. Researchers also investigated the relationship between bicyclist frequency and familiarity with bike boxes, finding "no significant association" and noting that "drivers can be familiar with bicyclist infrastructure without being a bicyclist" (p. 7).

Gaps in Literature

The literature indicated that motorist understanding of the purpose of bike boxes was high, yet motorist encroachment into bike boxes was also high. Johnson et al. (2010) provided some possible explanations, such as "failure to…acknowledge the space as legitimate, or failure to accept [bi]cyclists as legitimate road users" (p. 71). However, the literature did not probe into motorists' beliefs regarding the legitimacy of bicyclists or bike boxes. Further research could uncover the cognitive predecessors to the behavior. Law enforcement presence may influence motorist compliance with bike boxes, as motorists may be less inclined to encroach when there is a possibility of getting a fine. Further research is needed to verify the possibility.

The research also suggested that bicyclists do not always comply with bike boxes, encroaching into pedestrian crossing areas. The literature reviewed did not inspect safety outcomes of the behavior, such as pedestrian-bicyclist conflict rates or collision events. Further knowledge would help stakeholders determine how to best direct efforts into educational campaigns. In addition, research has yet to gather pedestrian perceptions, beliefs, or experiences regarding bike boxes. Experiences a person has while acting as a pedestrian may carryover to when they drive a motor vehicle. The research indicates motorists have somewhat poor perceptions of bike boxes and negative interactions, acting as a pedestrian, may further deteriorate these perceptions.

Summary and Conclusions

The research indicated bicyclist compliance with bike boxes was mixed and motorist compliance with bike boxes was low. The presence of bike boxes appeared to increase motorists yielding to bicyclists. Conflicts between bicyclists and motorists appeared low at bike boxes, although some bicyclists reported difficulty interacting with motorists while using the facility. Findings regarding safety implications of green colored bike boxes were mixed. Bicyclist perceptions of bike boxes were generally more positive than those of motorists. Coloring bike boxes green appeared to influence bicyclists to stop within the facility's markings. However, coloring bike boxes green yielded mixed results for motorists. Bicyclist and motorist understanding of bike boxes appears high.

Two-Stage Turn Boxes

Two-stage turn boxes, also called *two-step crossing for left-turn bicycles* (Zhao, Yan, & Wang, 2019), *two-stage turn queue boxes* (NACTO, 2014), *two-phase left-turn boxes* (Castello et al., 2017), *two-stage bicycle turn boxes* (Knopp, 2017), *left turn boxes* (Monsere, McNeil, & Dill, 2011), and *turn boxes* (Ohlms & Kweon, 2018), are painted road markings found at both signalized and unsignalized intersections. They are typically used on multi-lane roadways, roadways with high traffic speeds or volumes, or high occurrence of left-turning bicyclists from a right-side facility. The two-stage turn box is meant to assist bicyclists turning left across traffic from a right-side cycle track or bike lane or turning right from a left-side cycle track or bike lane. In addition, the facility is intended to reduce bicyclist-motorist conflicts, prevent conflicts between other bicyclists in bike lanes and pedestrians in crosswalks, and separate turning bicyclists from through bicyclists (NACTO, 2014). Figure 3 provides an example.

Figure 3. Example Two-Stage Turn Box, in Urban Bikeway Design Guide (NACTO, 2014)

The two-stage turn box has been discussed (Knopp, 2017) in the United States since at least 1972 when it was presented in California's Bikeway Planning Criteria and Guidelines (Fisher et al., 1972). In 2014 Atlanta, Cambridge (Massachusetts), Philadelphia, Portland, New York City, Salt Lake City, and Chicago used two-stage turn boxes (NACTO, 2014).

Sources

The research team identified three studies involving road user behavior and knowledge around two-stage turn boxes.

- Monsere et al. (2011) evaluated two road sections in Portland, where motor vehicle lanes were removed to install bicycle facilities. Researchers used observational and survey methods one year after facility installation. They gathered bicyclist and motorist perceptions and observed use of the facilities.
- Casello et al. (2017) observed bicyclists making left turns at six intersections in Toronto, Canada. They recorded whether bicyclists passed through intersections legally and whether their use of the facilities were consistent with intended design. Table 5 provides a chronological overview of these sources and the road users and components present in the literature.

- The research team excluded a third study that involved two-stage turn boxes from this review due to methodological concerns. Ohlms and Kweon (2018) documented road user behaviors at a unique intersection involving both two-stage turn boxes and bike boxes. Refer to the section on bike boxes for more detail on the exclusion.

Table 5. Overview of Sources Relevant to Two-Stage Turn Boxes

Source	**Bicyclists**	**Motorists**	**Pedestrians**	**Use, Comprehension, Safety**	**Attitudes, Beliefs, Perceptions**	**Education Strategies**	**Knowledge, Comprehension**
Monsere et al., 2011	✓	✓		✓			✓
Casello et al., 2017	✓			✓			

Note: A ✓ indicates that the source does address this road user or component.

Use, Compliance, and Safety

Observational research on two-stage turn boxes suggests that use of the facility is not always consistent with the design. None of the sources reviewed investigated safety metrics such as crash rates, injury rates, or conflicts between road users.

Bicyclists not using two-stage turn boxes as intended (waiting within the two-stage turn box markings) and both bicyclists and motorists making prohibited turns were observed frequently. A study in Portland found that 29% of bicyclists waited inside the box before turning, 29% made the turn from an adjoining cycle track or waited to the side or behind the box, and 29% turned from the general-purpose lane; the remaining 13% completed an "other" action undefined by the researchers (Monsere et al., 2011). In Ontario Casello et al. (2017) observed 54% of bicyclists waiting as intended inside the box, with 70% of bicyclists completing the turn legally (with the signal).

Attitudes, Beliefs, and Perceptions

None of the sources reviewed investigated attitudes, beliefs, or perceptions regarding two-stage turn boxes.

Education Strategies

None of the sources reviewed investigated education strategies regarding two-stage turn boxes.

Knowledge and Comprehension

Only one study investigated knowledge and comprehension of two-stage turn boxes. Monsere et al. (2011) conducted intercept surveys with 125 bicyclists approximately 12 months after the implementation of a cycle track that included a two-stage turn box in Portland. Results indicate that 76% of bicyclists understood how to correctly use the facility when viewing diagrams of possible left-turn actions at a signalized intersection. Interestingly, when viewing the same diagrams, only 54% of bicyclists reported that they used the facility this way. Such rates of disuse (not using the box as intended) despite a high level of comprehension suggests a decision-making process may be involved: a substantial portion of bicyclists understand how to use the facility but choose not to for some reason. For instance, a person biking might choose to merge left into the general-purpose left turn lane to turn left and avoid the two-stage turn box process all together. Bicyclists may legally choose not to use the turn box and to proceed with vehicular traffic.

Gaps in Literature

The body of literature for two-stage turn boxes is limited. Initial findings suggest that the facilities were not always used appropriately, with proper use ranging from 29% (Monsere et al., 2011) to 54% (Casello et al., 2017) of bicyclists observed. High concomitant rates of improper use and comprehension suggest a reasoning among bicyclists that researchers have yet to explore.

Attitudes, beliefs, perceptions, and education strategies were not investigated by any of the identified sources. Future research could significantly advance the state of knowledge by exploring any of these areas. Probing bicyclists' attitudes, beliefs, and perceptions toward two-stage turn boxes could help explain the discrepancy between proper use and comprehension rates. Education—whether via public outreach, nearby signage, or law enforcement—may help bicyclists feel safer, thus bringing proper use rates into alignment with comprehension.

Comprehension was only investigated in a localized sample of bicyclists. How well the two-stage turn box is understood by a wider sample of bicyclists, or motorists in general, remains unknown.

Summary and Conclusions

Appropriate use of two-stage turn boxes is low, especially relative to comprehension rates. Many factors may explain this but have yet to be documented in the literature. Further research can bridge the current knowledge gaps and improve the effectiveness of the two-stage turn box.

Bicycle Signals and Detectors

Bicycle signals are traffic signals directed specifically toward bicyclists. They are similar to traditional motor vehicle signals with green, amber, and red colored lenses, but may also have bicycle symbols stenciled onto the lenses, or signage indicating that the signals are bicyclist-specific. Bicycle signals can be implemented alongside push buttons, signs, and pavement markings. They are intended to reduce bicyclist stress and delay and discourage unsafe or illegal crossings (NACTO, 2014). Figure 4 provides an example of a bicycle detector road marking.

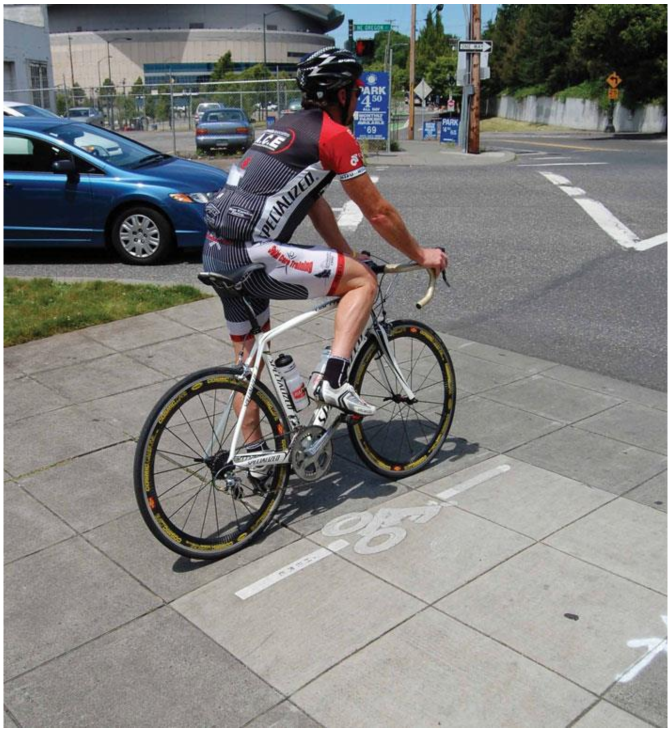


Figure 4. MUTCD 9C-7 Bicycle Detector Road Marking in Portland, Oregon (NACTO, 2014)

Bicycle detection devices sometimes complement bicycle signals (shown in Figure 5). Such devices may use push button inputs, in-pavement induction detector loops, video, or microwave. Induction detector loops designed for motor vehicles can detect bicycles but require calibration to detect the relatively smaller metallic mass of bicycles. Bicycle detectors can reduce delay for bicyclists, increase bicyclist convenience, discourage non-compliance with red signals, and can be used to lengthen bicyclist crossing phases.

Figure 5. Bicycle Signal in Washington, DC (DDOT)

The literature reviewed does not identify the first implementation of bicycle signals or bicycle detectors, but the 1978 edition of the Manual on Uniform Traffic Control Devices allowed for separate signals for bicycle facilities—the predecessor of the bicycle signal. Bicycle signals are used throughout Europe, China, and the United States (NACTO, 2014). Bicycle detectors are also used in Europe, the United States, and Australia (NACTO, 2014; Zeibots et al., 2014).

Sources

This review concerned road users' use and understanding of facilities. As such, sources focused on design guidance and excluded detection hardware and algorithms. The research team identified seven relevant studies but were unable to obtain full-text versions of two studies (Danila & Fink, 2013; Guo et al., 2014) and omitted one (Chancellor-Goddard & Johnson, 2019) due to methodological and data reporting concerns. Those concerns included: (1) of the 48 hours of video footage captured, only 12 were analyzed, with no reason provided, and (2) the design employed inconsistent data collection periods and they failed to present any statistical analysis. Of the four relevant sources reviewed, three originated in the United States and one originated in Australia.

- Chao et al. (1978) observed bicyclist use of push buttons and waiting locations at nine signalized intersections in Tempe, Arizona.
- More than three decades later, Zeibots et al. (2012) observed bicyclist use of bicycle signals and interactions with bicycle detectors at three intersections in Sydney, Australia. Bicyclists in the study approached intersections from cycle tracks.
- Bussey (2013) observed bicyclist use of induction detector loops at three locations in Portland, before and after bicycle road markings and/or signage were added. The induction detector loops were designed for motor vehicles but could be triggered by bicyclists located in precise locations. In addition, bicyclist perceptions were gathered through intercept surveys and self-administered online surveys.
- Boudart et al. (2015) also conducted a study in Portland, observing bicyclist use of a push button and a bicycle detector with a feedback light at a signalized bicycle crossing.

Table 6 provides a chronological overview of these sources and the road users and components present in the literature.

Table 6. Overview of Sources Relevant to Bicycle Signals and Detectors

Source	Bicyclists	Motorists	Pedestrians	Use, Comprehension, Safety	Attitudes, Beliefs, Perceptions	Education Strategies	Knowledge, Comprehension
Chao et al., 1978	✓			✓			
Zeibots et al., 2012	✓			✓			
Bussey, 2013	✓			✓			✓
Boudart et al., 2015	✓			✓		✓	✓

Note: A ✓ indicates that the source does address this road user or component.

Use, Compliance, and Safety

The sources reviewed investigated several behaviors surrounding bicycle signals and detectors, including bicyclists' use of push buttons, bicyclist waiting locations, and signal compliance. The identified research did not address safety.

Chao et al. (1978) observed bicyclist use of three types of push buttons at signalized intersections, including: pedestrian push buttons (not intended for bicyclists), pedestrian/bicyclist push buttons (intended for both road users), and bicyclist push buttons (intended for bicyclists only). Overall, 46% of bicyclists used one of the three types of push buttons. The presence of bike lanes was not associated with significant differences in push button use, nor was the presence of motor vehicles. Only 18% of bicyclists who arrived after other bicyclists used push buttons. Researchers hypothesize that these bicyclists had seen others use the push buttons or assumed they had. When comparing bicyclist use of different types of push buttons, researchers found the highest rate for bicyclist push buttons (48%), followed by pedestrian/bicyclist push buttons (33%), followed by pedestrian push buttons (14%). The research suggests that although push buttons intended for bicyclists are only used about half of the time, bicyclists use them more frequently than other types of push buttons.

Chao et al. (1978) also documented bicyclist waiting locations among the three push button types. Researchers found that bicyclist-specific push buttons were associated with the greatest proportion of bicyclists waiting in front of the crosswalk in the bicycle lane (when present), and in front of the crosswalk directly adjacent to the sidewalk (when a bicycle lane was not present). They hypothesized bicyclists thought this was the most appropriate waiting area. Sites that had pedestrian/bicyclist push buttons were associated with the greatest proportion of bicyclists waiting in an area defined by the sidewalk, crosswalk, and the right corner of the intersection. This area was thought to obstruct the right-of-way of right-turning motor vehicles and crossing pedestrians, posing the greatest risk of collision. Taken with relatively lower usage rates than bicyclist push buttons, researchers concluded that the pedestrian/bicyclist push button was not a desirable design.

Bicyclist waiting location has also been studied at bicycle signalized intersections with bicycle detectors. Zeibots et al. (2014) recorded bicyclist waiting locations at three intersections where bicyclists approached from cycle tracks. No road markings or signs indicated where bicyclists should place themselves to be detected. Researchers observed 32% to 40% of bicyclists stopping at the proper location to activate the bicycle signals. The majority of bicyclists (35% to 51%) stopped ahead of the detection area, which researchers noted mirrors the behaviors of bicyclists at non-cycle track locations. While no data is presented to verify non-cycle track bicyclist behavior, researchers hypothesized that the forward location increased bicyclist visibility and safety, and avoided motor vehicle exhaust.

Bussey (2013) explored methods of influencing bicyclists to wait at locations where they would activate bicycle detectors. In this case, inductive detection loops designed for motor vehicles were used, but bicyclists could trigger them from precise locations. Adding a road marking stencil of a bicyclist (see: MUTCD's 9C-7 Bicycle Detector Symbol, shown in Figure 6) with a green background was most effective at influencing bicyclists to wait over the proper location of the loop detector; 48% of bicyclists did so when encountering this stencil, compared to 24% of bicyclists who encountered the stencil without a background color. Interestingly, installing an explanatory MUTCD R10-22 road sign (shown in Figure 7) with a stencil (no background) resulted in 35% of bicyclists waiting at the proper location to activate the detector.

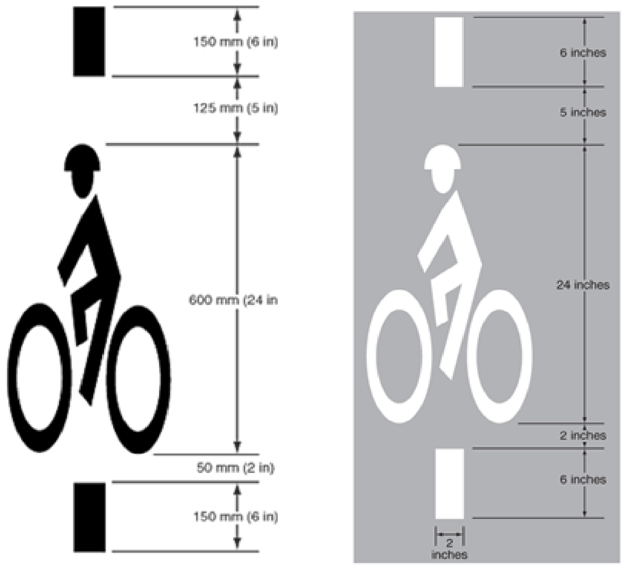


Figure 6. MUTCD 9C-7 Bicycle Detector Pavement Marking (MUTCD, 2012)

Figure 7. MUTCD R10-22 Bicycle Signal Actuation Sign (MUTCD, 2012)

Boudart et al. (2015) evaluated a feedback light on a bicycle signal with a detector. Researchers added a blue feedback light to the face of bicycle signal that illuminated when bicyclists triggered an inductive loop detector. The loop detector was embedded in the sidewalk of a signalized bicycle crossing. Bicyclists could call for a green phase of the signal by pushing a button or placing their bicycle over a bicycle icon (MUTCD 9C-7) sidewalk marking that denoted the location of the detector loop. While a “Bike Signal” sign was present below the bicycle signal, an explanatory (MUTCD R10-22) sign was not. The blue feedback light was associated with a significant increase in the proportion of bicyclists waiting over the stencil from 15% before installation to 21% after. In a subsequent phase of observation, researchers placed a sign board near the crossing that gave information about the blue feedback light. After adding the sign board, the proportion of bicyclists waiting over the stencil (not using the push button) increased from 21% to 45% while the proportion pressing the button (and waiting beside it) decreased from 60% to 38%. The research suggested that a blue feedback light on a bicycle signal may increase proper bicyclist waiting location, but not as strongly as an informational sign.

Results on bicyclist compliance with bicycle signals were mixed. At intersections where bicyclists could see both motor vehicle signals and bicycle signals, 32% to 51% of bicyclists did not stop for red bicycle signals and followed the direction of green motor vehicle signals (Zeibots et al., 2012). No signs explaining the use or presence of bicycle detectors were displayed at study locations. They hypothesized that bicyclists may have made their own safety assessments—as the majority checked behind themselves for motor vehicles—but did not provide data to support this claim. Another plausible explanation is that bicyclists thought that the signals were broken or did not detect them, so they proceeded using the vehicle signals. At a bicycle crossing that included a bicycle detector, Boudart et al. (2015) observed that over 92% of bicyclists complied with a bicycle signal. Compliance rates did not significantly change after a feedback detector light or sign presenting information on the feedback light were installed. It is possible that compliance did not change from 92% due to a ceiling effect.

Attitudes, Beliefs, and Perceptions

None of the sources reviewed investigated attitudes, beliefs, or perceptions regarding bicycle signals or bicycle detection.

Education Strategies

One study included an education component. As described in a previous section, Bourdart et al. (2015) examined bicyclist behaviors at a signalized crossing with an induction detector. During the first phase, researchers observed 60% of bicyclists used the call button and 21% position themselves over the stencil. When the sign board was added, call button use decreased to 38% and waiting on the pavement marking increased to 45%. Over all phases, a constant proportion of bicyclists used the call button and then moved to the stencil (3% to 5%) or did not comply with the signal (13% to 14%). These results suggested that bicyclists may not have previously understood the meaning of the MUTCD 9C-7 symbol. Once they learned its meaning, from the sign, more bicyclists used the symbol, but a significant proportion continued to use the call button. They did not provide possible explanations for the final composition of behaviors.

Knowledge and Comprehension

Only one of the reviewed sources investigated bicyclist knowledge and comprehension surrounding bicycle detection. Bussey (2013) showed bicyclists photographs of signalized intersections that included an MUTCD 9C-7 bicycle detector stencil in the center of the roadway and asked where they would wait at a red signal, and why. Fifty-seven percent of bicyclists indicated that they would wait over the stencil; of which 51% would do so to trigger the signal and 31% simply because the location was marked. Twenty-two percent of bicyclists responded that they would wait within 5 feet of the curb; of which 56% would do so to stay out of traffic and 40% for visibility or safety purposes. Fifteen percent indicated that they would wait between 5 and 10 feet from the curb; of which 59% would do so to stay out of traffic. The remaining bicyclists would wait somewhere over the large loop detector (designed for motor vehicles) but not over the specific stencil location; the reasons for choosing this location varied, but not in a systematic fashion.

Bussey (2013) also used intercept surveys to assess bicyclists' comprehension of the MUTCD 9C-7 bicycle detector road marking. Of the respondents, 46% correctly identified its purpose as the waiting location where a bicyclist would be detected. Further, 34% of bicyclists believed the stencil indicated a bicycle lane; 12% thought it was a bicyclist waiting location only, with no relation to the detector; 7% did not know what the stencil meant; 2% believed it meant bicycles were allowed in the location; and 1% gave other answers. The results indicated a lack of understanding of bicycle detector road markings among bicyclists.

Gaps in Literature

The literature review studied bicyclist waiting locations at bicycle-signalized intersections, discussing the findings in terms of safety with some locations considered safer than others. Further research that focuses on safety outcomes, such as collision and injury rates, could verify these claims and identify differences between motor-vehicle-signalized intersections and bicyclist-signalized intersections. Certain types of collisions may be more likely at bicycle-signalized intersections.

Research that explored bicyclist understanding and use of bicycle detection systems focused on induction detector loops. Embedded in the pavement, with sometimes small detection areas, bicyclists may not understand how to operate them properly. Other detection methods, such as camera-based systems, may be more easily understood due to familiarity with the technology. A bicyclist unfamiliar with bicycle detection methods may understand the purpose of a camera, as they are encountered more often in day-to-day life, more readily than a detector loop embedded in the pavement, which is only found in specific roadway settings. However, confusion about the camera's purpose may arise; further research would be required.

A blue feedback light was studied to evaluate its effects on bicyclists using a bicycle signal at a road crossing (Boudart et al., 2015). It may be that the feedback light is not appropriate to use in other circumstances where other road users are present. Pedestrians and motorists may be confused about the purpose of the light, as blue is not a common motor vehicle signal color, but rather used for emergency vehicles. Due to the dynamic environment of intersections, bicyclists may also overlook the signal when attending to motor vehicles and/or pedestrians.

Education strategies relating to bicycle signals or detectors is limited. Research conducted by Boudart et al. (2015) suggested that presenting information on a sign increased bicyclists' use of an induction detector indicated by the MUTCD 9C-7 symbol. However, even with this information, 45% of bicyclists positioned themselves over the marking while 38% continued to use the call button. Continuing research could expand upon these findings to uncover methods to further increase use of bicycle detection systems, or why some bicyclists choose to use the call button instead.

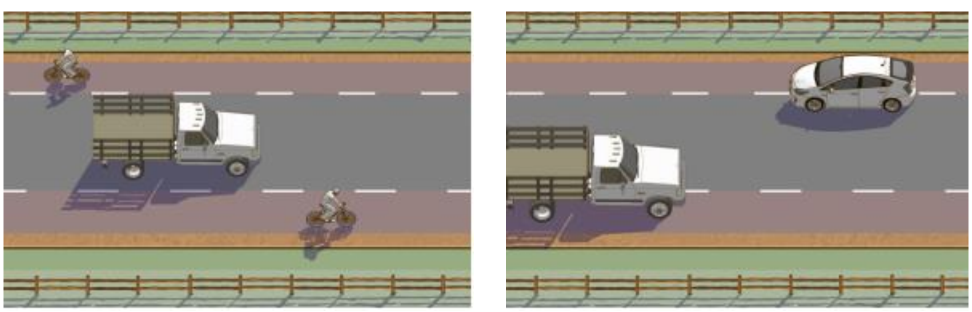
Researchers have not yet addressed law enforcement activities regarding bicycle signals and detection. Bicyclists were observed complying with motor vehicle signals instead of bicycle signals when no signs or road markings were present (Zeibots et al., 2012). Law enforcement presence may result in higher proportions of bicyclists complying with bicycle signals in similar situations. However, the combination of law enforcement and ambiguous signals may cause bicyclists to revert to learned behaviors and disregard the bicycle signal to a greater degree than previously observed.

Summary and Conclusions

The research indicated that approximately half of bicyclists used push buttons at signalized intersections, with bicyclist-specific push buttons garnering higher use than bicyclist/pedestrian or pedestrian-specific alternatives. These bicyclist-specific push buttons are associated with bicyclists waiting at safe locations at intersections, while bicyclist/pedestrian push buttons are associated with bicyclists waiting at locations that expose them to risk of collision with motor vehicles. When approaching intersections with bicycle detectors, signage and road markings appeared to influence bicyclist waiting locations. Findings suggested that when no signs or road markings were present, a greater proportion of bicyclists waited ahead of the detection area rather than within it. The MUTCD 9C-7 bicycle detector pavement marking was more effective at guiding bicyclists to wait at the proper location than the informational MUTCD R10-22 sign, especially when used with a green background. Adding feedback to bicyclist detection systems further increased the proportion of bicyclists waiting at the appropriate location to be detected, especially when information about the feedback was presented. However, one-third of surveyed bicyclists believed that this marking denoted a bicycle lane.

Advisory Bike Lanes

The *advisory bike lane* goes by many names. FHWA uses both "advisory shoulder" (2016) and "dashed bicycle lane" (2017); Kassim et al. (2019) uses "advisory bike lane" but mentions "non-compulsory bicycle lane" and "suggestion lane" as alternatives. Advisory bike lanes (ABLs) typically appear in pairs, on both sides of a low-volume, low-speed, two-way road with no centerline (Amiton et al., 2010; FHWA, 2016; FHWA, 2017). The lanes designate reserved space for bicyclists and pedestrians, only to be used by motorized traffic when two motor vehicles meet. In such cases, motorists are meant to encroach into the ABL, yielding to non-motorized traffic, and then re-merge back into the traffic lane (FHWA, 2017). Figure 8 provides a basic diagram.



(Left) Motorists travel in the center two-way travel lane. When passing a bicyclist, no lane change is necessary.

(Right) When two motor vehicles meet, motorists may need to encroach into the advisory shoulder space.

Figure 8. Advisory Bike Lane Diagram (FHWA, 2016)

ABLs are "relatively new" in the United States and Canada (Kassim et al., 2019). FHWA currently considers the facility experimental, with five active official experiments in Minnesota, Montana, and Virginia (FHWA, 2017). Williams (2017) describes eight more existing implementations, including one in Ottawa, the focus of Kassim et al.'s (2019) study. Several sources (Gilpin et al., 2017; Williams, 2017) asserted that many ABLs exist in Europe, but the researchers could not confirm the number of existing ABLs.

Sources

The research team found very little scientific literature regarding ABLs.

- Cooper and Wright (2014) indirectly studied ABLs by removing centerlines from several road segments with bike lanes using dashed pavement markings.
- Gilpin (2017) presented 10 case studies, including photos and diagrams of pavement markings and signage.
- The researchers identified Kassim et al. (2019) as the only analysis of the ABL, carried out in Canada. The subsequent sections discuss these three studies in greater detail. Table 7 provides a chronological overview of these sources and the road users and components present in the literature.

The research team identified several other sources that provided guidance or lessons learned, but no behavioral or safety analysis.

- Amiton et al. (2010) described best practices learned from implementations in Portland.
- FHWA (2016) provided guidelines regarding motor vehicle speeds and volumes appropriate for ABLs.
- Williams (2017) compared the design specification of many of the same implementations.

It is important to note that some of these and other sources claim that the ABL is safe, but there is no research to support this claim.

Table 7. Overview of Sources Relevant to Advisory Bike Lanes

Source	Bicyclists	Motorists	Pedestrians	Use, Comprehension, Safety	Attitudes, Beliefs, Perceptions	Education Strategies	Knowledge, Comprehension
Cooper and Wright, 2014	✓	✓		✓			
Gilpin et al., 2017	✓	✓		✓	✓	✓	✓
Kassim et al., 2019	✓	✓		✓			

Note: A ✓ indicates that the source does address this road user or component.

Use, Compliance, and Safety

Research has investigated motorist speed and bicyclist positioning in the presence of ABLs but has not yet considered safety metrics.

Cooper and Wright (2014) and Kassim et al. (2019) examined motorist speeds in the presence of ABLs. Cooper and Wright removed the centerlines and expanded bike lanes (already using dashed lines) on three road segments, essentially installing ABLs, while using another segment as a control. Modest decreases in speeds were observed; one site saw a statistically significant (at the 90% confidence level) decrease in speeds from 29.2 mph to 28.3 mph. Posted speed limits on these segments were not reported. As the data collection timeframe is not provided, the amount of time it took to produce this effect in drivers is unknown. They conclude by stating that collisions will be monitored for three years following implementation for effects on safety.

Kassim et al. (2019) conducted a before-after study of an ABL implementation in Ottawa. One year following implementation, speeds and several lateral distances were measured. They observed a 5% decrease in the 85th percentile speed among motor vehicles (from 32.85 to 30.81 km/h) and an 8% increase in average bicyclist speed. Both speed changes were statistically significant. The increase in bicyclist speed is attributed to "increased comfort…within the defined operating spaces and a reduction in the variation of the travel path" (p. 7). Bicyclists were found to use these defined operating spaces more reliably as well. One of the two parallel ABLs in this study was adjacent to a curb, while the other ran adjacent to roadside parking, with a small buffer space providing some distance between bicyclists and parking vehicles. Bicyclists' lateral positioning relative to the curb did not change, but the average distance between bicyclists and the buffer edge line significantly decreased from 1.09 m to 0.68 m after implementation. The average lateral distance between bicyclists and motor vehicles also increased by a statistically significant 0.51 m (the weighted average of the change in lateral distance when vehicles and bicycles were traveling in the same and different directions). They added to this finding by observing that "when cyclists are seen to be using [an ABL], the opposing motor vehicle tried to distance themself as far away as possible from the cyclist, even when a safe encroachment into the other [ABL] on the other side of the road can be made" (p. 9).

Gilpin et al. (2017) described the only crash known to the them to be associated with ABLs to date. It occurred in Edina, Minnesota, when a motorist moved aside for oncoming traffic and struck a car parked legally in the adjacent parking lane. The driver reported being "a little confused with the newly painted bike lanes" despite behaving in accordance with the ABL's intended use (p. 28).

Attitudes, Beliefs, and Perceptions

None of the sources reviewed investigated attitudes, beliefs, or perceptions regarding ABLs. Gilpin et al. (2017) briefly describes the public's response in 10 case studies, summarized in Table 8.

Table 8. Summary of ABL Case Studies (Gilpin et al., 2017)

Location	Public Response
Alexandria, Virginia	Meetings prior to implementation “yielded positive and negative reaction…Little reaction occurred after the facility was installed.”
Bloomington, Indiana	“Little public response and no negative response at all.”
Boulder, Colorado	“The number of post-installation comments was small. Some bicyclists questioned the need for the facility given that the unmarked street was already working well.”
Burlington, Vermont	“Prior to implementation, two people expressed confusion about the facility. Following installation, some cyclists expressed concern over lane widths.”
Cambridge, Massachusetts (Irving and Scott Streets)	“Post-installation reaction from bicyclists was positive. Some concerns were received from drivers who wondered if the street had been converted to one-way travel.”
Cambridge, Massachusetts (Lakeview Avenue)	“Post-installation reaction from bicyclists was positive. No other response was received”
Edina, Minnesota (West 54th Street)	“There was virtually no response to this facility, aside from favorable input from bicyclists.”
Edina, Minnesota (Wooddale Avenue)	“Significant public opposition following installation convinced the city council to remove the facility shortly after installation.”
Hanover, New Hampshire	“Pedestrians and bicyclists called it the “best thing the city could ever do.” Initial opposition focused on perceived safety hazards.”
Minneapolis, Minnesota	“Public concerns declined significantly one month after installation. Little response was received from bicyclists. During a survey, some wondered why they were being surveyed about what they thought was a regular bike lane.”
Ottawa, Ontario	“Some concerns around safety were expressed prior to installation but only one negative comment was received after installation.”
Sandpoint, Idaho	“Residents expressed some concern around safety before implementation. Most responses after installation consisted of complaints or confusion around whether the street had been converted to one-way travel or not.”

Education Strategies

None of the scientific sources reviewed investigated education strategies regarding ABLs.

Kassim et al. (2019) failed to mention or analyze the effects of public outreach surrounding the ABL implementation in Ottawa, but Gilpin et al. (2017) described extensive public education efforts. Several sites covered in Gilpin et al. used particularly informative signs. These signs instructed drivers to share the center lane and yield to bicycles when passing. Other sites used standard bike lane signage or no sign at all. Figure 9 shows the sign installed at one site in Cambridge, Massachusetts. The research also described public outreach activities. These efforts included flyers, a video on the city’s website, public service announcements, an online media campaign, a print media campaign, interviews on local new programs, and temporary signs diagramming its operation when it was first installed. The effects of this outreach, however, were not quantified by the authors.

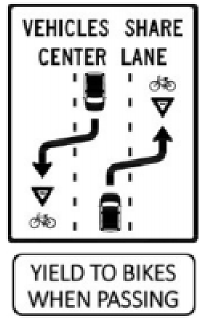


Figure 9. Example ABL Signage (Gilpin et al., 2017)

Knowledge and Comprehension

None of the sources reviewed investigated knowledge or comprehension regarding ABLs. However, commentary in Gilpin et al. (2017) indicates a degree of confusion among motorists. Motorists in Cambridge, and in Sandpoint, Idaho, expressed confusion about whether the street had been converted to one-way travel. The motorist involved in the crash also expressed confusion regarding the “newly painted bike lanes” (p. 28). Bicyclists responding to a survey in Minneapolis thought an ABL was a “regular bike lane” (p. 32). These misunderstandings could lead to safety-critical discrepancies in driver expectations. Although ABLs should only be implemented on low-speed roads, bicyclists and pedestrians are still susceptible to injury.

Gaps in Literature

As the ABL remains a novel facility, little research has been conducted, and many knowledge gaps persist.

Cooper and Wright (2014) and Kassim et al. (2019) performed limited investigations into the use of ABLs by motorists and drivers. None of the sources reviewed investigated use by pedestrians. Compliant use by motorists involved encroaching into the ABL while yielding to non-motorized traffic when meeting oncoming vehicles. This maneuver created a potentially dangerous situation for pedestrians and bicyclists as it placed them in the path of motorized traffic and likely requires a significant decrease in speed on the part of the driver. Drivers may misjudge the position and/or speed of ABL users and collide with them. To date, no safety analysis has been conducted, so the frequency of this outcome is unknown.

A quantitative analysis of road users’ attitudes, beliefs and perceptions has yet to be published. Gilpin et al. (2017) mentioned several surveys conducted by local organizations, but the research team could not locate the referenced documents.

The effects of education strategies have yet to be determined. Gilpin et al. (2017) described the public outreach conducted at several sites, but did not make a comparison among these sites. This source may be informative in the site selection phase of future studies seeking to quantify differences attributable to education efforts.

As described in previous sections, comprehension may be insufficient among all road users. Gilpin et al. (2017) reported confusion among motorists and bicyclists, but this was anecdotal rather than quantitative. Simple surveys presenting photos of ABLs could probe various road users' understanding of them.

None of the resources mentioned law enforcement; thus, it is unclear how instrumental law enforcement could be in promoting safe, compliant use by all road users.

Summary and Conclusions

ABLs are still novel in the United States and Canada. Their prevalence in Europe may be widespread but the research team could not verify the claim. Researchers found ABLs to decrease motorists' speed (Cooper & Wright, 2014; Kassim et al., 2019) and improve bicyclist-motorist lateral separation (Kassim et al., 2019), but long-term effects on safety are unclear. There appears to be confusion among motorists who interpret the lack of a centerline as indicative of one-way travel and among cyclists who do not see a difference between ABLs and traditional bike lanes (for whom there is functionally very little difference). Much remains unknown about ABLs. Official experiments registered with FHWA may close some knowledge gaps in the future.

Buffered Bike Lanes

Buffered bike lanes, also referred to as *buffered bicycle lanes* (Goodno et al., 2013), *bike lanes plus buffer* (Duthie et al., 2010), *separated bicycle paths by lane markings* (Li et al., 2012), and *buffer-separated preferential lanes* (MUTCD, 2009), are standard bike lanes separated from motorized traffic by painted road markings (Figure 10) or parking lanes (with the bike lane situated between the parking lane and the curb). They are intended to be used on streets with high vehicle speeds, high traffic volumes, and/or high truck traffic. They can also be found on streets with extra motor vehicle lanes or extra motor vehicle lane width (NACTO, 2014). Cycle tracks are very similar but separate drivers and bicyclists with some sort of physical barrier as opposed to road markings; this section exclusively addresses buffered bike lanes.

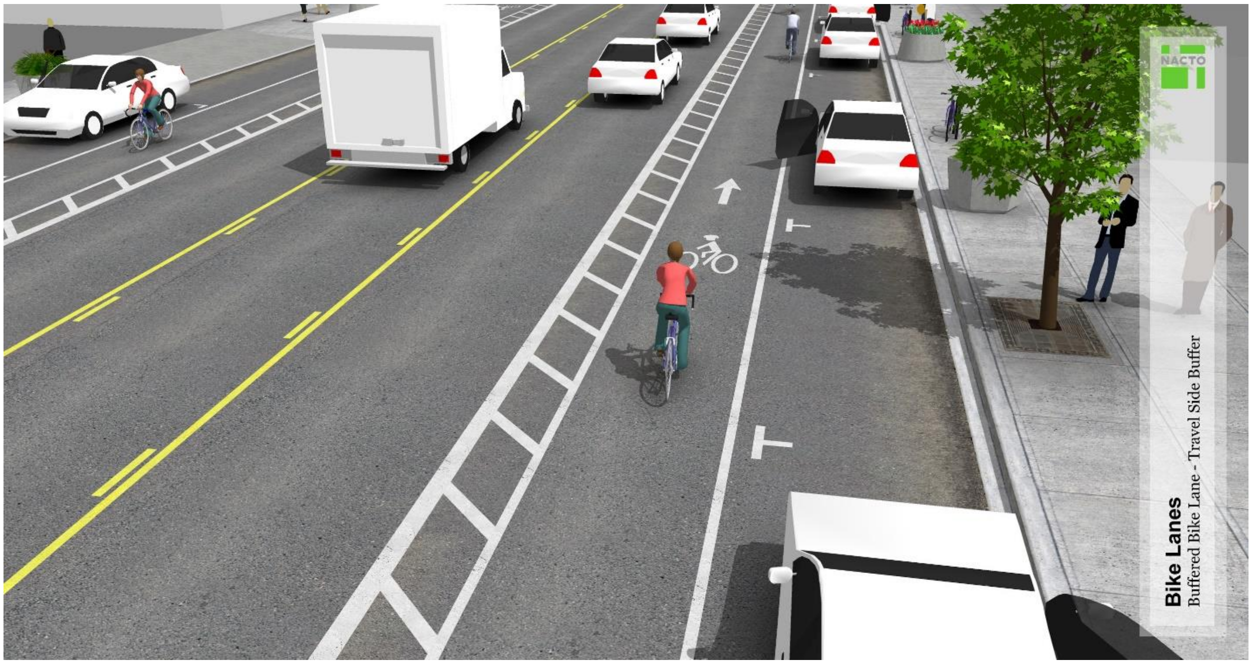


Figure 10. Sample Buffered Bike Lanes, in Urban Bikeway Design Guide (NACTO, 2014)

As of 2020, cities using buffered bike lanes included Nanjing, China (Li et al., 2012); Manitoba, Canada (Suderman & Redmond, 2013); Fort Lauderdale, Florida (Sando & Hunter, 2014); San Jacinto, Texas (Duthie, 2010); Austin, Texas (Duthie, 2010; NACTO, 2014); San Francisco, California (Monsere et al., 2015; NACTO, 2014); Portland, Oregon (Monsere et al., 2015; NACTO, 2014); Washington, DC (Monsere et al., 2015; Parks et al., 2014); Marin County, California; Billings, Montana; Cape Coral, Florida; Los Angeles, California; Minneapolis, Minnesota; New York City, New York; Phoenix, Arizona; Seattle, Washington; and Tucson, Arizona (NACTO, 2014).

Sources

The research team identified nine sources relevant to road users' use and understanding of buffered bike lanes. The research team omitted one study (Parks et al., 2013) as it discusses the same study as Goodno et al. (2013). Thus, this review describes eight studies.

- Duthie et al. (2010) studied bicyclist behavior at sites in Austin, San Jacinto, and San Antonio, that included a buffer between bike lanes and parked motor vehicles.
- Monsere et al. (2011) also studied bicyclist behavior on buffered bike lanes, but the buffer zones evaluated were located between motor vehicle traffic and bike lanes; researchers also gathered bicyclist and motorist perceptions of the facility. They evaluated two road sections in Portland where motor vehicle lanes were removed to install buffered bike lanes.
- Monsere et al. (2012) using findings from their previous research, further discussed the perceptions of bicyclists and motorists regarding the buffered bike lanes.
- Goodno et al. (2013) also measured perceptions with an intercept survey as part of a before-after assessment of a buffered bike lane in Washington, DC.

- Suderman and Redmond (2013) present the results of the evaluation of an innovative buffed bike lane design in Winnipeg.
- Sando and Hunter (2014) compared motorist and bicyclist behaviors on buffered and non-buffered bike lanes in Fort Lauderdale.
- Shifting focus toward intersections, Monsere et al. (2015) compared five types of intersections with unique combinations of bicycle facilities to understand how bicyclists and motorists interacted with each other.
- More recently, Sanders and Judelman (2018) conducted an address-based sample survey for Michigan residents to gather bicyclist and motorist attitudes, habits, and preferences toward bicycling and roadway design features, including buffered bike lanes.

Table 9 provides a chronological overview of these sources and the road users and components present in the literature.

Table 9. Overview of Sources Relevant to Buffered Bike Lanes

Source	Bicyclists	Motorists	Pedestrians	Use, Comprehension, Safety	Attitudes, Beliefs, Perceptions	Education Strategies	Knowledge, Comprehension
Duthie et al., 2010	✓			✓			
Monsere et al., 2011	✓	✓		✓			
Monsere et al., 2012	✓	✓		✓	✓		✓
Goodno et al., 2013	✓	✓		✓			✓
Suderman & Redmond, 2013	✓		✓		✓		
Sando & Hunter, 2014	✓	✓		✓			
Monsere et al., 2015	✓	✓		✓			✓
Sanders & Judelman, 2018	✓	✓		✓	✓		

Note: A ✓ indicates that the source does address this road user or component.

Use, Compliance, and Safety

The literature indicated that bicyclist volumes increased after the installation of buffered bike lanes, but compliance with signals at intersections serviced by the facility ranged from high to low. Researchers observed conflicts between bicyclists and motorists at intersections and the safety benefits of buffered bike lanes became more apparent at other road sections.

Research suggested that installing buffered bike lanes was associated with increased bicyclist volumes on the streets they service. Survey responses revealed that 65% of bicyclists chose to travel on specific streets more often after buffered bike lanes were installed (Monsere et al., 2011), and 71% of bicyclists would choose a longer route if it had buffered bike lanes (Monsere et al., 2012). Further observation verified the bicyclists' claims with a 271% increase in bicyclist counts at one location and 71% increase at another (Monsere et al., 2011). Researchers believed the 71% increase was an underestimate because they measured bicyclist counts before and after installation at different locations. Other research has supported these findings; bicyclist counts increased more than 250% after the installation of buffered bike lanes in Washington, DC (Goodno et al., 2013).

The intended use of buffered bike lanes for bicyclists simply states that bicyclists ride within the bike lane, as opposed to the buffer section or the traffic lane. Monsere et al. (2015) found high compliance with buffered bike lanes (using the lane as intended) at an intersection; 93% of bicyclists traveled straight through and 86% of motorists turned properly. It is important to note that in addition to a buffered bike lane, this intersection also included "sharrows"[4] and was preceded by a cycle track that included restricted-entry posts. While compliance was high, it is unknown how the other facilities influenced the findings. Observation of motorists revealed that when turning right across a buffered bike lane, 57% turned from the motor vehicle lane, while 37% traveled into the buffered bike lane before executing the turn (Monsere et al., 2011).

Goodno et al. (2013) conducted research on another aspect of compliance, *motor vehicle signal* compliance, on approach from buffered bike lanes. In their limited observations, they found that an average of 42% of bicyclists disobeyed motor vehicle signals at intersections that were serviced by buffered bike lanes, and higher violation rates occurred at intersections with low traffic volumes (Goodno et al., 2013). Surveys conducted in the same study indicated that bicyclists understood the rules but chose not to follow them.

Conflicts can arise when motor vehicles cross buffered bike lanes in the path of bicyclists, as they do when turning. Survey data from bicyclists revealed relatively high interactions with right-turning motor vehicles while using buffered bike lanes: 30% had witnessed a near-collision and 36% were involved in a near-collision as the motor vehicles performed this action (Monsere et al., 2012). Other research found more crashes involving bicyclists after buffered bike lanes installation, even after accounting for increased bicycle volume (Goodno et al., 2013).

Findings suggested buffered bike lanes may improve safety for bicyclists. When comparing a buffered bike lane to a bike lane without a buffer, researchers observed that the buffer allowed bicyclists to ride outside the area where motor vehicle doors open into (Duthie et al., 2010). This reduced the chance of a bicyclist inadvertently colliding with an opened vehicle door. In addition, the distance between passing motor vehicles and bicyclists was greater on a road with a buffered bike lane than on one with a bike lane without a buffer (Sando & Hunter, 2014).

Attitudes, Beliefs, and Perceptions

Research suggested different perceptions of buffered bike lanes between bicyclists and motorists.

Attitudes toward buffered bike lanes were generally positive among bicyclists. Survey data revealed that bicyclists believed the facilities made it safer for them (Monsere et al., 2012). Respondents to the survey administered by Sanders and Judelman (2018) indicated that separated bicycle facilities would encourage them to bicycle more often, and that they would be more comfortable bicycling alone or with children; although cycle tracks with physical barriers and separated bike paths were preferred over buffered bike lanes, buffered bike lanes were preferred over the absence of bicycle facilities overall. Similarly, Suderman and Redmond (2013)

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[4] A sharrow is a shared-lane marking, and comes from merging the words share and arrow. It is a roadway marking of a bike between two wide arrows, indicating vehicles and bicyclists share that lane.

conducted a questionnaire with users of an innovative buffered bike lane facility, which incorporated a bus platform and pedestrian way-finding measures, in the City of Winnipeg. The results of the questionnaire showed that, while bicyclists were initially cautious when using the facility, users had no trouble maneuvering through the facility and felt comfortable and safe.

Motorists did not always share positive perceptions toward buffered bike lanes. Researchers found 61% of motorists surveyed felt that driving became less convenient with the installation of the facility and 56% thought parking became more stressful and challenging, but 64% liked that bicycles and motor vehicles were more separated because of the facilities (Monsere et al., 2012).

Education Strategies

None of the sources reviewed investigated education strategies regarding buffered bike lanes.

Knowledge and Comprehension

Researchers identified considerable confusion regarding buffered bike lanes among both bicyclists and motorists. Monsere et al. (2012) found that 36% of bicyclists were unsure when motor vehicles were allowed in buffered bike lanes. Goodno et al. (2013) found that approximately half of motorists incorrectly believed that motor vehicles were prohibited from crossing into buffered bike lanes when parking or turning. When asked about intersections serviced by buffered bike lanes, 44% of motorists thought the signals, signs, and street markings failed to make clear who had right-of-way. Monsere et al. (2015) found that 55% of bicyclists in Portland incorrectly believed that the buffer portion of the facility was the proper location for bicyclists. Researchers hypothesized these perceptions were due to the omission of crosshatch painted markings, as is recommended by NACTO.

Gaps in Literature

The sources described in this review highlight compliance and comprehension issues among motorists and bicyclists as well as a prevalence of near-collisions and crashes involving bicyclists.

Studies observed a range of compliance rates among bicyclists traveling through intersections with buffered bike lanes (Goodno et al., 2013; Monsere et al., 2015). Other road features may be responsible for part of this difference, but researchers did not find a direct comparison.

Understanding of certain aspects of buffered bike lanes appears lacking. Education efforts can remedy this, but research has not yet explored the topic. Additional signage, especially at intersections, could help to improve all road users’ understanding of buffered bike lanes. Public outreach or increased law enforcement may achieve the same effect.

The prevalence of near-collisions and crashes involving bicyclists and motorists at intersections with buffered bike lanes is concerning because the purpose of the facility is to separate the two road users. This separation may be so effective as to lead to motorists to not expect bicyclists at intersections. Motorists may believe they have the right-of-way and expect bicyclists to yield to them. Alternatively, motorists may insufficiently scan for bicyclists or may not have sufficient time to scan for and react to faster moving bicyclists in buffered bike lanes when approaching intersections. Exploring these gaps may lead to new design guidance to improve safety for bicyclists.

Summary and Conclusions

Bicyclists appeared to favor buffered bike lanes. Several sources documented increased bicyclist volumes associated with buffered bike lane installations. Survey responses indicated that bicyclists felt safer on them, despite approximately one-third of respondents having witnessed or experienced near-collisions with right-turning motor vehicles. Signal non-compliance among bicyclists may explain part of this pattern, but the relationship is unclear. Motorists did not share these sentiments, and indicated increased inconvenience and stress associated with buffered bike lanes.

Both types of road users exhibited confusion regarding proper use of buffered bike lanes. Motorists appeared unclear as to when they can cross the buffer and who had the right-of-way at intersections, while bicyclists were unclear about where they should ride within the facility.

Buffered bike lanes may improve safety by increasing the space between bicyclists and moving and parked motor vehicles. At intersections, however, the impact on safety is unclear. Future research may address this and other knowledge gaps.

Contraflow Bike Lanes

Contraflow (or contra-flow) bike lanes are also known as *counter-flow bike lanes* (Bjørnskau et al., 2012) and *limited one-way streets* (Chalanton & Dupriez, 2014). These bike lanes allow bicyclists to travel in the opposite direction of one-way vehicular traffic (Pritchard et al., 2019) and may be appropriate where the 85th percentile speed is less than 25 mph or vehicle flows are less than 1,000 vehicles per day (Department for Transport, 1998). They may be designated with signs, pavement markings, or physical buffers (Department for Transport, 1998; Ryley & Davies, 1998; Barnes & Schlossberg, 2013). Figure 11 shows a contraflow bike lane.

Figure 11. Contraflow Bike Lane in Baltimore, Maryland (NACTO, 2014)

In the United Kingdom, three main design types exist: conventional contraflow bike lanes include physical segregation at both ends of a one-way street with signage indicating that bicycles are permitted and vehicles are not; “false one-way streets” are those with two-way status, but motor vehicles are prevented from entering at one end; and, “alternative” schemes do not have mandatory bike lanes or physical segregation and instead rely on signage to communicate the presence of bicyclists in the contra-flow direction (Ryley & Davies, 1998). Most implementations in North America are either single intersection treatments or short stretches of roadway which allow two-way bicycling in the context of one-way motor vehicle traffic (Burkin, 2019).

The first contraflow bike lanes may have been implemented in the 1970s in the United Kingdom, with over 60 installations as of 1998 (Ryley & Davies, 1998). They are especially prolific in Belgium—24% of all roadways accessible to bicyclists are contraflow bike lanes, and 48% of intersections include at least one contraflow approach (Chalanton & Dupriez, 2014). North American examples can be found in New Orleans, Minneapolis, Berkeley (California), Richmond (Virginia), Ithaca, (New York), and Vancouver (British Columbia).

Sources

The research team identified and obtained eight relevant studies for this review. Six originated in Europe and two originated in the United States.

- Ryley and Davies (1998) conducted a before-after analysis with video footage and interviews with bicyclists and bicycle-mounted law enforcement officers at five sites in the United Kingdom with varying contraflow designs.
- Alrutz et al. (2002) used archival crash data from 15 German cities to investigate contraflow safety impacts.
- Sewall and Nicholson (2010) used video footage to observe rates of contraflow cycling and motorist compliance in and around London.
- Bjørnskau et al. (2012) administered surveys to bicyclists, pedestrians, and motorists before and after the installation of bike lanes in Norway.
- Barnes and Schlossberg (2013) removed the physical barriers of an existing contraflow bike lane in Eugene, Oregon, and applied several other treatments to a single street segment to investigate mode shifts and behavioral changes among bicyclists, pedestrians, and motorists.
- Chalanton and Dupriez (2014) conducted a thorough analysis of 234 crashes on Belgian roads and intersections with contraflow bike lanes.
- Burkin (2019) details the implementation of *advisory* contraflow bike lanes at several intersections in Massachusetts, including neighborhood engagement activities.
- Pritchard et al. (2019) used GPS data, video footage, and automated counters to investigate mode shifts in Switzerland.

Table 10 provides a chronological overview of these sources and the road users and components present in the literature.

Table 10. Overview of Sources Relevant to Contraflow Bike Lanes

Source	Bicyclists	Motorists	Pedestrians	Use, Comprehension, Safety	Attitudes, Beliefs, Perceptions	Education Strategies	Knowledge, Comprehension
Ryley & Davies, 1998	✓			✓	✓		
Alrutz et al., 2002	✓	✓	✓	✓		✓	
Sewall & Nicholson, 2010	✓	✓		✓		✓	
Bjørnskau et al., 2012	✓	✓	✓	✓	✓		
Barnes & Schlossberg, 2013	✓	✓	✓	✓	✓		
Chalanton & Dupriez, 2014	✓	✓	✓	✓	✓		
Burkin, 2019	✓	✓		✓		✓	
Pritchard et al., 2019	✓			✓			

Note: A ✓ indicates that the source does address this road user or component.

Use, Compliance, and Safety

Studies explored many aspects of contraflow bike lanes. Researchers documented increases in bicyclist volumes on roads where contraflow lanes are implemented, contraflow travel in the absence of dedicated lanes, shifts away from sidewalk bicycling, and decreased motorist speeds. Wrong way driving generally decreased in association with contraflow lanes and yielding between motorists and bicyclists was not problematic. Numerous studies provided evidence against the opinion that contraflows are unsafe, in terms of both conflicts and crashes.

Several studies documented increases in bicyclist volumes associated with contraflow lane implementation. Bjørnskau et al. (2012) described the implementation of one-way bike lanes in both directions on two one-way streets. Two of these lanes can thus be considered contraflow lanes. Red asphalt and special traffic signals for contraflow-traveling bicyclists were also used. Counts indicated that bicyclist volumes increased by 50% at test sites and decreased at controls. They noted that some of the increase may be due to a transfer of bicyclist traffic from neighboring streets, but it was unclear if any transfer from the controls occurred. Pritchard et al. (2019) studied this transfer, or "diversion," more closely using GPS, radar, and count data. Trips nearly doubled on the road that was treated with a contraflow lane, and researchers found that participants providing GPS data were willing to go up to 50 meters out of their way (i.e., deviate from the shortest path) to use the contraflow lane. The contraflow lane was able to influence bicyclist route choice but did not induce any non-bicyclists to change mode. Other sources documented increases in bicyclist volumes and stable motorist volumes on streets with contraflows (Barnes & Schlossberg, 2013; Burkin, 2019).

Contraflow lanes make bicycling against the flow of motorized traffic legal, but large proportions of bicyclists have been found to do so without contraflow lanes. Forty-one percent of the bicyclists observed by Ryley and Davies (1998) traveled contraflow prior to implementation compared to 49% after (a statistically insignificant increase). Alrutz et al. (2002) observed a similar statistically insignificant change. In contrast, Bjørnskau et al. (2012) documented an increase in contraflow bicycling at test sites, though the magnitude and statistical significance of this increase was not reported.

When traveling against the flow of traffic in the absence of contraflow lanes, most bicyclists positioned themselves where such lanes *would* be (to the left of oncoming traffic in countries where motorists drive “on the left” and to the right of oncoming traffic in countries where motorists drive “on the right’). Sewall and Nicholson (2010) documented this behavior among 64% of bicyclists observed. Burkin (2019) found that 100% of bicyclists observed (N=33) positioned themselves to the right of oncoming traffic (in the United States) when motorized traffic was present, and 93% (N=150) did so in the absence of traffic.

Some bicyclists use the sidewalk to travel against one-way traffic, and shift to using contraflow lanes once made available. In Germany, Alrutz et al. (2002) reported that 60% of bicyclists use the sidewalk for contraflow travel in the absence of contraflow lanes, compared to 20% when contraflow lanes were present. In interviews with bicyclists in Norway, bicyclists stated that they bicycled “less” on sidewalks after contraflow bicycling was permitted (Bjørnskau et al., 2012). An experiment in Massachusetts observed sidewalk use among 10% of bicyclists observed prior to implementation, compared to 2% ten months later, and 0% sixteen months after implementation (Burkin, 2019).

Motorists appeared to reduce speed when driving on roads with contraflow lanes. Ryley and Davies (1998) reported a 1- to 5-mph reduction in 85th percentile speeds at three test sites. However, the research did not test the statistical significance of this claim. Alrutz et al. (2002) also reported “significantly” reduced speeds when encountering bicyclists on streets less than 3.5 meters wide, but did not quantify the reduction or present any related statistical analysis.

Research found wrong-way driving decreased following the implementation of contraflow bike lanes. Bjørnskau et al. (2012) deemed wrong-way driving “rare” and found “no indication that [it] happens more frequently just because the cyclists are permitted to do so” (p. IV). Ryley and Davies (1998) provided quantitative data to test this claim: 21 of 1,267 (2%) motor vehicles were observed traveling the wrong way across 4 sites pre-implementation compared to 7 of 1,616 (less than 1%) post-implementation, representing a statistically significant difference ($p<0.01$).

Burkin (2019) examined yielding among motorists and bicyclists. Prior to implementation, when contraflow bicycling was illegal, bicyclists yielded to motorists in 55% of instances where the two road users occupied the same space, compared to 14% after implementation ($p < 0.01$).

Several studies investigated conflicts surrounding contraflow bike lanes. In 56 hours of video footage at 5 sites before and after implementation, Ryley and Davies (1998) observed “no instances where cyclists were judged to be put in any serious danger…nor were any cases observed where cyclists endangered pedestrians” (p. 13). They qualified these findings by noting the rarity of such conflicts and the low likelihood of observing them during the study. Bjørnskau et al. (2012) observed just 9 conflicts out of 70 hours of video footage. They did not present statistical analysis, but concluded that “counter-flow cycling leads to few traffic conflicts” (p. IV). Alrutz et al. (2002) claimed that critical conflicts between motorists and bicyclists were more frequent when both road users are traveling in the same direction, compared to bicyclists riding contraflow, but did not provide supporting data. Evidence from Barnes and Schlossberg

(2013) suggested that conflict rates decreased following the implementation of a contraflow lane. They collected 27 hours of video before and after implementation, with 13 and 9 conflicts observed in each time period. The research did not report the number of interactions, precluding the assessment of the statistical significance of this reduction, but they did document a 69% increase in contraflow bicyclists and a 5% decrease in motorists. Burkin (2019), however, found a statistically significant decrease in close passing, from 3 of 33 interactions before implementation, to 0 of 44 interactions after (p<0.05).

Studies mostly found pedestrian conflicts to decrease in relation to contraflow lanes. Alrutz et al. (2002) stated that pedestrians were more often involved in critical conflicts with contraflow bicyclists, attributing these conflicts to pedestrians and bicyclists failing to see one another as pedestrians crossed the contraflow lane mid-block. In contrast, Barnes and Schlossberg (2013) observed increased mid-block crossing volumes and decreased pedestrian-related conflicts after implementation. They attributed this favorable outcome to fewer pedestrians walking in the (previously physically segregated) contraflow lane, thus reducing conflicts caused by blockage of contraflow bicycle traffic.

As with conflicts, some studies failed to record any relevant crashes. Ryley and Davies (1998) studied five sites treated with contraflow lanes. Four were treated too recently for them to conduct a proper assessment but did not experience any crashes in 8 months. The fifth site experienced zero crashes in the 3 years before or after implementation. Barnes and Schlossberg (2013) also observed zero crashes, but this may be due to an extremely short observation window (27 hours of video footage). Alrutz et al. (2002) reported a "slight" decrease in crashes associated with contraflow lanes but failed to account for exposure. Chalanton and Dupriez (2014) collected data on 992 crashes in Brussels involving bicyclists from 2005 to 2010. Of these, 126 involved a bicyclist traveling on a contraflow, entering an intersection from a contraflow, or entering a contraflow. Forty-nine percent of these (n=126) crashes occurred at intersections, compared to 48% of all (n=992) bicyclist-involved crashes. The number of bicyclists on contraflows is further decomposed by direction of travel: 47 crashes involved bicyclists traveling against traffic, where 66% occurred at intersections; and 79 involved bicyclists traveling with traffic, where 40% occurred at intersections. They concluded that "the danger is therefore greater when the cyclist is traveling with the traffic on a road section or against the traffic at an intersection" (p. 16). This study did not include a before-after analysis, but rather a cross-sectional analysis of roads with and without contraflow lanes.

Attitudes, Beliefs, and Perceptions

Attitudes, beliefs, and perceptions concerning contraflow bike lanes varied by road user. The studies included in this review made conflicting findings regarding pedestrians and motorists, while bicyclists were very much in favor of the facility.

Bjørnskau et al. (2012) interviewed road users before and after implementation of two contraflow lanes in Norway. Pedestrians reported a greater level of insecurity following implementation, despite also considering sidewalk bicycling to be less of a problem. They suggested that the insecurity stemmed from the new need to check for traffic from both directions when crossing the street. In contrast, Barnes and Schlossberg (2013) interpreted increased mid-block crossing volumes and decreased pedestrian-related conflicts as an "increased level of safety and comfort" (p. 92). Notably, researchers inferred this rather than asking pedestrians directly.

Bjørnskau et al. (2012) also surveyed motorists and found differing opinions at the two sites. Motorists in Kirkegata, Norway, felt that conditions for motorists were worse after implementation, but this may be due to the removal of parking, while motorists in Skippergata, Norway, (where parking was not removed) exhibited no change in opinion about driving conditions. They did not find changes in perceptions of safety among drivers at either site. In contrast, Chalanton and Dupriez (2014) stated that "some people cite the surprise at seeing a cyclist riding against traffic as a reason for considering contra-flows to be dangerous" (p. 31), but the origin of this data is unclear as the study did not include a survey (nor is this statement accredited to prior research).

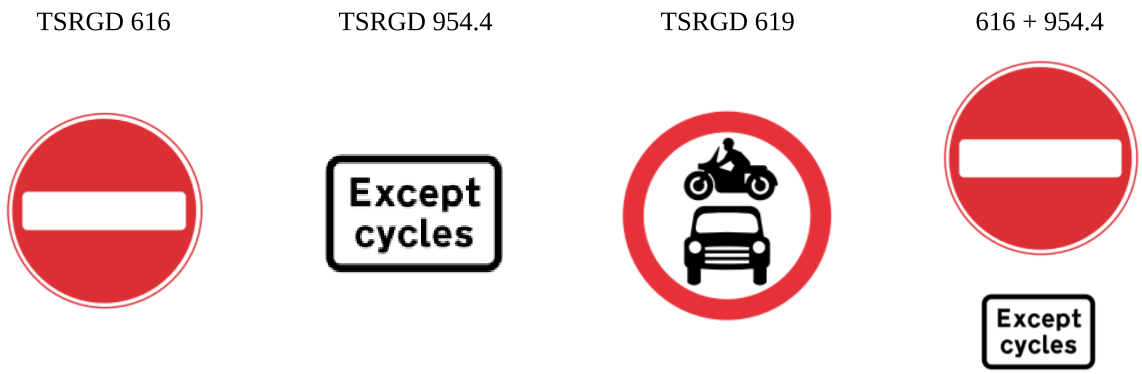
Bicyclists, meanwhile, expressed favor for contraflow lanes. They stated, "very clearly, that it is sensible to permit counter-flow cycling and to implement marked cycle lanes in both directions in one-way streets" (Bjørnskau et al., 2012, pp. II-III). Ryley and Davies (1998) interviewed 134 cyclists across 5 sites; all but one felt that contraflow travel was "useful" and 79% felt that it was fairly or very safe. They added that these bicyclists particularly liked design features that made contraflow cycling more visible to drivers, such as signage, lane markings, and colored surfacing.

Ryley and Davies (1998) discuss opinions among others that contraflow lanes are unsafe. They cited "opposition…from some professionals and members of the public, based on the belief that contra-flow cycling is dangerous" (p. 3) as a potential reason for the low numbers of contraflow lanes. The bicycle-mounted law enforcement officers interviewed indicated that "there was a general view that contra-flow cycling was inherently dangerous" (p. 3) but they rebutted this sentiment, claiming that the concern "is not based on evidence, as there were few contra-flow schemes to observe and no authority reported any significant problems with existing contra-flow schemes" (p. 4). Note that this study is more than 20 years old as of the writing of this report; accordingly, its findings may not be entirely valid today.

Education Strategies

Signage was the only education strategy investigated by the reviewed sources, while two other strategies were discussed briefly by researchers.

The bicyclist entrances at contraflow lanes must allow bicyclists to enter and prohibit motor vehicles from doing the same. This can be accomplished with signage, and optional physical segregation. The *Traffic Signs Regulations and General Directions* (TSRGD) regulates the design and use of traffic signs in the United Kingdom. A Traffic Advisory Leaflet distributed by the United Kingdom's Department for Transport (1998) stated that "under no circumstances should plates exempting cycles [TSRGD diagram 954.4] be placed under [TSRGD diagram 616]" (Signing section, para. 2), claiming that the combination would rapidly erode the "status of diagram 616 as one of the best understood and observed of traffic signs" (Signing section, para. 2). The leaflet went on to prescribe TSRGD diagram 619 where no physical segregation is provided, adding that "compliance with this sign was found to be good" (Signing section, para. 2) at sites monitored by Transport for London (Department for Transport, 1998). Sewall and Nicholson (2010) investigated the impacts of replacing the TSRGD 619 sign with a combination TRSGD 616/954.4 sign. Figure 12 provides a visual depiction of these signs.



Compared in Sewall & Nicholson, 2010

Figure 12. Selected Signage Used at Contraflow Entrances in the United Kingdom

Sewall and Nicholson (2010) replaced signs at four locations—two in London and two outside of London—each with nearby controls displaying TSRGD 616, and measured contraflow bicycling volumes and motorist compliance. The analysis presented is methodologically flawed and did not support the authors' claims. They failed to compare changes at the test sites with changes at controls, and measured motorist non-compliance in the *number* of noncompliant vehicles rather than the rate. However, the study provided enough raw data to conduct a secondary analysis.

The research team tabulated the number of compliant and noncompliant vehicles observed and documented in Sewall and Nicholson (2010) and used these frequencies in a binomial linear regression. Although compliance increased at both test and control sites, the increase in compliance at test sites was not significantly different from the increase observed at controls (test = +0.26 percentage points, control = +0.10 percentage points, p>0.10). The research team also analyzed rates of contraflow cycling, but with one modification. Rather than calculating the percentage change in the number of contraflow bicyclists and applying a seasonal adjustment, we tabulated the number of bicyclists traveling against and with the flow of traffic on the road with a contraflow lane. This analysis did not count bicyclists who did not travel on the treated intersection approach. These frequencies were also used in a binomial linear regression with surprising results: the rate of contraflow cycling increased more at control sites than test sites (control = +6.88 percentage points, test = +0.47 percentage points, p>0.10), but the difference was not statistically significant.

Sewall and Nicholson (2010) incorrectly concluded that the 616/954.4 sign is "more widely respected" (p. 9.2) and "more readily understood by [bi]cyclists" (p. 9.2) and leads to "improved compliance by motorized vehicles" (p. 9.2). Our analysis, however, did not find evidence of any changes in motorist compliance or contraflow bicycling associated with the 616/954.4 signs. An amendment to the 2002 TSRGD permitted the combination of signs 616 and 954.4 in 2011. The 2014 version of the London Cycling Design Standards then set this as the standard for entrances to contraflows.

Signage can communicate directly with bicyclists and motorists, but other education strategies can be used to increase overall awareness of contraflow lanes. Burkin (2019) described a resident engagement strategy including volunteer-led potlucks and other public outreach efforts, distributing fliers to the 175 homes on the affected street. The author concluded that neighborhood support was crucial since contraflow lanes are especially suitable for residential streets. Alrutz et al. (2002) recommended a strategy on a different scale, suggesting that "a simultaneous opening of one-way streets in a section of a city also promotes efficiency in a public awareness campaign" (Section 4, para. 1).

Knowledge and Comprehension

None of the sources reviewed investigated knowledge or comprehension regarding contraflow lanes.

Gaps in Literature

Research has explored many aspects of contraflow lanes, but three areas remain unexplored. First, although Burkin (2019) employed public outreach efforts, an assessment of the effect of these actions was not conducted. Future research could test metrics such as compliance and contraflow cycling with and without various forms of public outreach. None of the reviewed sources investigated knowledge and comprehension, despite observations of bicyclists riding with the flow of motorized traffic. Future research could help determine if this was done intentionally or due to a misunderstanding of the contraflow signage or lane markings. Finally, research has yet to consider law enforcement's role in encouraging proper use by all road users, particularly at intersections. Some facilities are difficult to surveil, but contraflow lanes are often implemented in narrow streets with relatively low speeds. Enforcement could affect both behaviors and knowledge.

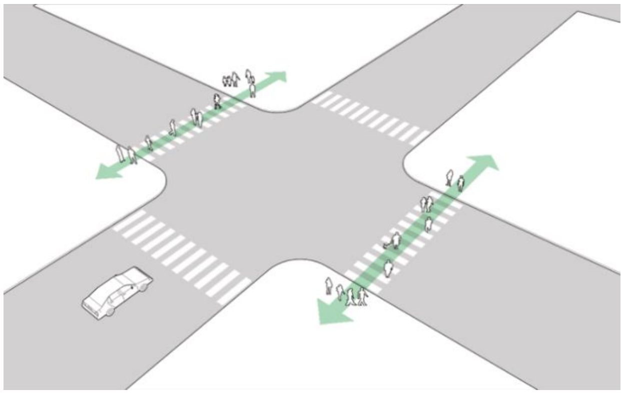
Summary and Conclusions

Researchers have explored road users' behaviors surrounding contraflow bike lanes. Research suggested that contraflows increase bicyclist volumes and decrease sidewalk riding while also decreasing motorist speeds and wrong-way driving. These effects converge to yield low conflict and crash rates, despite widely held opinions that contraflows are inherently unsafe. Signage was not found to significantly influence motorist compliance or contraflow cycling volumes. No other interventions were investigated for potential impacts on knowledge or comprehension of contraflows.

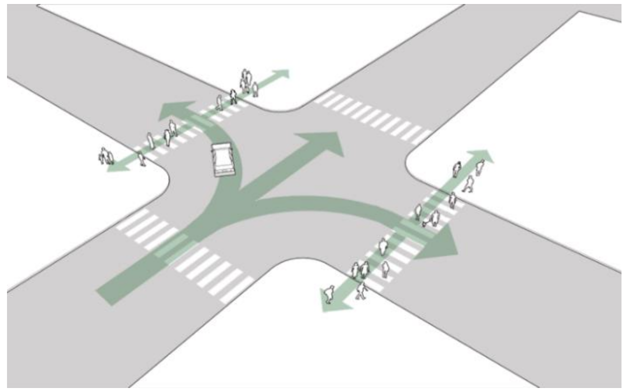
Primarily Pedestrian Facilities

Leading Pedestrian Intervals

Leading pedestrian intervals (LPIs), or *pedestrian head starts* (Fleck, 2000; Hubbard et al., 2008), are adjustments to signal timing schemes that provide pedestrians with additional time to begin crossing an intersection. An LPI gives pedestrians a 3- to 7-second head start before vehicles traveling in the parallel direction are given the right-of-way. This is meant to establish the pedestrians' presence in the intersection with the goal of improving pedestrian safety (NACTO, 2013). Figure 13 shows pedestrian and motor vehicle crossing phases at an intersection with a leading pedestrian interval.



First Phase: Pedestrian Crossing



Second Phase: Motor Vehicle Travel

Figure 13. Diagram of Leading Pedestrian Interval (NACTO, 2013)

The literature reviewed did not identify the first implementations of LPIs, but they are described in the 1961, 1971, and 1978 editions of the MUTCD. They are typically installed at intersections with high pedestrian volumes and high volumes of conflicting turning vehicles. In 2015, LPIs were implemented at 117 intersections in Washington, D.C., and 24 intersections in Philadelphia, PA (Kubilins & Branyan, 2015). Additionally, nearly 3,500 intersections in New York City were equipped with LPIs in 2019 as part of their Vision Zero initiative (Barone, 2019).

Sources

The research team identified 5 relevant studies, all of which originated in the United States.

- King (2000) conducted a before-after crash analysis of LPIs at 26 intersections in New York City, New York. Van Houten et al. (2000) examined the influence of a three-second LPI on pedestrian behavior and conflicts with turning vehicles. They collected data on the number of conflicts between pedestrians and turning vehicles, the number of times pedestrians yielded to turning vehicles, and pedestrian crossing distances at three signalized intersections in St. Petersburg, Florida.
- Hubbard et al. (2008) used video footage to compare motor vehicle-pedestrian interactions at intersections with and without LPIs in Anaheim, California. Additionally, researchers evaluated the consequences of implementing LPIs without enacting right-turn-on-red restrictions.
- Fayish and Gross (2010) conducted a before-after study at signalized intersections in State College, Pennsylvania, that were converted to include LPIs to evaluate their impacts on crashes.
- Similarly, Goughnour et al. (2018) conducted a before-after study, but instead focused on the development of crash modification factors (CMFs) for protected/permissive left-turn phasing and LPIs. They collected data from Chicago, New York City, Charlotte (North Carolina) and Toronto.

Table 11 provides a chronological overview of these sources and the road users and components present in the literature.

Table 11. Overview of Sources Relevant to Leading Pedestrian Intervals

Source	Bicyclists	Motorists	Pedestrians	Use, Comprehension, Safety	Attitudes, Beliefs, Perceptions	Education Strategies	Knowledge, Comprehension
King, 2000		✓	✓	✓			
Van Houten et al., 2000			✓	✓			
Hubbard et al., 2008		✓	✓	✓			
Fayish & Gross, 2010		✓	✓	✓			
Goughnour et al., 2018		✓	✓	✓			

Note: A ✓ indicates that the source does address this road user or component.

Use, Compliance, and Safety

The sources reviewed did not comment on pedestrians' use of LPIs, instead focusing on yielding behavior between pedestrians and motorists, observed vehicle-pedestrian conflicts, and crash rates.

In a before-after study, Van Houten et al. (2000) equipped three urban signalized intersection in St. Petersburg with three-second LPIs and observed subsequent pedestrian behaviors. They found that, after the implementation of LPIs, the odds of a motorist yielding to a pedestrian increased by approximately 60% following the implementation of LPIs. They concluded that this likely occurred because LPIs provided pedestrians the opportunity to establish themselves in the crosswalk before vehicles were permitted to enter the intersection, as is the intent of the facility. Once pedestrians were in the crosswalk, motorists were more likely to yield to them.

Several researchers found a reduction in the number of vehicle-pedestrian conflicts and crashes following the implementation of LPIs. Van Houten et al. (2000) observed significantly fewer vehicle-pedestrian conflicts associated with the LPIs: the odds of a pedestrian experiencing a conflict with a vehicle when leaving the curb were reduced by approximately 95%. Research has shown the reduction in vehicle-pedestrian conflicts to translate to a reduction in vehicle-pedestrian crashes. Another before-after study found a nearly 60% reduction in the number of vehicle-pedestrian crashes at intersections where an LPI was implemented (Fayish & Gross, 2010). King (2000) reported similar findings: using up to 10 years of crash data at 26 intersections with LPIs in New York City, researchers identified a nearly 30% reduction in the number of crashes involving turning vehicles relative to control sites. However, King did not report the statistical significance of these results. Examining data from three cities, Goughnour et al. (2018) calculated a crash modification factor of 0.87 for pedestrian crashes. In other words, pedestrian crashes decreased by 13% following the implementation of LPIs across all three cities.

Despite the observed benefits of implementing LPIs, research suggests that their use alone may not be sufficient to improve pedestrian safety. Hubbard et al. (2008) conducted a before-after study to evaluate pedestrian service provided both by a three-second LPI and by concurrent pedestrian service (a traditional signal without an LPI) with permitted right-turn-on red (RTOR).

Researchers found that the LPI did not result in reduced impacts of right-turning vehicles on pedestrians and there was actually an increase in the number of pedestrians compromised on the curb (delayed by a turning vehicle or forced to change travel path or speed in response to a turning vehicle) in the LPI signal scenario. This was primarily due to vehicles turning right during the LPI, leading researchers to believe that the safety benefits may be reduced if there are no restrictions on RTOR. The MUTCD states that, if an LPI is used, agencies should consider prohibiting turns across the crosswalk through the use of RTOR restrictions (FHWA, 2009).

Attitudes, Beliefs, and Perceptions

None of the sources reviewed investigated attitudes, beliefs, or perceptions regarding LPIs.

Education Strategies

None of the sources reviewed investigated educational strategies regarding LPIs.

Knowledge and Comprehension

None of the sources reviewed investigated knowledge and comprehension regarding LPIs.

Gaps in Literature

Several studies investigated the safety of LPIs, but little else. This review did not identify research into the attitudes, beliefs, or perceptions toward LPIs. Future research could explore pedestrian feelings of safety when using an LPI, pedestrian awareness of LPIs, motorist opinions of LPIs, as well as education strategies, particularly for motorists. The safety benefits provided by LPIs rely on motorists yielding, which may further improve with additional education. Research has yet to explore the most needed information and the best way to convey the information. Signage, public outreach, and law enforcement may vary in their effectiveness as education strategies, but this review did not identify such research.

Summary and Conclusions

Overall, the research indicated that the implementation of LPIs at signalized intersections has positive effects on pedestrian safety. Researchers found that the implementation of LPIs resulted in increased motorist yielding rates and lower vehicle-pedestrian conflict and crash rates, but also an increase in the number of pedestrians compromised on the curb. However, these safety benefits may rely on other facilities, such as RTOR restrictions.

Offset Crossings

Offset crossings, also referred to as *Z-crossings* (Foster et al., 2014), *staggered crossings* (Global Designing Cities Initiative & National Association of City Transportation Officials, 2016), or *Danish offsets* (Foster et al., 2014; Nambisan et al., 2007; Pulugurtha et al., 2012) are mid-block crossings that include a refuge island; the crossings on either side of the island are *offset* to encourage pedestrians to look at oncoming traffic before the second stage of crossing (Figure 14). Offset crossings are appropriate to use when pedestrian volumes are low to medium, when vehicle volumes are medium, and when vehicle speeds are above 18.6 mph (30kmh) (NACTO, 2016).

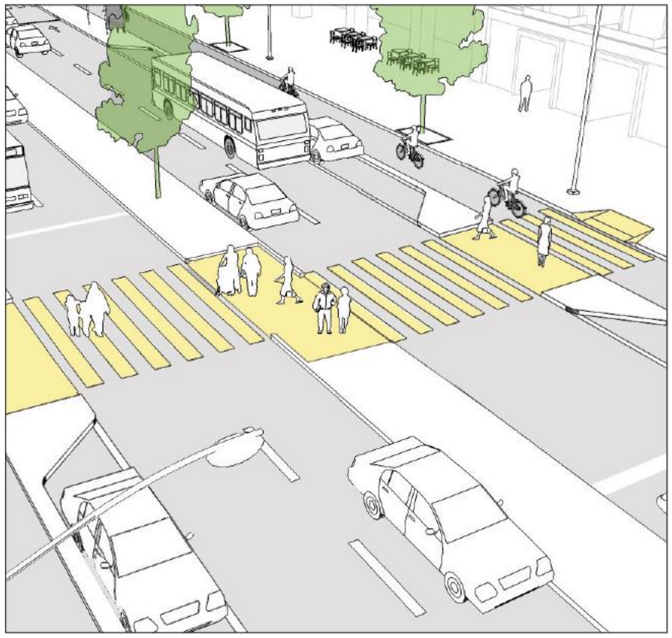


Figure 14. Example Offset Crossing, in Urban Street Design Guide (NACTO, 2013)

The research reviewed did not identify the first use of offset crossings, but two were installed between 2004 and 2008 in Las Vegas, Nevada, as part of a larger pedestrian safety program funded by FHWA (Pulugurtha et al., 2012). Offset crossings are also currently in use in Portland (Foster et al., 2014).

Sources

The literature on offset crossings is extremely limited. The research team identified three sources related to road users' use and understanding of offset crosswalks but could not obtain one of the studies (Nambisan et al., 2007).

- Pulugurtha et al. (2012) observed pedestrian and motorist behavior at two sites in Las Vegas, Nevada, before and the after installation of offset crossings. They referred to the markings used in these crosswalks as "high-visibility" but photos indicated that these markings correspond to the traditional *continental* or *ladder* markings (National Committee on Uniform Traffic Control Devices, 2011). Such markings may be considered standard for offset crossings, so the intervention can be fairly described as simply an offset crossing. Table 12 provides a chronological overview of these sources and the road users and components present in the literature.
- Foster et al. (2014), however, deployed confounding treatments at two sites in Portland, one of which included an offset crossing. This site was also treated with rectangular rapid-flashing beacons and an audible warning reminding pedestrians that drivers may not stop when the RRFBs were activated. Thus, any results of the analysis may be attributable to the RRFBs, the audible warning, the offset crosswalk, or any combination of the three treatments. Motorists were likely responding to the RRFBs and may not have even noticed that the crosswalk was offset. The countermeasures noticed by pedestrians were more ambiguous. They may have seen the RRFBs or the crosswalk, understood the intent, and chose to use the offset crosswalk; once inside the crosswalk, behaviors could

be attributed to the audible warning or the crosswalk's offset geometry. Further, this study did not compare behaviors before and after implementation, but rather with and without RRFB activation.

Table 12. Overview of Sources Relevant to Offset Crossings

Source	**Bicyclists**	**Motorists**	**Pedestrians**	**Use, Comprehension, Safety**	**Attitudes, Beliefs, Perceptions**	**Education Strategies**	**Knowledge, Comprehension**
Pulugurtha et al., 2012		✓	✓	✓			
Foster et al., 2014		✓	✓	✓			

Note: A ✓ indicates that the source does address this road user or component.

Both sources noted an absence of prior research documenting the effectiveness of the facility in influencing pedestrian or motorist behavior (Pulugurtha et al., 2012), or how often pedestrians followed the zigzag pattern (Foster et al., 2014).

Use, Compliance, and Safety

The literature examined several pedestrian behaviors surrounding offset crosswalks, including diversion (deviating from the shortest path to cross at the facility), looking for oncoming vehicles at various stages of the crossing, and walking in a zigzag pattern. Studies also examined motorist yielding to pedestrians. Some researches attempted to investigate safety aspects, but too few safety-critical events were observed to conduct an analysis.

Offset crossings are used at mid-block locations, where pedestrians may otherwise cross wherever is most convenient. Doing so makes them less predictable to motorists and thus more vulnerable. Pulugurtha et al. (2012) compared several pedestrian behaviors before and after implementing two offset crossings. Nearly all pedestrians checked for oncoming vehicles before beginning to cross both the first and second halves of the crossing, and no statistically significant change was detected in the after period. Similarly, the proportion of pedestrians trapped in the street did not change significantly between the two periods. They noted a "significant improvement in the proportion of pedestrians who were diverted" (p. 107), but diversion (deviating from the most convenient path to the designated crossing facility) was impossible in the before period due to the lack of a facility to which to divert. The researchers coded 0 of the 692 pedestrians observed in the before period as diverting, compared to 45 of 389 (12%) in the after period; it may be inappropriate to describe this as an "improvement," but the diversion proportion is a useful statistic. Foster et al. (2014) examined one offset crossing (with RRFBs and an audible pedestrian warning) and found that 82% of pedestrians used the infrastructure; 52% of these pedestrians diverted to do so, and the same proportion walked in the intended zigzag pattern. They found that diversion and following the zigzag pattern to be independent behaviors.

Both sources examined motorist yielding to pedestrians. Pulugurtha et al. (2012) found a statistically significant increase in the proportion of motorists who yielded to pedestrians, from

20% to 44%. They also noted a “significant increase in the distance at which drivers stopped or yielded” (p. 107), but the presented analysis does not support this claim. Foster et al. (2014) provide yielding rates at the site that included an offset crosswalk with and without RRFB activation. Yield rates in the first and second crossing stages were 15% and 65% without RRFB activation, respectively, compared to 82% and 99% with RRFB activation. They did not attempt to explain the differences in yield rates at the two crossing stages. These findings suggest that RRFB activation can significantly increase motorist yield rates but are too confounded to reveal anything regarding the offset crossing. First, the research did not make comparisons before and after implementation. Doing so would greatly clarify the source of any observed changes. Second, although the studies observed behaviors with and without RRFB activation, the associated signage did not change, thus motorists were more aware of the crossing than before any treatments were installed.

Foster et al. (2014) intended to investigate avoidance maneuvers. However, they observed only 2 instances (both hard braking) during the study’s 32 total hours of video recording. They added that in one instance, the driver was close to the crosswalk when the RRFB was activated. This further supports the possibility that the RRFBs were responsible for drivers’ behaviors rather than the offset crossing.

Attitudes, Beliefs, and Perceptions

None of the sources reviewed investigated attitudes, beliefs, or perceptions regarding offset crossings.

Education Strategies

None of the sources reviewed investigated education strategies regarding offset crossings.

Knowledge and Comprehension

None of the sources reviewed investigated knowledge or comprehension regarding offset crossings.

Gaps in Literature

Current research on offset crossings has evaluated the likelihood of pedestrians to use the facility and travel within its markings and motorist yield rates. However, it is unknown how these findings relate to safety; attitudes, beliefs and perceptions; education strategies; knowledge and comprehension; and law enforcement.

Research has inspected pedestrians’ decisions to follow the path of offset crossings, but less is known about how the behavior affects safety outcomes. It is unclear whether pedestrians crossing outside the markings would increase the likelihood of motorist hard braking events or collisions. Foster et al. (2014) intended to study safety regarding motorist avoidance maneuvers but observed too few cases to draw conclusions. As Pulugurtha et al. (2012) noted, before and after crash data could help quantify the impact of offset crossings on pedestrian safety.

The literature reviewed did not inspect road users’ attitudes, beliefs, or perceptions regarding offset crossings. Given that a high proportion of pedestrians looked for oncoming traffic before offset crossing installation, it would be interesting to know what safety benefits they believed the facility offered. Pedestrians may have not considered the offset crossing to be necessary. There also exists a gap in knowledge regarding motorists' attitudes toward offset crossings, particularly in how effective they believe the facility to be, or if it detracts from convenience while driving.

This review did not identify research that evaluated the effectiveness of educational strategies on offset crossings. It is unknown whether educating pedestrians on the purpose of the offset crossing pattern (to look for oncoming traffic) would influence their decision to use the facility. It is also unknown what information, if any, motorists need to safely interact with pedestrians using offset crossings.

The studies reviewed did not directly examine road user knowledge and comprehension. It is unknown whether motorists and pedestrians understand the purpose of offset crossings. One could infer road user knowledge from proper use and compliance rates, yet without direct measures, this review cannot make sound conclusions.

There also exists a gap in knowledge regarding law enforcement activities and offset crossings. It is unknown if police presence would encourage pedestrians to divert their path to a greater degree to use offset crossings or follow the zigzag path. Law enforcement presence may also influence motorist yielding rates, but research has yet to address the topic.

Summary and Conclusions

Researchers have examined pedestrian behaviors and motorist yield rates surrounding offset crossings. Most pedestrians appeared willing to use the offset crossing, though only 12% to 52% were willing to deviate from their shortest path to do so. The offset geometry is intended to encourage pedestrians to look at oncoming traffic before beginning the second crossing stage. However, nearly all observed pedestrians were seen checking for oncoming traffic with and without the crossing, despite only 52% strictly adhering to the zigzag pattern, suggesting that such geometry may not be necessary. One study observed an increase in motorist yield rates attributable to the crossing.

Pedestrian Scrambles

The pedestrian scramble (as it is called here) is also known as the *Barnes Dance* (Chen et al., 2014), the *exclusive pedestrian phase* (FHWA, 2009; Gårder, 1989), and simply the *diagonal crossing* (Greenwood, 2010). A scramble consists of an exclusive pedestrian signal phase and optional pavement markings and signs to indicate that pedestrians may cross diagonally (Figure 15). In the most common configuration, a scramble stops all vehicular traffic at an intersection and allows pedestrians to cross in all directions, including diagonally. Variations include those that do not permit diagonal crossing and those that also allow pedestrians to cross in parallel with moving vehicles outside of the pedestrian-only phase (Kattan, 2009).

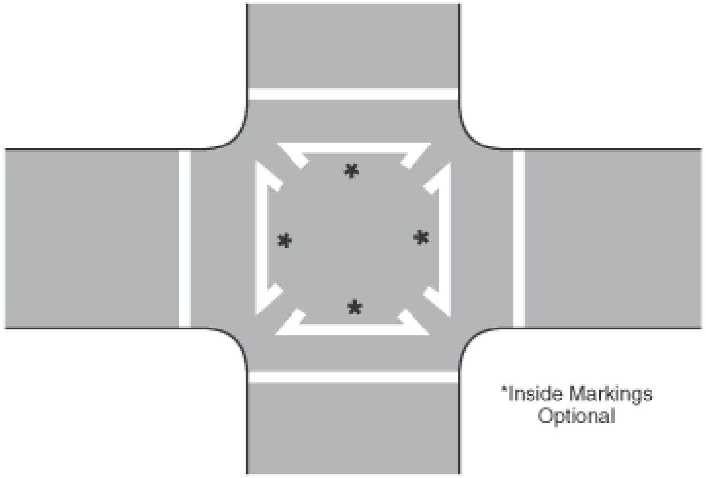


Figure 15. Pedestrian Scramble Diagram (FWHA, 2009)

Scrambles were developed in the mid-twentieth century in several U.S. cities and have been used in Denver, Kansas City, Vancouver (Washington), Oakland, San Diego, Baltimore, and New York City (Kattan, 2009). They are widely used in Japan and in the last decade have been reintroduced in Canada and the United States as a way of prioritizing pedestrians (Greenwood, 2010).

Sources

This review focused primarily on road users' behaviors and knowledge. The research team excluded studies on timing optimization. The research team identified six relevant studies, but could not obtain one (Greenberg, 1995). Of the 5 the team obtained, one originated in Sweden, three in the United States, and one from Canada.

- Gårder (1989) conducted a before-after analysis of three scrambles in Sweden, of which two were in populous Stockholm, and one in a town with fewer than 15,000 residents.
- Bechtel et al. (2004) evaluated a single intersection in Oakland, before implementation, immediately after, and several months thereafter; recruited volunteers to help the public learn how to use the facility; and increased law enforcement efforts during peak traffic times.
- Kattan (2009) evaluated a pilot project in Canada, adding a survey component to explore signal noncompliance among pedestrians.
- Chen et al. (2014) used police-reported crashes in New York City to estimate the effect of the scramble on pedestrian-motorist crashes.
- Medina et al. (2014) used field data from a busy intersection to evaluate pedestrian behavior during a scramble phase.

Table 13 provides a chronological overview of these sources and the road users and components present in the literature.

Table 13. Overview of Sources Relevant to Pedestrian Scrambles

Source	**Bicyclists**	**Motorists**	**Pedestrians**	**Use, Comprehension, Safety**	**Attitudes, Beliefs, Perceptions**	**Education Strategies**	**Knowledge, Comprehension**
Gårder, 1989		✓	✓	✓			
Bechtel et al., 2004		✓	✓	✓	✓	✓	✓
Kattan, 2009		✓	✓	✓	✓		
Chen et al., 2014		✓	✓	✓			
Medina et al., 2014			✓	✓			

Note: A ✓ indicates that the source does address this road user or component.

Use, Compliance, and Safety

The literature generally indicated that pedestrians use the diagonal crossing option provided by scrambles, but that noncompliance was potentially problematic. Regardless, scrambles appeared to have a positive impact on both conflict and crash rates.

Pedestrian scrambles often included pavement markings and a traffic sign to indicate that diagonal crossing is allowed. This was the case in Kattan (2009), with survey results that indicated that 73% of respondents "often cross diagonally" (p. 83). Pedestrians also crossed diagonally without painted crosswalks to encourage the movement (Bechtel et al., 2004).

As discussed in the following section, scrambles succeeded in improving pedestrian safety, but not without tradeoffs. Pedestrian and motor delay "increased considerably" (Gårder, 1989, p. 441). Indeed, the goal of the scramble was not to minimize delay to users, nor maximize vehicle capacity (Bechtel et al., 2004). This delay may have led to pedestrians crossing against the signal, a pattern widely observed and studied. Gårder interviewed 450 pedestrians about crossing against the signal and identified two groups: "those that almost never walk against [the] red light, and those that frequently do" (p. 443). These same respondents indicated that "more supervision by [the] police" and "shorter waiting time for green" (p. 443) as countermeasures that would deter this behavior. Bechtel et al. (2004) observed pedestrians walking on the parallel vehicle green signal (against the "Don't Walk" signal), "taking their cues from the vehicle signal rather than the pedestrian signal" (p. 21), noting that the rate of noncompliance would likely have been higher without the presence of volunteers helping pedestrians properly use the new facility.

Kattan (2009) observed a similar pattern: the number of violations increased by a factor of 1.5 post-implementation, with much of the increase attributable to pedestrians who were able to cross safely despite entering the intersection after the "Don't Walk" signal began flashing. Thirteen percent of the violations consisted of pedestrians walking on the parallel vehicle green signal and 2% involved pedestrians who "were at risk of being struck by a vehicle traveling through the intersection with a green light" (p. 82).

Three of the four studies examined the effect of scrambles on conflicts. Gårder (1989) defined a conflict as “an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged” (p. 437). Conflicts between pedestrians and motorists decreased at all three sites, but the scramble in the small town exhibited a larger decrease than either of those in Stockholm.

Bechtel et al. (2004) defined conflicts broadly as “actions that may lead to crashes” (p. 22) and observed a 39%- to 52% decrease in pedestrian-motorist conflicts associated with converting to the scramble. Kattan (2009) used a more visible definition of conflicts: "a pedestrian or vehicle taking sudden evasive action to avoid a vehicle-pedestrian collision that would have occurred had the users' paths remained unaltered" (p. 81) and observed a 90% reduction in conflicts due to the scramble.

Chen et al. (2014) evaluated the effect of scrambles on crashes rather than conflicts, by comparing police-reported crash rates at 516 scramble intersections to 36 matched controls. The rarity of crashes prompted the other researchers discussed here to use conflicts as a surrogate safety measure. They addressed this limitation by increasing the observation window to 5 years prior and 2 years following implementation. Use of control sites also allowed them to address a potential regression-to-the-mean effect. The study found pedestrian crashes decreased at both treatment and comparison sites (by 51% and 9%, respectively). Notably, multiple-motor vehicle crashes increased by an average of 10% at treatment sites but decreased by 12% at control sites.

Attitudes, Beliefs, and Perceptions

Surveys revealed positive attitudes toward the scramble. Kattan (2009) found that 79% of respondents were in favor of the implementation, with 70% believing that it would improve safety. It should be noted, however, that this survey was a convenience sample of 149 pedestrians. Bechtel et al. (2004) found a “positive attitude in the community toward the signal modification” (p. 25), but did not provide specific statistics.

Medina et al. (2014) compared pedestrian behavior at parallel crossings and diagonal crossings during the scramble phase of a busy college intersection. Researchers found that 58% of observed pedestrians waited until the beginning of walk interval to use parallel crossings. In contrast, 75% of observed pedestrians waited until the beginning of the walk interval to use a diagonal crossing, which could indicate that pedestrians are more hesitant to use diagonal crossings.

Education Strategies

Direct education is one way that pedestrians can learn proper use of the scramble. Bechtel et al. (2004) conducted extensive public outreach for 6 weeks following the implementation of a scramble in Oakland, California. The outreach consisted of workshops and presentations throughout the community and trained volunteers stationed at all four corners of the intersection distributing multilingual brochures and verbally giving pedestrians tips on crossing safely. They concluded that these actions likely had the effect of reducing noncompliance (Bechtel et al., 2004).

Signage and pavement markings can also instruct road users on how to properly use the scramble. Studies often observed pedestrians crossing diagonally (Kattan, 2009; Bechtel et al., 2004), but none of the sources reviewed conducted a direct or indirect comparison of diagonal crossing rates according to the presence of signage or pavement markings. As discussed in the following section, two signs were used to discourage motorists from encroaching on pedestrians in Bechtel et al. (2004).

Knowledge and Comprehension

One study directly probed pedestrian comprehension with a survey and discussed motorist comprehension observations. Surveyed pedestrians "exhibited the understanding that they could cross diagonally…but that they were no longer permitted to cross on the parallel vehicle green signal" (Bechtel et al., 2004, p. 25). They did not provide specific response rates. They also noted "general confusion [among motorists] about which phase came next" (p. 21) immediately after implementation, but this appeared to become less problematic several months later. Some drivers attempted to turn right during the pedestrian-only phase, despite a "No Turn When Ped Crossing" sign. This sign was eventually replaced by a "No Turn on Red, 7 a.m. to 7 p.m." because the former "may have been confusing" (p. 22) and the latter "is less ambiguous" (p. 22) but the researchers did not statistically analyze this difference.

Gaps in Literature

The sources reviewed inspected pedestrian scrambles from pedestrian and motorist perspectives but not from those of bicyclists. Bicyclist use, perceptions, and understanding are currently unknown regarding pedestrian scrambles. The relatively longer distance required to cross diagonally, rather than adjacently, may influence bicyclists to ride across intersections instead of walking. This may increase the risk of conflicts and collisions between pedestrians and bicyclists.

While the research indicated that pedestrians had positive attitudes toward pedestrian scrambles, less is known about motorists' attitudes. The literature suggested that motor vehicle delay increased following the installation of a pedestrian scramble, but it is unknown how the delay affected motorist attitudes, if at all. In addition, research has yet to determine if motorist attitudes affect behaviors at pedestrian scrambles. Addressing potentially negative motorist attitudes may further enhance the already observed safety benefits of pedestrian scrambles.

This review did not yield research that probed users' understanding in the absence of educational efforts or without use of convenience sampling. Systematic intercept studies could reveal how the typical pedestrian learns to use the scramble. Further, simulator studies or head-mounted eye trackers in the real world could reveal more about drivers' and pedestrians' decision-making processes while crossing.

The literature indicated that some pedestrians and motorists experienced confusion using pedestrian scrambles. In fact, Bechtel et al. (2004) observed pedestrians taking cues from motor vehicle signals instead of pedestrian signals. However, none of the literature reviewed inspected pedestrian or motorist comprehension of road markings. The road markings included in the research may have hindered road user understanding. Further research could inspect other road marking patterns or directional arrows, which may enhance proper pedestrian scramble use.

Summary and Conclusions

Research suggests the pedestrian scramble is an effective facility to improve pedestrian safety, although it may lead to longer delay for both motorists and pedestrians and increased noncompliance from pedestrians. While pedestrian scramble use declined in the last decades of the 1900s to promote vehicle movement, current efforts to increase walking and biking as well as their safety have led to increased use of this crosswalk configuration. Though there may be some confusion at first, road users seem to quickly learn proper use. Educational efforts may reduce noncompliance, as observed by Bechtel et al. (2004) and Kattan (2009).

Puffin Crossings

Puffin crossings were developed to address the problem of insufficient pedestrian crossing time at signalized intersections. Puffin crossings typically consist of traffic and pedestrian signals, push-button devices, and detectors. Detectors located along the crossing extend the pedestrian green interval, if needed, to ensure that slower or older pedestrians have enough time to cross the roadway safely. Additionally, pedestrian curbside detectors can detect the absence of pedestrians in the wait areas, which helps eliminate false signal calls and therefore reduces vehicle delays (Fitzpatrick et al., 2015). In essence, puffins are mid-block crossings with detectors to extend crossing times.

Puffin crossings were first implemented in 1992 in Great Britain and were initially developed to replace pelican crossings at mid-block crossing locations and far-side pedestrian signals at intersections. Pelican crossings, like puffin crossings, are comprised of traffic and pedestrian signals as well as push button devices, but do not use detectors to modify pedestrian signal timing. Although they are not used often in the United States, puffin crossings are widely used in the United Kingdom (Zegeer et al., 2013).

Sources

This review focused primarily on road users' behaviors and knowledge. The research team excluded studies on detection technology development from the review. The research team identified 12 relevant studies, but were unable to obtain 4 (Rajbhandari, 2006; McLeod et al., 2004; Kirkham, 2006; Yamazaki, 2012), despite extensive searches of online resources and requesting copies directly from the authors. Of the 8 studies the research team obtained, one originated in France, one in Denmark, and 5 in the United Kingdom; Ekman and Sherborne (1992) conducted their study in both the United Kingdom and Sweden.

- Davies (1992) provided results of the first Puffin experiments using curbside pressure-sensitive mats to detect pedestrians and crossing detection to adjust crossing time.
- Ekman and Sherborne (1992) conducted a before-after analysis to evaluate the safety impacts of converting signalized intersections into puffins.
- Mathieu (1994) conducted a similar analysis in France, which focused on mid-block crossings and motorist behavior. However, the author did not provide a quantitative analysis.
- Reading et al. (1995) evaluated the impacts of replacing a pelican crossing with a puffin crossing and expanded upon prior research by measuring behaviors in addition to red light compliance.
- Walker et al. (2005) also converted pelican crossings into puffin crossings and evaluated motor vehicle-pedestrian conflicts.

- The following year, Webster (2006) evaluated the impacts newly installed puffin crossings had on pedestrian collisions using a minimum of 72 months of crash data for 23 puffin crossing locations.
- Maxwell et al. (2011) conducted a similar study but included a larger sample size.
- Øhlenschlæger et al. (2018) examined crossing behaviors as well as perceived safety and comfort.

Table 14 provides a chronological overview of these sources and the road users and components present in the literature.

Table 14. Overview of Sources Relevant to Puffin Crossings

Source	Bicyclists	Motorists	Pedestrians	Use, Comprehension, Safety	Attitudes, Beliefs, Perceptions	Education Strategies	Knowledge, Comprehension
Davies, 1992			✓	✓	✓		✓
Ekman & Sherborne, 1992			✓	✓			
Mathieu, 1994		✓	✓	✓			
Reading et al., 1995		✓	✓	✓			
Walker et al., 2005		✓	✓	✓			
Webster, 2006		✓	✓	✓			
Maxwell et al., 2011		✓	✓	✓			
Øhlenschlæger et al., 2018			✓	✓	✓		

Note: A ✓ indicates that the source does address this road user or component.

Use, Compliance, and Safety

The installation of puffin crossings is generally associated with increased pedestrian use and motorist compliance, especially when compared to unsignalized crossings. Several studies documented considerable safety improvements.

Research has shown that the implementation of puffin crossings has resulted in improved motorist yielding behavior. In a before-after study conducted in France, Mathieu (1994) observed fewer driver red light violations after the implementation of puffin crossings at mid-block crossings. Puffin crossings and pedestrian detection methods were also associated with increased pedestrian compliance. In the context of this research, pedestrian compliance entails abiding by the signal and properly using the equipment at each crossing, including push-buttons. Ekman and Sherborne (1992) observed over a 10% reduction in the number of pedestrian red-light violations after a puffin crossing was implemented at a signalized intersection in Sweden.

In a separate before-after study, researchers compared pelican and puffin crossings and found fewer pedestrian red light violations in the puffin scenarios, noting that longer vehicular cycle times were associated with increased pedestrian non-compliance (Reading et al., 1995). Despite the improvements in compliance, several studies (Reading et al., 1995; Davies, 1992; Walker et al., 2005) found that very few pedestrians used the push-button at puffin crossings. In studies that compared pelican and puffin crossings, push-button usage was typically lower at puffin crossings than at pelican crossings (Walker et al., 2005; Reading et al., 1995).

Improvements in motorist compliance appeared to result in improvements in the number of complete pedestrian crossings. Øhlenschlæger et al. (2018) examined the results of implementing puffin crossings at large intersections and found that the number of pedestrians trapped in the middle of the roadway while crossing decreased after implementation. In a separate observational study conducted at numerous puffin crossings, researchers found pedestrians that began to cross during the green phase always completed the crossing before vehicles were given the right-of-way (Walker et al., 2005).

Three sources investigated the safety effects of puffin crossings. Ekman and Sherborne (1992) experimented with the use of microwave detectors to detect pedestrians and extend vehicle all-red times at two signalized intersections. They found a reduction in the overall number of serious vehicle-pedestrian conflicts at both study locations. However, this reduction was only statistically significant for one of two sites (Ekman & Sherborne, 1992). Webster (2006) evaluated the change in crashes before the implementation of 23 puffin crossings in London. The author grouped and analyzed sites according to the type of crossing facility that existed prior to the puffin crossing: no formal crossing, a zebra crossing (marked crosswalk with white stripes), or a pelican crossing. After evaluating a minimum of 72 months of crash data per site, Webster (2006) found a 39% reduction in total collisions at locations where a puffin crossing replaced a pelican crossing (significant at the 10% level), and a 15% reduction where no formal crossing existed previously, but the latter was found to be statistically insignificant. In a similar before-after study, Maxwell et al. (2011) reviewed crashes at 50 locations that were converted from far side pedestrian signals, including pelican crossings, to puffin crossings. Researchers found a 19% reduction in the frequency of crashes resulting in injuries across all study locations after the conversion to puffin crossings; pedestrian crashes specifically were reduced by 24% (Maxwell et al., 2011).

Attitudes, Beliefs, and Perceptions

By providing additional crossing time, puffin crossings improved pedestrian comfort, especially for older pedestrians and those with impaired mobility. Three before-and-after studies found that perceived security and comfort among pedestrians increased after the implementation of puffin crossings (Øhlenschlæger et al., 2018; Reading et al., 1995; Davies, 1992). Øhlenschlæger et al. (2018) used a questionnaire and found that the feeling of security increased by almost 5% after the installation of a puffin crossing. However, this increase was not statistically significant. Similarly, Davies (1992) collected feedback at two study locations where puffin crossings were recently installed. The results of the surveys indicated that a majority of respondents—nearly 90% at Rustington and 70% at Woolwich—felt safe while crossing (Davies, 1992). Approximately 40% of respondents believed that the puffin crossing was safer than the previous crossing. In one study comparing puffin and pelican crossings, researchers found that pedestrians traveled through puffin crossings more slowly than the latter, suggesting that they were less stressed while crossing the roadway (Reading et al., 1995).

Education Strategies

None of the sources reviewed investigated educational strategies regarding puffin crossings.

Knowledge and Comprehension

Little research has been conducted on road users' understanding of puffins. Davies (1992) found that less than 40% of respondents at the Rustington location understood that they must stand on the mat and press the push-button to properly operate the crossing. Comprehension was even lower at the Woolwich location, with less than 20% of respondents understanding how to properly activate the signal. Many respondents believed that pressing the push button alone was sufficient. In contrast, video observations showed that most participants stood on the mat but ignored the push button. However, Davies concluded that these behaviors could improve with additional education.

Gaps in Literature

There remains much to be explored regarding education strategies and puffin crossings. Pedestrians and motorists may need different information about the crossing. Pedestrians must be informed how to use it, but they (and motorists) may not need to know about its potential to increase the pedestrian crossing signal time. Whatever information is needed, the best way to convey it has yet to be explored. Signage, public outreach, and law enforcement may vary in their effectiveness as education strategies, but this review did not identify any such research.

Summary and Conclusions

Overall, puffin crossings had a positive effect on pedestrian safety. Puffin crossings were not only associated with improved motorist yielding behavior, but also with improved pedestrian compliance, meaning that fewer pedestrians crossed the roadway against the signal. Reviewed research also showed the implementation of puffin crossings resulted in an increase in the number of fully completed crossings and reduced the number of motor vehicle-pedestrian conflicts and crashes. Despite the improvements made in pedestrian safety, researchers indicated that knowledge and comprehension of puffins could be improved, which could result in greater safety benefits.

Raised Crosswalks

Raised crosswalks are crosswalks situated on ramped, flat-topped speed tables that span the entire width of the roadway. Raised crosswalks are typically 10 feet wide and 3 to 6 inches above street level, allowing pedestrians to cross at-grade with the sidewalk (FHWA, 2018). Similar to traditional crosswalks, raised crosswalks require the incorporation of standard crosswalk design elements, such as pavement markings and warning signs (FHWA, 2017). Figure 16 displays an example raised crosswalk.

Figure 16. Example Raised Crosswalk (FHWA, 2017)

Raised crosswalks can improve pedestrian safety by making pedestrians more prominent in the driver's field of vision. Due to their height and the use of approach ramps, they often act as traffic calming measures since they reduce vehicle speeds, further improving pedestrian safety (FHWA, 2018). Despite the safety benefits associated with raised crossings, they cannot be installed everywhere due to volume and speed constraints. Resulting noise pollution and drainage issues also limit their implementation (FHWA, 2018). The literature reviewed did not identify the first implementation of raised crosswalks, but the first edition of *The Handbook of Road Safety Measures* (Elvik & Vaa, 2004) referenced the facility.

Sources

This review focused primarily on road users' behaviors and knowledge. Therefore, the research team excluded studies on design criteria and guidance and obtained 4 relevant studies—one originated in Sweden, one in the United States, one in Australia, and one in Israel.

- Gårder et al. (1998) conducted a before-after study to evaluate the effects of raised bicycle crossings on bicyclists' safety.
- Huang and Cynecki (2000) conducted a before-after study to evaluate the pedestrian safety benefits of several traffic calming measures, including a "raised intersection" in Cambridge. The study measured motorist yielding rates, but not in relation to the raised intersection.
- Candappa et al. (2014) used a questionnaire to evaluate pedestrian perceptions, which had previously been lacking.

- Gitelman et al. (2017) examined motorist yielding behavior in an evaluation of changes in road-user behaviors following the installation of raised pedestrian crosswalks and speed humps.

Table 15 provides a chronological overview of these sources and the road users and components present in the literature.

Table 15. Overview of Sources Relevant to Raised Crosswalks

Source	**Bicyclists**	**Motorists**	**Pedestrians**	**Use, Comprehension, Safety**	**Attitudes, Beliefs, Perceptions**	**Education Strategies**	**Knowledge, Comprehension**
Gårder et al., 1998	✓	✓		✓	✓		
Huang & Cynecki, 2000			✓	✓			
Candappa et al., 2014		✓	✓	✓	✓		
Gitelman et al., 2017		✓	✓	✓			

Note: A ✓ indicates that the source does address this road user or component.

Use, Compliance, and Safety

The literature described how raised crosswalks increased bicyclist usage, decreased motorist speeds, increased both pedestrian and motorist compliance, and decreased both conflicts and crashes.

Gårder et al. (1998) examined 6 of 44 intersections in Sweden where pre-existing urban bicycle crossings were raised by 4 to 12 centimeters and treated with red pavement coloring. They measured bicyclist flows using automatic counters at two test sites and two control sites. Researchers found that bicyclist flows increased by 50% relative to the control sites, attributing this increase to a “better” layout (Gårder et al., 1998).

Gårder et al. (1998) also measured motor vehicle speeds, though they did not disclose how or at which sites. All raised crossings were installed at T intersections, and only turning vehicles would interact with them, thus the research only reported on turning vehicle speeds. The research found these speeds decreased by 40% following the installation of the raised crossings. Research also reported statistically significant reductions in motor vehicle speeds at roundabout entrances and unsignalized mid-block locations (Candappa et al., 2014).

Raised crosswalks have been associated with increased compliance among both pedestrians and motorists. Huang and Cynecki (2000) observed pedestrians at a raised crosswalk in Cambridge, finding that the percentage of pedestrians crossing inside the crosswalk increased by 26% post-implementation. Candappa et al. (2014) observed a similar increase at a roundabout in Melbourne, Australia: a 38% increase in the number of pedestrians crossing within the crossing zone for at least 95% of the crossing distance. Pedestrian surveys at this site indicate that motorist compliance (yielding to pedestrians) also increased, though the researchers did not observe this directly. Prior to implementation, 30% of respondents agreed with the statement "Drivers mostly give way to pedestrians," compared to 78% post (p. 636).

Researchers studied both conflicts and crashes in relation to raised crosswalks. Gitelman et al. (2017) found a statistically significant reduction in the number of pedestrian-motor vehicle conflicts at 5 of 16 study locations; the remaining locations either did not experience any observed pedestrian-motor vehicle conflicts or experienced reductions that were not statistically significant. Gårder et al. (1998) observed decreases in conflict rates at raised crosswalks for all three road user types: a 20% decrease for motorist-bicyclist conflicts, a 60% decrease for motorists-only, and an 80% decrease for motorist-pedestrian conflicts. They added that these improvements may be contributed to reduced motorist speeds. They did not, however, define conflict and may have used an inappropriate exposure metric (e.g., hours of observation rather than counts of road users). Researchers observed a safety-in-numbers effect among motorist-bicyclist crashes at the raised crosswalks: "If the bicycle flow is doubled, for example, from 50 to 100 bicyclists per hour, the relative risk [the number of reported crashes per bicyclist] would be reduced by 38%; whereas the total number of reported accidents would grow by about 25%."

Attitudes, Beliefs, and Perceptions

Of the four relevant sources reviewed, two sought to evaluate how road users perceived raised crossings. Gårder et al., (1998) randomly selected bicyclists passing through treated intersections and asked them to assess safety after the treatment compared to before. They did not provide either the wording of this question nor the scale of the responses (e.g., "much more safe," "slightly more safe," or a numeric scale). Researchers reported consistency across locations, averaging a 20% improvement. Candappa et al. (2014) reported similar results from an on-site questionnaire. Just 26% of respondents felt that the roundabout was "safe" prior to implementation, compared to 64% after. Respondents also indicated that the raised crossing was more visible to drivers and easier to use when crossing the roundabout.

Education Strategies

None of the sources reviewed investigated educational strategies regarding raised crosswalks.

Knowledge and Comprehension

None of the sources reviewed investigated knowledge or comprehension regarding raised crosswalks.

Gaps in Literature

Although many of the sources reviewed evaluated pedestrian usage at raised crosswalks, the review identified little research on the impacts raised crosswalks have on crashes. Candappa et al. (2014) examined crash data before and after the implementation of raised crosswalks but, given the small number of crashes that occurred at the study site, they did not conduct a statistical analysis.

Additionally, this review identified little research on motorist yielding behavior at raised crosswalks. Huang and Cynecki (2000) collected some data on the number of motorists yielding to pedestrians, but not at the study location that included the implementation of raised crossings. Gitelman et al. (2017) also examined yielding behaviors, but only collected data at locations with both raised crosswalks and preceding speed humps.

There remain many opportunities for research to explore education strategies and the information required by pedestrians and motorists. Signage, public outreach, and law enforcement may vary in their effectiveness as education strategies, but no such research was identified in the course of this review.

Summary and Conclusions

Overall, researchers found the implementation of raised crosswalks to be associated with neutral-to-positive impacts on safety. The installation of raised crosswalks was also associated with increased bicyclist usage, decreased motorist speeds, and increased compliance among pedestrians and motorists.

Rectangular Rapid-Flashing Beacons

According to the *Interim Approval for Optional Use of Rectangular Rapid-Flashing Beacons*, RRFBs consist of two rapidly and alternately flashing rectangular yellow indications that have LED array-based pulsing light sources (Furst, 2008). Research has since expanded upon this definition to include different numbers of LEDs, flashing patterns, and beacon positions. Figure 17 shows a typical implementation.

Figure 17. RRFB in Davis, California (Lara Justine, Pedestrian & Bicycle Information Center)

RRFBs supplement standard pedestrian warning signs to make pedestrians and bicyclists more visible to motorists (Pecheux, 2009). Pedestrians and bicyclists are meant to activate the beacons, ensure that traffic has yielded, and then proceed across the roadway. Most implementations are activated by roadside pushbuttons rather than passive detection (Porter et al., 2016b).

The first RRFBs were installed in Miami (Department of Civil and Coastal Engineering, 2008; Pecheux, 2009) and St. Petersburg, Florida, (Hunter et al., 2009; Van Houten & Malenfant, 2009) in 2008. This research formed the basis for the *2008 Interim Approval*. Since then, RRFBs have proliferated across the United States. Zegeer et al. (2017) documented 50 implementations as of 2017, often used in conjunction with advance yield or stop markings and signs and/or refuge islands. Canada also adopted the RRFB in several cities (Moshahedi et al., 2018). FHWA issued several Official MUTCD Interpretations since the Interim Approval in 2008 including the following.

- December 9, 2009 — 4-376(I) - RRFB Overhead Mounting
- August 3, 2010 — 4(09)-4(I) - RRFB Flash Pattern
- August 12, 2010 — 4(09)-5(I) - RRFB Use With W11-15 Sign
- January 9, 2012 — 4(09)-17 (I) - RRFB Light Intensity

- June 13, 2012 — 4(09)-21 (I) - Clarification of RRFB Flashing Pattern
- August 8, 2012 — 4(09)-22 (I) - Flashing Pattern for Existing RRFBs
- September 27, 2012 — 4(09)-24 (I) - Dimming of RRFBs During Daytime Hours
- October 22, 2013 — 4(09)-38 (I) - RRFB Flashing Extensions and Delays
- July 25, 2014 — 4(09)-41 (I) - Additional Flash Pattern for RRFBs
- March 28, 2016 — 4(09)-58 (I) - Placement of RRFB Units Above Sign

The 2008 Interim Approval was terminated in 2017 upon learning that the RRFB device had been patented by a private company (Knopp, 2018). After the patent was expressly abandoned, the concept of the RRFB returned to the public domain, and a new Interim Approval was issued in 2018.

Sources

The RRFB is particularly well studied. The research team identified 22 relevant sources, 20 of which originated in the United States with the remainder originating in Canada. The research team identified 2 additional sources, but full-text versions could not be obtained (Domarad et al., 2013; Morrissey, 2013).

- The University of Florida's Department of Civil and Coastal Engineering (2008) described logistical and technical considerations surrounding four RRFB deployments in Miami.
- Pecheux (2009) took a closer look at two of these deployments, documenting various safety improvements.
- Van Houten and Malenfant (2009) examined four RRFB implementations on multilane roads in St. Petersburg.
- Hunter et al. (2009) examined one implementation at a trail crossing in the same city.
- Shurbutt et al. (2009) experimented with the *number of beacons* and compared RRFBs to traditional overhead yellow flashing beacons.
- Shurbutt and Van Houten continued experimentation in 2010 by angling the beacons directly at approaching drivers and adding advance warning signs.
- In 2011 Van Wagner et al. investigated the effects on motorist speeds and Ross et al. implemented RRFBs at sites with 45 mph posted speeds.
- Salamati et al. (2012) used a driving simulator to investigate visual fixation patterns.
- Hunter-Zaworski and Mueller (2012) continued to experiment with positioning and combining RRFBs with other facilities.
- Fitzpatrick et al. (2014) and Brewer et al. (2015) continued field experimentation with staged pedestrian crossings.
- In 2015 Fitzpatrick et al. compared RRFBs to *circular* rapid-flashing beacons at 12 sites in 4 U.S. cities (2015a), then experimented with the *placement* of the beacons at 8 different sites in 4 U.S. cities (2015b).

- Mishra et al. (2015) evaluated the first RRFBs in Canada.
- Dougald (2016) introduced the concept of *immediate yielding* and conducted a survey of trail users to gauge opinions of an RRFB installation
- Porter et al. (2016b) conducted the first evaluation of an RRFB with automatic pedestrian detection.
- Zegeer et al. (2017) developed CMFs for RRFBs.
- In 2018 Al-Kaisy et al. introduced the concept of *voluntary* yielding.
- Moshahedi et al. (2018) then explored the relationship between motorist yielding and road characteristics, environmental factors, and device specifications.
- Kutela and Teng quantified the transition among yielding types (2019) and explored beacon activation (2020).

Table 16 provides a chronological overview of these sources and the road users and components present in the literature.

Table 16. Overview of Sources Relevant to Rectangular Rapid-Flashing Beacons

Source	**Bicyclists**	**Motorists**	**Pedestrians**	**Use, Comprehension, Safety**	**Attitudes, Beliefs, Perceptions**	**Education Strategies**	**Knowledge, Comprehension**
Dept. Civil Coastal Eng., 2008		✓		✓			
Pecheux, 2009		✓	✓	✓			
Van Houten & Malenfant, 2009							
Hunter et al., 2009	✓	✓	✓	✓			
Shurbutt et al., 2009		✓		✓			
Shurbutt & Van Houten, 2010		✓		✓			
Ross et al., 2011		✓		✓			
Van Wagner et al., 2011		✓		✓			
Salamati et al., 2012		✓		✓			✓
Hunter-Zaworski & Mueller, 2012		✓		✓			
Fitzpatrick et al., 2014		✓		✓			✓
Brewer et al., 2015		✓	✓	✓			
Fitzpatrick et al., 2015a		✓		✓			
Fitzpatrick et al., 2015b		✓		✓			
Mishra et al., 2015		✓		✓			
Dougald, 2016	✓	✓	✓	✓	✓		✓
Porter et al., 2016b		✓		✓	✓		
Zegeer et al., 2017		✓	✓	✓			
Al-Kaisy et al., 2018		✓	✓	✓			
Moshahedi et al., 2018		✓		✓			
Kutela & Teng, 2019		✓		✓			
Kutela & Teng, 2020			✓	✓			

Note: A ✓ indicates that the source does address this road user or component.

Use, Compliance, and Safety

Several studies quantified beacon activation and differences among pedestrians and bicyclists in various situations. Yielding was the primary focus of much of the literature, with researchers investigating the effects of RRFB characteristics, other facilities used in conjunction with RRFBs, beacon activation, and road user characteristics. Different types of yielding are identified and measured over long periods of time. Safety-critical behaviors and outcomes were also documented.

Studies found beacon activation to vary by scenario and user characteristics. Dougald (2016) distributed surveys one year after implementation of an RRFB at a trail crossing in Virginia and observed pushbutton use over time via video footage. Eighty percent of survey respondents indicated that they had activated the pushbutton at least once since implementation, with 35% doing so “all the time,” 45% only when traffic was present, and 20% when the crossing time seemed excessive. Frequent trail users were significantly less likely to do so (p<0.01). Video footage showed that activation rates in the presence of traffic increased over time, from 41% three weeks post-implementation to 51% 5 months post-implementation (p<0.10). Hunter et al. (2009) also recorded trail users’ interactions with an RRFB at a trail crossing: "32% of the trail users pushed the button to activate the flashing signals and 49% did not; for 19%...the button had already been pushed" (p. 9). Al-Kaisy et al. (2018) observed activation rates of 57% and 81% at two uncontrolled mid-block crossings in Montana. In contrast, Brewer et al. (2015) found that 94% of pedestrians activated the RRFBs at school crossings. Kutela and Teng (2020) compared pushbutton use at several facilities, finding that pedestrians crossing at RRFBs were almost four times more likely to do so compared to those who crossed at controlled intersections (p<0.001), adding that residential land use, more lanes, and higher speed limits were associated with higher activation rates, while age and involvement in secondary activities were associated with lower rates.

Much of the reviewed literature focused on motorist yielding and a subset of the sources explored different types of yielding. Several researchers observed a platooning effect: motorists following other motorists as they pass through the crossing without yielding (Hunter et al., 2009; Dougald, 2016; Fitzpatrick et al., 2015b). To mitigate this tendency, Dougald (2016) considered *immediate yielding,* instances when the first arriving motor vehicle can and does yield. As discussed in a subsequent section, this type of yielding was examined in conjunction with beacon activation.

Al-Kaisy et al. (2018) distinguished between *voluntary* yielding (giving way to someone waiting to use the crosswalk) and *mandatory* yielding (yielding to road users already in the crosswalk in a conflict avoidance maneuver). This type of yielding was also discussed in light of beacon activation. When crosswalks traverse medians, a distinction must be made between *nearside* and *farside* yielding (Brewer et al., 2015). When crosswalks traverse several lanes, pedestrians and bicyclists may encounter a *multiple-threats state,* in which traffic in one lane may yield while the other does not.

Kutela and Teng (2019) used video footage of pedestrian crossings to describe the transition among several yielding situations: for RRFBs, the weighted average transition from non-yield to multiple-threats takes 13 seconds, from multiple-threats to full-yield takes 5 seconds, and from non-yield directly to full-yield is 15 seconds. Unless otherwise noted, “yielding” in sections below refers to the ratio of the number of yielding vehicles to the number of yielding and non-yielding vehicles.

Numerous studies documented both short- and long-term increases in motorist yielding after the implementation of RRFBs. The first implementations at intersections in Miami saw yielding increases from 0% and 1% to 65% and 92%, respectively (Department of Civil and Coastal Engineering, 2008). Pecheux (2009) documented similar increases, from 5% and 8% to 58% and 77%, respectively. In Oregon Ross et al. (2011) saw yielding rates increase from 18% to 80%. Hunter et al. (2009) reported an increase in *motorist* yielding from 2% to 35%, alongside yielding decreases among bicyclists (from 78% to 56%) and pedestrians (from 19% to 9%).

Brewer et al. (2015) reported increases in motorist yielding of between 35 and 79 percentage points among four mid-block crossing sites in Texas. Mishra et al. (2015) observed smaller increases in Canada where yielding was already quite high: from “mid 70% to 90% in most cases” prior to implementation to “between 90% and 100%” after implementation (p. 8).

Shurbutt et al. (2009) used a reversal design to measure yielding over time: starting at a baseline of 18%, yielding increased to 81% with the two-beacon system, then 88% with the four-beacon system; 14 months later, yielding further increased to 96%; removing and re-implementing the RRFBs led to a 25% yield rate followed by 99% (p.88). These findings provided strong evidence for the RRFB’s ability to increase motorist yielding.

Shurbutt and Van Houten continued experimentation in 2010. Baseline yielding rates were 0% during baseline, and increased to 33% seven days post-implementation, then to 72% thirty days post-implementation, averaging 80% one-year post-implementation (p. 26). In their fifth experiment, they compared RRFBs alone to RRFBs with advance warning signs (also with LEDs). Baseline yielding increased from 9% to 95% with the RRFBs alone, and the additional signage did not produce any additional statistically significant increase (p. 30). The timing of these measurements was unclear, but a subsequent return to baseline conditions was associated with a 0% yield rate, supporting the claim that the changes in yield rates were due to the RRFBs rather than novelty.

Porter et al. (2016b) observed an interesting trend in yielding over time. Researchers found that yielding rates did increase linearly over time (across 5 measurement periods within a span of 2 months) but “being a RRFB location or turning on the RRFBs was not directly significantly associated with increased driver yielding” (p. 515). However, this study differed from others by using an automatic pedestrian detection component rather than a staged pedestrian protocol. They mentioned an “activation” phase (where users must activate the beacons with a pushbutton), and an experimental design allowing each site to serve as its own control, but details are lacking.

Results from several studies indicated that motorist yielding is influenced by characteristics of the RRFB and other facilities, road user characteristics, and beacon activation.

Research explored flashing pattern, beacon shape and brightness, and the number and position of beacons. Fitzpatrick et al. (2015a) compared three flashing patterns and found no significant differences in yielding among them. Moshahedi et al. (2018) found similar results. Fitzpatrick et al. (2015a, 2015b) also experimented with beacon shape and brightness, finding no significant effects on yielding; they add that “agencies should focus on meeting the [Society of Automotive Engineering[5]] minimum intensity [so that] the probability of unbearable discomfort glare is less than one percent” and that different daytime and nighttime brightness values may be appropriate.

Several researchers documented significant effects associated with the number of beacons. Shurbutt et al. (2009) and Van Houten and Malenfant (2009) compared yielding rates with two- and four-beacon RRFB installations. The two studies employed nearly identical designs: After a baseline period, two-beacon systems were installed at study locations, followed by four-beacon systems, then back to two, then back to four. Fourteen months later, the four-beacon systems were measured again before a return to baseline conditions and one final installation of the four-beacon systems. Relative to the baseline, Shurbutt et al. observed a 63%increase in yielding with

[5] Since 2006, renamed as SAE International.

2 beacons, compared to a 70% increase with 4 beacons, a statistically significant difference ($p<0.01$). Van Houten and Malenfant observed a 60% increase in yielding with 2 beacons, relative to baseline, and a 70% increase with 4 beacons ($p<0.01$). These two studies provided strong evidence for the increased yielding associated with RRFBs but, due to their design, implementation order may have confounded the effects of the four-beacon system relative to the two-beacon.

Hunter-Zaworski and Mueller (2012) also experimented with the number of beacons, using various pre-existing implementations at six locations in Oregon. They did not conduct or provide any statistical analysis, but they provided the raw data. The research team re-analyzed this data using a stepwise logistic regression model with yield rates as the dependent variable. The full model included terms for beacon position (side or overhead), type (RRFB or traditional beacon), number of beacons (two or four), number of lanes (two, three or four), presence of a median, a mid-block location indicator, the presence of advanced stop bars, and interactions. The reduced model included only terms for the numbers of beacons and lanes. The four-beacon system was associated with a 1.9-fold increase in yielding (95% confidence interval [CI]: 1.1 – 3.5, $p < 0.05$) relative to the two-beacon system, and each additional lane was associated with a 1.5-fold increase in yielding (95% CI: 1.0 – 2.1, $p < 0.05$).

Four studies explored various elements of positioning. Shurbutt and Van Houten (2010) positioned the LEDs at an angle, rather than parallel with the road, to directly face motorists as they approached the crossing. This modification was associated with an additional increase in yielding of 17 to 24 percentage points (the former excluding the rate measured at 7 days, both $p < 0.05$), relative to the parallel LED RRFBs. Fitzpatrick et al. (2015b, p. 5) compared yielding with beacons above and below pedestrian crossing signs at 13 sites in 4 States; statistical analysis yielded no significant differences. Moshahedi et al. (2018) also experimented with above/below positioning but found that positioning the beacons above the pedestrian crossing sign was associated with significantly greater yield rates (odds ratio relative to below = 1.5, $p < 0.05$). Salamati et al. (2012) used a driving simulator to assess motorist yielding behaviors while exiting roundabouts. Researchers tested two offset distances from the circulating lane to the crosswalk and found that relocating the RRFB from 20 to 60 ft increased yielding from 52% to 74% ($p < 0.0001$).

Studies measuring motorist yield rates and RRFBs also considered properties of other facilities. Shurbutt et al. (2010) tested the addition of advance warning signs and found that they did not further increase yielding rates. Fitzpatrick et al. (2014) considered many factors, and found that a higher posted speed limit, shorter total crossing distance, and one-way traffic are each associated with increased yielding rates. They also found that city was a significant factor, hypothesizing that a large number of RRFB implementations may contribute to greater driver familiarity and thus higher yielding rates (p. 52).

Three studies specifically investigated the effects of medians. As previously mentioned, Hunter-Zaworski and Mueller (2012) reported compliance rates but provided no statistical analysis. Re-analysis of raw data indicated that medians did not significantly affect yield rates. Porter et al. (2016b) found that drivers approaching a crosswalk without a median were 1.6 times more likely to yield than drivers at locations with medians (p. 517). In direct contrast, Mashahedi et al. (2018) found the opposite: motorists were 1.2 times more likely to yield when medians were present (p. 19).

Characteristics of road users emerged as a significant factor in yielding patterns. Salamati (2012) administered questionnaires to participants in a driving simulator experiment involving roundabouts. Drivers who reported passing through roundabouts more than once per week yielded more often than others, but only in the base scenario; those reporting more encounters with pedestrians in intersections also exhibited higher yield rates, in both the base and RRFB scenarios. Hunter et al. (2009) documented significant changes in yielding among various road users before and after RRFB implementation. Bicyclists and pedestrians decreased from 78% to 56% and from 19% to 9%, respectively, while motorists increased from 2% to 35%.

Al-Kaisy et al. (2018) investigated *voluntary* yielding (yielding to pedestrians and bicyclists waiting beyond the curb) using video recordings of 380 non-staged crossings at two sites. Results indicated that the presence of children, the elderly, or bicyclists was associated with higher rates of voluntary yielding. The effect of the number of road users trying to cross the road is unclear. They claim that "the larger the number of sidewalk users waiting at the crosswalk, the more likely for motorists to yield as they approach the crosswalk location" but this claim is made on very few observations (p. 13). Re-analysis of the data provided (removing scenarios with less than ten observations) indicated that the number of sidewalk users waiting at the crosswalk was not statistically significant.

Researchers found beacon activation significantly affected yield rates. Hunter et al. (2009) documented a baseline yielding rate of just 2%; after implementation, yielding increased to 14% when beacons were not activated, compared to 54% when they were activated. Dougald (2016) found that yield rates increased over time regardless of activation but increased at a higher rate among activation cases. Fitzpatrick et al. (2015b) reported that drivers were 3.7 times more likely to yield when the beacon was activated. A re-analysis of data provided by Al-Kaisy et al. (2018) indicated that motorists were 2.2 times more likely to *voluntarily* yield to pedestrians when the beacons were activated. In contrast, Porter et al. (2016b) concluded that yielding was “not related with actual lights flashing for a pedestrian” (they use this terminology rather than “activation” because this study used automated pedestrian detection).

The literature described both safety-related behaviors and outcomes. Behaviors included decreases in motorist speeds, non-motorists getting trapped in the median, and pedestrians checking for traffic before crossing. Outcomes included both conflicts and crashes.

Researchers observed modest decreases in motorist speeds in relation to RRFBs. Van Wagner et al. (2011) deployed an RRFB in conjunction with a speed limit sign (35 mph) that was designed to flash when motorists exceeded 41 mph. Researchers used both reversal and alternating design elements to assess motorist speeds, finding that 73% of passing vehicles exceeded 41 mph without the RRFB compared to 53% with the RRFB (p. 631). Ross et al. (2011) recorded speeds before and after RRFB implementation at three locations in Oregon; the 85th percentile speeds remained constant at two sites and decreased by just 5% (from 44 mph to 42 mph) at the third (p. 24). Dougald (2016) used LIDAR to measure the speeds of vehicles passing in both directions through a trail crossing before and after adding an RRFB to other prior safety improvement efforts (advance crosswalk warning signs, crosswalk signs at the high visibility crosswalk, and zig-zag pavement markings). For both directions of travel, mean speeds were statistically significantly lower within 200 feet of the crosswalk; for one direction, speeds were also lower within 400 feet (p. 26-27).

Two early studies quantified the number of pedestrians trapped in the median, with similar results. Pecheux (2009) documented a decrease from 44% to 1% of pedestrians and Hunter et al. (2009) documented a decrease from 18% to 6% of trail users. Porter et al. (2016b) also considered pedestrian scanning behaviors, observing 88% of pedestrians checking for oncoming traffic before entering the roadway, adding that this behavior did not change with the addition of RRFBs.

Surprisingly few researchers analyzed conflicts and crashes. Pecheux (2009) described the "percentage of evasive conflicts" at two study locations but did not explicitly define the metric. Regardless, this percentage (presumably of all interactions) decreased from 11% to 3% at one site and from 6% to 0% at the other (p. 59). Ross et al. (2011) also documented a decrease, from four conflicts per 100 crossings to one adding that post-implementation conflicts included instances where drivers proceeded through the intersection before pedestrians finished crossing and when yielding vehicles in one lane blocked the view of vehicles approaching in another. Hunter et al. (2009) distinguished between avoidance maneuvers (minor changes in speed or direction) and conflicts (sudden changes in speed or direction). Researchers observed just two conflicts, both in the after period, and no statistically significant pre-post change in either metric. Mishra et al. (2015) did not observe enough conflicts to conduct statistical analysis and was unable to attain sufficient crash data. Zegeer et al. (2017) developed CMFs for RRFBs, but the statistical model was not statistically significant. Further, they cautioned against its use, as 32 of 50 sites used in its estimation were located in St. Petersburg.

Attitudes, Beliefs, and Perceptions

Several sources used surveys to complement behavioral observations. Eighty-five percent of respondents to Dougald's (2016) survey of 224 trail users felt that the RRFB increased safety for bicyclists and pedestrians (p. 31) with 77% reporting a favorable or highly favorable opinion of the facility (p. 32). Notably, 66% of these respondents expected motorists to yield when the beacons were flashing (p. 30). Porter et al. (2016b) interviewed 265 students at a Virginia university. Results indicated that perceptions of safety took some time to develop: perceptions of safety were significantly higher 2 months post-implementation compared to 1 month post-implementation or pre-implementation; all other self-report metrics (being involved in a near-miss as a pedestrian or motorist, always using crosswalks as a pedestrian, and always yielding to pedestrians as a motorist) remained constant.

Education Strategies

None of the sources reviewed directly investigated education strategies regarding RRFBs. Fitzpatrick et al. (2014) briefly commented that some cities may have undertaken more comprehensive education efforts, but these efforts were not measured or considered in analysis.

Knowledge and Comprehension

The sources reviewed did not extensively explore comprehension. Salamati's (2012) simulator experiment included debriefing questionnaires, which revealed that 11% of participants were "seemingly unaware of the RRFB's purpose" (p. 73). Fitzpatrick et al. (2014) observed higher yield rates in cities where RRFBs were more widely deployed and hypothesized that "this familiarity could improve driver understanding and expectations for yielding" (p. 49). Dougald (2016) observed possible confusion regarding right-of-way during field observation, and confirmed it with a survey: 47% of respondents correctly responded that pedestrians and bicyclists have the right-of-way at marked crosswalks, while 36% believed that motorists have it, and 9% did not know.

Gaps in Literature

Much research explored various aspects of RRFBs, including who uses the pushbuttons and when, how often motorists yield and the factors that affect yielding, and safety-related behaviors and outcomes. The RRFB is well-suited to educational and law enforcement efforts, but no identified research explored these concepts. Due to their high visibility, various educational strategies could be designed to increase pedestrian use and motorist compliance. These could include on-site informational signs as well as other traditional media (television and radio). The effects of law enforcement are entirely unknown. Strategies could be developed to increase pedestrian or motorist compliance. Future research into these components could reveal ways to further increase safety surrounding RRFBs.

Summary and Conclusions

A large body of research indicated that RRFBs were effective and flexible treatments for crossing pedestrians and bicyclists. They have been applied to mid-block locations, intersections, and trail crossings. Despite inconsistent beacon activation, motorists yielded to pedestrians and bicyclists significantly more often in the presence of RRFBs than otherwise, and this behavior emerged quickly and persisted over time. Neither flashing pattern nor beacon shape appeared to affect yielding, but deploying more beacons was generally associated with greater yield rates. In addition to yielding, motorist speeds close to RRFB implementations decreased, and fewer pedestrians became stranded in the median. Perceptions about RRFBs were positive among all road users, and comprehension could be improved, especially knowing who has the right-of-way.

Refuge Islands

Refuge islands, also known as *safety islands* (NACTO, 2013) or *crossing islands* (FHWA, 2013, 2018), are protected spaces placed in the center of a street to facilitate bicycle and pedestrian crossings (NACTO, 2013). Refuge islands enhance pedestrian safety and comfort by providing pedestrians with a protected space to wait for an acceptable gap in traffic, allowing pedestrians to focus on crossing one direction of traffic at a time, and reducing the amount of time a pedestrian is in the roadway (FHWA, 2018). Refuge islands can also act as a form of traffic calming by reducing vehicle speeds leading up to crosswalk locations (FHWA, 2013). Figure 18 shows a refuge island.

Figure 18. Refuge Island in Chicago, Illinois (NACTO, 2013)

Refuge islands can be installed at uncontrolled crossings, such as mid-block crossings, as well as at signalized intersections. The use of refuge islands is typically recommended in locations where pedestrians are required to cross four or more travel lanes and in certain high speed, high volume locations where pedestrians may have difficulty finding adequate gaps in traffic (FHWA, 2018). They should always be used in conjunction with crosswalk markings. The use of signs, delineators, and other crosswalk visibility enhancements is also recommended.

Sources

The research team identified 16 relevant studies, but were unable to obtain 3 (Little & Saak, 2010; Qiu, Xu, & Zhang, 2010; Dongdong & Qing, 2011) despite extensive searches of online resources and requesting copies directly from the authors. Of the 13 relevant studies obtained, 6 originated in the United States, 2 in Canada, 1 in Australia, 1 in Poland, 1 in Hungary, 1 in Italy, and 1 in China.

- Gårder (1989) evaluated the risk to pedestrians at 120 intersections in Stockholm and Malmö.
- Huang and Cynecki (2000) conducted a before-after study to evaluate the pedestrian safety benefits of several traffic calming measures, including refuge islands installed in Sacramento, California, and Corvallis, Oregon.
- Zegeer et al. (2001) performed an analysis of 5 years of pedestrian crashes at 1,000 marked crosswalks and 1,000 matched unmarked comparison sites across the United States to determine whether marked crosswalks at uncontrolled locations are safer than unmarked crosswalks under various traffic and roadway conditions.
- Thouez et al. (2003) examined the relationship between pedestrian behavior, primarily pedestrian crossing compliance, and the physical and environmental characteristics of 20 signalized intersections in Toronto and Montreal.
- Hatfield et al. (2006) used a survey and field observations to better understand pedestrian and driver beliefs and behaviors related to pedestrians’ right-of-way in a variety of crossing scenarios.
- Li and Fernie (2010) conducted an observational study using video recordings to determine whether pedestrian crossing behavior at an eight-lane divided roadway becomes riskier in inclement weather.

- Mako (2015) used crash data and site observations to examine the effects of various road measures, including refuge islands, on safety at pedestrian crossings before and after implementation.
- Zegeer et al. (2017) collected data from 975 sites across 14 U.S. cities to develop CMFs for four treatment types, including refuge islands.
- Fitzpatrick et al. (2017) compiled data from previous studies and collected data at 25 new study locations to analyze motorist yielding behavior at uncontrolled crosswalks with RRFBs present. In addition to evaluating the impacts of the RRFBs, researchers also identified other environmental and crossing characteristics, such as the presence of refuge islands, that significantly impacted yielding behavior.
- Ni et al. (2017) conducted an intercept survey at 32 crosswalks in Shanghai to explore pedestrians' perceptions of various crosswalk features, including refuge islands.
- Vignali et al. (2019) conducted a before-after analysis of zebra crossings in Italy to determine how the installation of median refuge islands and "Yield here to pedestrians" signs with flashing LED lights influenced motorist speed' and crosswalk conspicuity.
- Solowczuk and Kacprzak (2019) recorded motorist speed measurements before and after refuge islands of different widths were installed. Their goal was to determine if refuge islands were efficient in reducing both the mean travel speed and the 85th percentile speed.
- Kang (2019) collected and reviewed collision data for 118 New York City intersections to evaluate the associations between the installation of 11 street design elements and changes in vehicle-pedestrian collisions.

Table 17 provides a chronological overview of these sources and the road users and components present in the literature.

Table 17. Overview of Sources Relevant to Refuge Islands

Source	Bicyclists	Motorists	Pedestrians	Use, Comprehension, Safety	Attitudes, Beliefs, Perceptions	Education Strategies	Knowledge, Comprehension
Gårder, 1989		✓	✓	✓			
Huang & Cynecki, 2000		✓	✓	✓			
Zegeer et al., 2001		✓	✓	✓			
Thouez et al., 2003			✓	✓			
Hatfield et al., 2006		✓	✓				✓
Li & Fernie, 2010			✓	✓			
Mako, 2015		✓	✓	✓			
Fitzpatrick et al., 2017		✓		✓			
Ni et al., 2017			✓		✓		
Zegeer et al., 2017			✓	✓			
Vignali et al., 2019		✓		✓			
Kang, 2019		✓	✓	✓			
Solowczuk & Kacprzak, 2019		✓		✓			

Note: A ✓ indicates that the source does address this road user or component.

Use, Compliance, and Safety

The sources reviewed focused primarily on motorist speeds and yielding, pedestrian use and compliance, vehicle-pedestrian and vehicle-bicyclist conflicts, and crash rates. Findings regarding motorist speeds and yielding were promising but inconclusive. Despite this and low pedestrian compliance, refuge islands were associated with fewer conflicts and crashes.

Researchers found that crashes at pedestrian crossings are primarily caused by motorists speeding and not giving priority to pedestrians (Mako, 2015). Research into the impacts of refuge islands on motorist speed and yielding behavior produced mixed results. Solowczuk and Kacprzak (2019) conducted a before-after study to evaluate the impacts of pedestrian refuge islands on motorists' speeds at 10 crossing locations. They found that pedestrian refuge islands did not have a significant speed-reducing effect and that any observed reductions in speed were a result of other factors, such as reduced visibility and the presence of residential buildings in close proximity.

In contrast, other researchers documented reductions in speeds and increases in yielding. Vignali et al. (2019) observed reductions in the average and 85th percentile speeds of approaching drivers (3 km/h, $p < 0.05$; 2.5 km/h, respectively). Average stopping distance relative to the crosswalk also increased significantly (approximately 4 meters) and the speed of motorists entering the crosswalk decreased by 2 km/h. These changes contributed to safer conditions for crossing pedestrians. The intervention in this study, however, included both refuge islands and "Yield here to pedestrians" signs with flashing LED lights; researchers noted that crosswalk conspicuity slightly increased in the after period so these changes could not be attributed solely to the refuge island. In addition, the potential effects of pedestrians positioned on the refuge island (compared to positioned on the adjacent sidewalk) were not discussed.

Fitzpatrick et al. (2017) investigated the effects of several roadway and traffic control device characteristics on motorist yielding behavior at uncontrolled crosswalks with RRFBs. They found that yielding behavior improved when raised medians or short refuge islands were present. In a before-after study that involved the installation of various traffic calming treatments at crossing locations throughout the United States, Huang and Cynecki (2000) found that, although motorist yielding improved after the installation of refuge islands, the increase was not statistically significant.

Along with motorist behaviors, some research explored pedestrian use and compliance related to refuge islands. Huang and Cynecki (2000) observed pedestrians at refuge islands in two U.S. cities and found that they directed more pedestrians to cross within the crosswalk. In Sacramento, California, the number of pedestrians using the crosswalk increased by over 10%. This number also increased at the Corvallis location, but the increase was not statistically significant.

Research on pedestrian compliance was primarily focused on pedestrian crossing signal compliance and use of the refuge island. Li and Fernie (2010) recorded road crossing behaviors at one eight-lane divided road strip at a downtown site in an effort to evaluate pedestrian safety at the existing two-stage crossing. Researchers observed that only 23% of all pedestrians complied with the requirement to cross in two stages by waiting on the refuge island. However, 35% of the pedestrians who waited on the refuge island did not comply with the pedestrian crossing signal during the first leg of the crossing. They hypothesize that two-stage crossings may frustrate pedestrians who are in a hurry, leading to reduced compliance and unsafe crossing behaviors. In contrast, when looking at pedestrian behaviors at 20 urban signalized intersections in Canada, Thouez et al. (2003) found that the presence of a refuge island was associated with improved pedestrian crossing signal compliance.

All sources reviewed indicate safety improvements associated with the installation of refuge islands. In an evaluation of traffic conflicts at 115 signalized and unsignalized intersections, Gårder (1989) found that the installation of a pedestrian refuge island reduced crash risk by approximately 33%. Similarly, Zegeer et al. (2001) found that raised medians or crossing islands were associated with significantly lower pedestrian crash rates at multilane study locations. Mako (2015) observed 42% fewer crashes following the installation of median or refuge islands. Additionally, researchers noted a 64% reduction in pedestrian-involved crashes in the after period. In developing CMFs, Zegeer et al. (2017) found that refuge islands were associated with a 32% reduction in pedestrian crash risk. Kang (2019) found a similar reduction in pedestrian collisions: an analysis of crash data from 118 intersections indicated that vehicle-pedestrian collision rates were reduced by approximately 38% following the installation of pedestrian refuge islands. Additionally, researchers noted that pedestrian collisions were further reduced when refuge islands were combined with lane removal or narrowing.

Attitudes, Beliefs, and Perceptions

Limited research has explored the attitudes, beliefs, and perceptions toward refuge islands. Ni et al. (2017) conducted intercept surveys with 1,286 pedestrians at 32 crosswalks in Shanghai. In order to gain insight on how crossing behavior impacted the pedestrians' perceptions, researchers categorized respondents as green walkers, late walkers, or red walkers. Responses indicated that the installation of a refuge island improved the perception of safety among all types of pedestrians. However, refuge islands were most highly favored by pedestrians observed entering crosswalks during the flashing green phase (late walkers). Researchers believe that this is because late walkers feel safer knowing they have the option to stop at a refuge island if they do not finish crossing the roadway in time.

In contrast, pedestrians who were observed entering crosswalks during the red signal indicator perceived refuge islands as less safe. The results of the survey also indicated that the installation of refuge islands may result in reduced pedestrian signal compliance. By providing pedestrians with a refuge in the middle of the roadway, they may be more willing to enter the crosswalk while the light is red or flashing green (used in many parts of China to indicate the pedestrian crossing clearance interval) since the risk of conflict is reduced (Ni et al., 2017).

Education Strategies

None of the sources reviewed investigated educational strategies regarding refuge islands.

Knowledge and Comprehension

One study probed knowledge and comprehension of refuge islands, primarily in regard to right-of-way rules. Hartfield et al. (2006) observed pedestrian behavior at two four-leg intersections and conducted on-site interviews with pedestrians. Responses indicated confusion associated with pedestrian right-of-way in certain crossing scenarios. Approximately 17% of survey respondents thought that a pedestrian refuge island granted pedestrians the right-of-way at otherwise unmarked sections of road, and a "concerning" (though unreported) number did not know who had the right-of-way (p. 841). Researchers concluded that there is a need to address the confusion regarding the right-of-way rules associated with different crossing scenarios in order to avoid potential vehicle-pedestrian conflicts.

Gaps in Literature

Additional research is required to fully understand the impacts of refuge islands on motorist speed and compliance. Many of the studies reviewed examined refuge islands in combination with other facilities, such as RRFBs. This makes it difficult to quantify the benefits provided by refuge islands alone.

This review identified little research into the attitudes, beliefs, or perceptions toward refuge islands. Although Ni et al. (2017) collected responses on perceived safety from over 1,200 respondents at 32 crosswalk locations, responses were only collected in one large city in China, which may not be reflective of perceptions in other parts of the world among different road users.

Additionally, there remains much to be explored regarding education strategies and refuge islands. Hatfield et al. (2006) documented confusion regarding pedestrian right-of-way in select crossing scenarios that could be resolved with additional education. The information needed and the best way to convey it have yet to be explored. Signage, public outreach, and law enforcement may be effective, but this review did not identify such research.

Summary and Conclusions

The research suggested that the use of pedestrian refuge islands had a positive impact on pedestrian safety. Although research into motorist speeds yielded mixed results, various studies showed that their installation resulted in significant reductions in both vehicle-pedestrian conflicts and crashes. Additionally, research showed that pedestrians have positive perceptions of refuge islands, associating them with improved safety and security.

Facilities Intended for Multiple Road User Types

Protected Intersections

Protected intersections are a type of signalized intersection intended specifically to improve pedestrian and bicyclist safety. They are designed to be used in conjunction with bike lanes or cycle tracks, extending protection from roadways into intersections. While designs vary, protected intersections are similar to standard signalized intersections but can include the following features (Falbo, 2013; Gilpin et al., 2015):

- **Approach taper:** The approach taper is applied to bike lanes or cycle tracks that enter a protected intersection. The bike lane or cycle track is directed slightly away from the roadway to align bicyclists with the setback.
- **Setback bicycle crossing:** The setback bicycle crossing is defined by road markings and separates through traffic from pedestrian and bicyclists crossing areas. It enhances the visibility of pedestrians and bicyclists and helps to establish priority for these road users.
- **Corner safety island:** The corner safety island is a raised area that provides a physical barrier between the bike lane and road traffic. It also defines the inside corner of the intersection. The barrier is intended to provide comfort to pedestrians and bicyclists. It is also designed to slow right-turning traffic as motorists must avoid it while executing the turn.
- **Corner apron:** The corner apron is designated by road markings and is an optional design feature to accommodate large motor vehicles.
- **Forward stop bar:** The forward stop bar is defined by road markings and designates the waiting area for forward-traveling and left-turning bicyclists. Located further into the intersection, the forward stop bar enhances the visibility of bicyclists for motorists waiting at a red signal or turning. In addition, the forward location gives bicyclists a head start when the signal turns green and reduces bicyclist travel distance needed to cross the intersection.
- **Pedestrian safety island:** The pedestrian safety island can be defined with road markings and/or tactile paving. It provides a separated area for pedestrians waiting at a "Don't Walk" signal and reduces the travel distance of crossing the intersection.
- **Yield for pedestrians:** The yield for pedestrians is defined by road markings and signs and is located at the entrance of the intersection on the servicing bike lane. The purpose

of the design element is to inform bicyclists to yield to crossing pedestrians before entering the stop bar location.

- **Signal operations:** Bicycle signal phasing can be achieved with a separate traffic signal for bicyclists. The signal precedes motor vehicle signals to allow bicyclists to enter the intersection before motorists. This enhances the visibility of bicyclists.

Figure 19 illustrates these key elements.

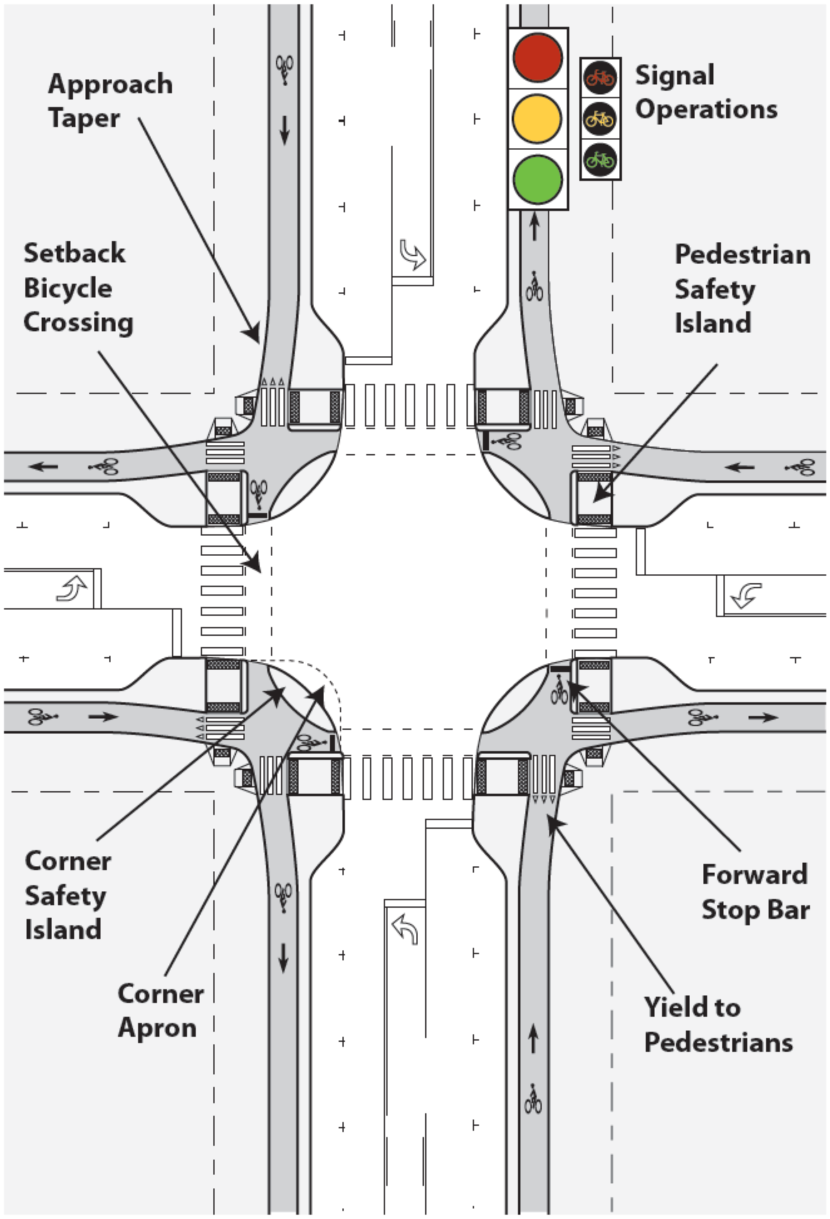


Figure 19. A Protected Intersection with Possible Design Features (Gilpin et al., 2015)

Protected intersections were first used in the Netherlands and other northern European countries. A variation of the facility was discussed in the United States in 1972 by the Institute of Transportation and Traffic Engineering at the University of California-Los Angeles in a report titled *Bikeway Planning Criteria and Guidelines* (Fisher et al., 1972). Another variation was also presented in 1972 by the City of Davis and the University of California-Davis titled *Davis Bicyclist Circulation and Safety Study* (De Leuw, Cather & Company, 1972). Since then, various design elements of protected intersections have appeared in guideline documents, such as those written by NACTO, AASHTO, the Florida Department of Transportation, FHWA, and the Massachusetts Department of Transportation.

The first protected intersections in the United States were completed in 2015 with installations in Salt Lake City, Chicago, Austin, and Davis (California) (Gilpin et al., 2015). By the end of 2015 Canada also had its first protected intersections in Vancouver and Montreal.

Sources

The research team identified three studies that investigated motorist and bicyclist use and safety regarding protected intersections. These studies did not examine intersections with all the previously listed features, but rather specific subsets.

- Warner et al. (2017) conducted a simulator study where participants assumed the role of motorists and executed right turns at intersections with various combinations of road treatments and intersections sizes. Researchers evaluated motorist behaviors as they interacted with protected intersections that included corner safety islands, with and without green bike lanes. Prior to turning, a simulated bicyclist approached from behind in an adjacent right-hand bike lane and traveled forward through the intersection. The researchers recorded collisions and evaluated motorist behaviors.
- In Denmark, Madesen and Lahrmann (2017) conducted observational analyses of motorists and bicyclists at signalized intersections with various types of treatments. One intersection included a setback bicycle crossing that is found in protected intersections.
- Christofa et al. (2019) also assessed participants' behaviors in a simulator experiment as they assumed the role of motorists and executed turns through protected intersections. Protected intersections varied in size and in the type, or absence, of crossing pavement markings. The study also included simulated bicyclists, but they began to cross the protected intersections before the motorist reached the turning point, instead of approaching from the rear as in the experiment conducted by Warner et al. (2017).

Table 18 provides a chronological overview of these sources and the road users and components present in the literature.

Table 18. Overview of Sources Relevant to Protected Intersections

Source	Bicyclists	Motorists	Pedestrians	Use, Comprehension, Safety	Attitudes, Beliefs, Perceptions	Education Strategies	Knowledge, Comprehension
Madesen & Lahrmann, 2017	✓	✓		✓			
Warner et al., 2017		✓		✓			
Christofa et al., 2019		✓		✓			

Note: A ✓ indicates that the source does address this road user or component.

Use, Compliance, and Safety

Researchers have used simulator experiments to study motorist use of protected intersections. Christofa et al. (2019) found that motorists approached protected intersections at lower speeds when the facility had green intersection crossing markings, compared to those with no intersection crossing markings and white intersection crossing markings. It is important to note that all intersection types included zebra crossings and motor vehicle stop lines. Researchers explained the effect is reasonable because the markings are most visible when approaching, rather than when executing turns. Interestingly, the researchers found no differences in motorist turning speeds when comparing protected intersections with no intersection crossing markings, white intersection crossing markings, and green colored intersection crossing markings. Taken with previous findings, the results suggested that intersection crossing markings appeared to influence motorists approach speeds rather than turning speeds.

Research also suggested the turning radii of protected intersections influenced motorist speeds. Gilpin et al. (2015) recommend against the use of wide radii at protected intersections because it may allow passenger vehicles to turn at a high rate of speed, which affects yielding compliance and crash severity. Findings of Christofa et al. (2019) suggested otherwise; their research indicated that motorists drove slower through protected intersections with wide turning radii compared to those with narrower radii. Although the results were statistically significant, the researchers explained that the difference was only 0.7 mph, which may have limited practical significance.

Reviewed literature evaluated safety regarding protected intersections in both simulator and observational settings. In a simulated environment, Warner et al. (2017) found preliminary evidence that protected intersections, with and without green pavement markings, may have reduced the frequency of high-risk conflicts when motorists made right turns across the path of a bicyclist, compared to intersections without refuge islands or pavement markings. Researchers noted however, motorists would likely collide with bicyclists unless they were seen in the rear-view or side mirrors because the bicyclists approached from the rear at a relatively high speed (16 mph). In addition, participants had a larger blind spot using the simulator than they would have driving in a real-world setting, due to the screen orientation and reduced field of view. Of the 626 right turns the study evaluated, 47 resulted in near-collisions and 28 resulted in collisions. Researchers calculated TTC for these near-collisions, defined as instances where collisions between motorists and bicyclists would be imminent if trajectories and speeds remained unchanged, but found inconclusive results regarding protected intersections. Preliminary evidence suggested that protected intersections, with and without green pavement crossing markings, resulted in fewer cases where collisions would have occurred in 0.9 seconds or less, compared to traditional intersections. However, results suggested that protected intersections, with and without green pavement crossing markings, resulted in a greater frequency of time to collision values of 1.5 seconds or less, compared to traditional intersections. Researchers hypothesized that differences in TTC values could be explained by protected intersections providing more space and time between motorists and bicyclists than traditional intersections. Ultimately, the research did not identify significant differences (Warner et al., 2017).

Other simulator research found that motorists approached protected intersections and executed turns at lower speeds when a bicyclist crossed the intersection across their path compared to when no bicyclist was present (Christofa et al., 2019). In fact, bicyclist presence had a greater impact on intersection approach speed than any other variable included in the evaluation (participant gender, age, and identification as a bicyclist; pavement marking type; and intersection turning radius). Whether the reduction is due to increased bicyclist visibility, an intent of the facility's design, has yet to verified.

One of the key features of protected intersections is the setback bicycle crossing. Setback bicycle crossings position motorists perpendicular to crossing bicyclists, in contrast to traditional bicycle crossings that are directly adjacent to motor vehicle lanes. Observational research in Denmark inspected conflicts between bicyclists and motorists at an intersection with a setback bicycle crossing. Madesen and Lahrmann (2017) observed fewer conflicts between bicyclists and right-turning motorists at an intersection that had a setback bicycle crossing compared to intersections with other treatments. The other intersections included either a through bike lane adjacent to the motor vehicle lane or a shared use (motor vehicle and bicycle) lane. Researchers concluded that moving the bicycle crossing away from the intersection appeared to improve bicyclist safety. The setback location required less motorist head movements because they approach it from a perpendicular direction, facilitating bicyclist detection.

Attitudes, Beliefs, and Perceptions

None of the sources reviewed investigated attitudes, beliefs, or perceptions regarding protected intersections.

Education Strategies

None of the sources reviewed investigated education strategies regarding protected intersections.

Knowledge and Comprehension

None of the sources reviewed investigated knowledge or comprehension regarding protected intersections.

Gaps in Literature

The research identified in this review did not discuss road user compliance at protected intersections. A facility may be designed to improve safety, but if road users do not use the facility as intended, the safety benefits may be reduced or disappear. For example, a bicyclist with increased visibility may still not be safe from a motorist violating the direction of a red traffic signal. Conversely, a highly visible bicyclist may influence motorists to comply with red traffic signals. Further research can help to identify the factors and directionality that affect safety at protected intersections.

The studies reviewed investigated motorist use of protected intersections, but research has not yet explored pedestrian or bicyclist use of the facility. As with other new facilities. these road users may not readily understand which locations are appropriate for crossing; bicyclists may use the pedestrian crossing areas and pedestrians may encroach on the bicyclist crossing area. Similar to other side-by-side combinations of general-purpose travel lanes, bike lanes, and crosswalks, a bicyclist swerving to avoid a pedestrian would be at risk of a collision due to the proximity of the adjacent motor vehicle lane.

Attitudes, beliefs, or perceptions of road users have not been gathered regarding protected intersections. It is unknown whether road users believe that protected intersections increase safety. Also, motorists may experience difficulty at newly installed protected intersections as the turning radius may have been altered from the previous intersection. Subjective measures could help to uncover elements of protected intersections, if any, that road users find problematic or difficult to use.

Education strategies have yet to be explored regarding protected intersections. Protected intersections have more design elements than traditional intersections and educational campaigns may affect how road users perceive, comprehend, and use the facility.

A gap in knowledge exists in road user knowledge or comprehension of protected intersections. Protected intersections are similar in some respects to traditional intersections but with additional features. It is unclear whether additional knowledge is required for road users to use protected intersections safely and effectively. Further research could identify trends that hinder road user comprehension.

Law enforcement activities have not been studied regarding protected intersections. A design challenge of protected intersections is the narrower turning radius that can accompany the facility. Although fire trucks are the design vehicle for curb radii in most jurisdictions, drivers of fire trucks and other large vehicles may have a difficult time navigating protected intersections in emergency situations. Research in this domain would further knowledge and help city planners and local governments decide whether to include protected intersections in their traffic safety plans.

Summary and Conclusions

Research indicated that motorists drive slower when approaching protected intersections that have green intersection crossing markings than those with white intersections crossing markings or no intersections crossing markings. Findings suggest motorists adopted lower speeds when traveling through protected intersections with wide radii than those with narrow radii, opposite of the intended effect of the design. Motorists turning speeds did not appear to be influenced by the type of intersection crossing markings at protected intersections. The presence of bicyclists at protected intersections may have influenced motorists to adopt lower speeds as they approached and traveled through the intersection. Setback bicycle crossings, a key design element of protected intersections, appeared to result in fewer conflicts between bicyclists and motorists, improving bicyclist safety.

Roundabouts

Roundabouts, also called traffic circles, rotaries, and a few other terms,[6] are one-way circular intersections with specific design and traffic control features (Robinson et al., 2000). Some characteristics of roundabouts are yield control of all entering traffic, channelized approaches, and geometric features designed to promote low travel speeds. Because traffic can only move in one direction, there is a reduction in the number of conflict points at roundabouts, making them generally safer than other intersection types in terms of aggregate crash statistics for low-medium volume conditions (Robinson et al., 2000). Roundabouts are typically designed to accommodate motorists as well as bicyclists and pedestrians. Pedestrians are often accommodated using the facilities necessary to walk around the perimeter of the roundabout. This includes sidewalks, crosswalks, and splitter islands. Bicyclists are typically expected to ride with traffic or use the roundabout like a pedestrian (Robinson et al., 2000). Figure 20 presents a diagram of a roundabout.

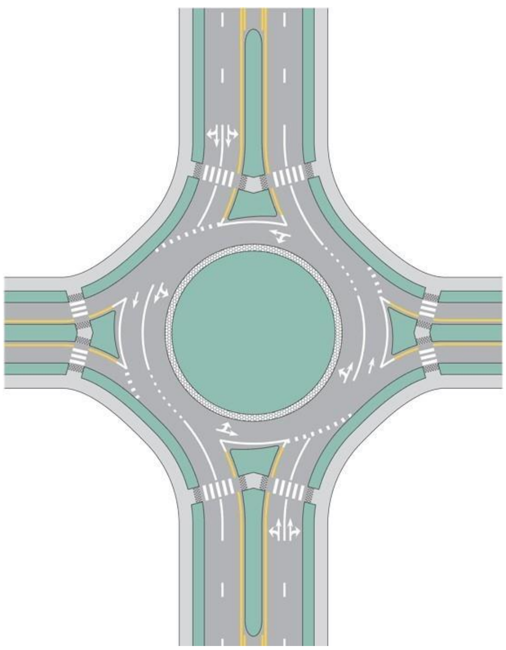


Figure 20. Example Roundabout (MUTCD, 2012)

[6] Wikipedia notes: "In U.S. dictionaries the terms roundabout, traffic circle, road circle and rotary are synonyms. … The U.S. Department of Transportation adopted the term modern roundabout to distinguish those that require entering drivers to give way to others. Many old traffic circles remain in the northeastern [United States]. … In the United States, traffic engineers typically use the term rotary for large-scale circular junctions between expressways or controlled-access highways. … In … New England … , 'rotary' is the general term for all roundabouts, including those with modern designs. … For instance, in Massachusetts, 'Any operator of a vehicle entering a rotary intersection shall yield the right-of-way to any vehicle already in the intersection.' In Rhode Island entering vehicles 'Yield to vehicles in the roundabout.'"

Traffic circles are distinct from roundabouts: they can use stop control, traffic signals, or no control on one or more entrances. Additionally, traffic circles may allow circulating traffic to yield to entering vehicles and may occasionally allow left-turn movements (Robinson et al., 2000).

Although circular junctions pre-date roundabouts by more than a hundred years before the invention of gas-powered vehicles, modern roundabouts first emerged in Britain in the 1960s, spreading to British-influenced countries and then greater Europe during the 1970s and 1980s (Sarkar, 2003). Many European countries now commonly use roundabouts and they have become increasingly popular in many cities throughout the United States. The Roundabout Database, developed by Kittelson and Associates, reports that all 50 States and the District of Columbia currently have at least one roundabout in operation (Kittelson & Associates, Inc., 2020).

Sources

The research team identified 5 relevant studies. Of these, 1 originated in Belgium, 1 in Sweden, 1 in Israel, and 2 in the United States.

- Sarkar (2003) conducted a review of the driver's manuals of 32 States and the District of Columbia. in 1998 and 2002 to determine the amount of information presented on roundabouts and traffic circles.
- Harkey and Carter (2006) performed an observational study at numerous roundabouts to characterize how pedestrians and bicyclists interact with vehicles.
- Daniels et al. (2009) conducted a before-after study of injury crashes with bicyclists at 90 roundabouts in Flanders, Belgium, to investigate possible differences in bicyclist safety between various bicycle facility designs.
- Sakshaug et al. (2010) used quantitative and qualitative methods in traffic conflict, interaction, and behavioral studies to determine how interactions and conflicts differ between two roundabout designs.
- Cohen et al. (2013) conducted a two-part study in Israel to quantify the effects of using guardrails at roundabouts to direct pedestrians to crosswalks.

Table 19 provides a chronological overview of these sources and the road users and components present in the literature.

Table 19. Overview of Sources Relevant to Roundabouts

Source	Bicyclists	Motorists	Pedestrians	Use, Comprehension, Safety	Attitudes, Beliefs, Perceptions	Education Strategies	Knowledge, Comprehension
Sarkar, 2003		✓				✓	
Harkey & Carter, 2006	✓	✓	✓	✓			
Daniels et al., 2009	✓			✓			
Sakshaug et al., 2010	✓	✓		✓			
Cohen et al., 2013			✓	✓			

Note: A ✓ indicates that the source does address this road user or component.

Use, Compliance, and Safety

The sources reviewed focused primarily on observed pedestrian and bicyclist behaviors on roundabouts, pedestrian, and motorist compliance, observed motor vehicle-pedestrian and motor vehicle-bicycle conflicts, and crash rates.

Harkey and Carter (2006) collected observational data for 769 pedestrian crossing events and 690 bicyclist events at 14 different roundabouts in the United States. They found that, although a majority of pedestrians exhibited normal crossing behavior at roundabouts, 25% of pedestrians hesitated on the curb or splitter island of one-lane approaches. This increased to 40% on two-lane approaches. Researchers also observed pedestrians running across the roadway, primarily across the exit legs of the roundabouts. Approximately 40% of observed pedestrians completed their crossings by running across the single exit lane approaches. This value decreased to 19% for two-lane exit approaches. Researchers hypothesized that the running behavior was done mainly out of courtesy for waiting motorists and not to avoid conflicts. In addition to observing pedestrian behaviors, researchers also analyzed bicyclist behavior at seven roundabout locations. They found that nearly 75% of bicyclists approaching the roundabout were positioned at the edge of the travel lane or, if available, a bike lane or paved shoulder. The remainder of the observed bicyclists either occupied the entire lane (15%) or used the sidewalk (12%). When riding inside the roundabout, 83% of observed bicyclists occupied the entire lane. In contrast, Shakshaug et al. (2010) found that more than half of the motorists who caught up with bicyclists in the roundabout did not stay behind but drove parallel to bicyclists. Both Shakshaug et al. (2010) and Harkey and Carter (2006) observed some instances of bicyclists entering the roundabout using the incorrect approach, contrary to the flow of the roundabout. Although only seven cases of wrong-way riding were recorded, it could result in severe safety problems (Harkey & Carter, 2006).

Research on pedestrian compliance focused primarily on whether crossings were made within the boundaries of the crosswalk. Cohen et al. (2013) conducted field observations at 10 roundabouts in Israel to evaluate the impacts of guardrails on pedestrian crossing behavior. Approximately 25% of the 11,116 observed crossings were not at a crosswalk, with over 60% of crossings occurring between 3 and 30 meters away from the crosswalk. Researchers found that crosswalk compliance rates improved in higher traffic volume scenarios and when the crosswalk was divided by a refuge/splitter island. Additionally, women exhibited higher compliance rates than men. In contrast, Harkey and Carter (2006) noted that the majority of observed pedestrians crossed the roadway within the boundaries of the crosswalk.

In addition to studying pedestrian compliance, some researchers have made observations on motorist compliance, primarily in regard to yielding to pedestrians. Harkey and Carter (2006) state that two-lane approaches were more difficult for pedestrians to cross because of lower motorist yielding. The results of the observational study indicated that 17% of the observed motorists did not yield to a crossing or waiting pedestrian. This value increased to nearly 45% in roundabouts with two-lane approaches.

Research has shown that roundabouts are safer for pedestrians than other forms of intersection control. Harkey and Carter (2006) collected observational data for 769 pedestrian crossing events and 690 bicyclist events at 14 different roundabouts in the United States. Researchers observed conflicts in just 0.5% of the pedestrian crossing events and 0.6% of the bicyclist crossing events, and zero collisions overall. Motor-vehicle-only conflicts were not reported upon. As a result, researchers concluded that roundabouts did not result in any substantial safety problems for pedestrians and bicyclists.

Other researchers have found that roundabouts have negative impacts on bicyclist safety. Daniels et al. (2009) conducted an "empirical Bayes before-after study" to investigate the impacts of different bicycle facilities on bicyclist safety in roundabouts. Using data from 90 roundabouts in the Flanders region of Belgium, researchers found an increase in the number of severe bicyclist injury crashes after the construction of a roundabout, regardless of the type of bicycle facilities provided. In a separate observational study, Shakshaug et al. (2010) used field reviews, video recordings, and crash analysis to determine how interactions and conflicts differ between two roundabout designs with separated bicycle facilities. Researchers found that, in roundabouts where bicyclists are integrated with motorists, the majority of conflicts were a result of entering motorists not yielding to circulating bicyclists. Additionally, 15% of all observed conflicts were a result of motorists driving parallel to bicyclists within the roundabout, which goes against traffic rules in the area (Shakshaug et al. 2010).

Attitudes, Beliefs, and Perceptions

None of the sources reviewed investigated attitudes, beliefs, or perceptions regarding roundabouts.

Education Strategies

None of the sources reviewed included the impacts of educational strategies on roundabout use and understanding. However, some research has been conducted on the prevalence of roundabout information in motorists' educational material. Sarkar (2003) reviewed driver manuals for 32 States and D.C. for information on roundabouts and traffic circles. Researchers found that the information provided was inadequate, with only 10 States providing instructions on how to properly navigate roundabouts as drivers. Additionally, none of the driver manuals provided information on bicycle and pedestrian right-of-way until 2002. In 2002 only three States provided information on pedestrians and bicyclists (Sarkar, 2003). Researchers recommended that driver manuals be updated to include information on pedestrian and bicyclist right-of-way rules and provide examples of suggested guidance (Sarkar, 2003).

Knowledge and Comprehension

None of the sources reviewed investigated knowledge or comprehension regarding roundabouts.

Gaps in Literature

This review did not identify research into the attitudes, beliefs, or perceptions toward roundabouts. Research could explore topics related to bicyclist and pedestrian perceptions of safety when using roundabouts or motorist perceptions of sharing the roadway with bicyclists in a roundabout. There also remains much to be explored regarding education strategies and roundabouts, particularly for motorists and bicyclists. Research has shown that very few State driver's manuals include sufficient information on how to properly navigate roundabouts, especially in the presence of pedestrians and bicyclists. Additionally, this review did not identify information on where and how bicyclists should navigate a roundabout. This could be responsible for the different riding behaviors observed in roundabouts, which may make it more difficult for motorists and bicyclists to properly share the roadway. The research suggested that the safety benefits provided by roundabouts rely primarily on motorists yielding, which additional education may further improve. Whatever information is needed, research has not yet explored the best way to convey it and measure its effectiveness.

Summary and Conclusions

Overall, the research suggested that the use of roundabouts had positive effects on pedestrian safety. However, pedestrian safety was largely dependent on the type of roundabout (one-lane versus multi-lane) and motorist yielding behavior. While motorists yielding rates were generally high for single-lane roundabouts, yielding rates were lower in two-lane roundabout scenarios. Additionally, research showed that roundabouts were typically associated with little to no observed vehicle-pedestrian conflicts and crashes. Despite the observed improvements in pedestrian safety, the impacts roundabouts have on bicyclist safety were mixed. While some studies showed that roundabouts have a positive impact on bicyclist safety, others suggested that their construction results in higher injury rates for bicyclists. Many researchers have suggested that this is likely due to improper motorist yielding behavior, which may improve with additional education.

Shared-Use Paths

Shared-use paths, also referred to as *multi-use paths* (Buehler & Pucher, 2012) *multiuse pathway*s (Teschke et al., 2012; Li, Muresan, & Fu, 2017), or *shared paths* (Hatfield & Prabhakharan, 2016) are facilities that can be used by many modes of transport, including bicyclists, in-line skaters, skateboarders, scooter riders, pedestrians with and without strollers, runners, equestrians, and people using wheelchairs (Aultman-Hall & LaMondia, 2005; Architectural and Transportation Barriers Compliance Board, 2011). Shared-use paths are used for recreation and transportation, and may extend or compliment roadway networks. They are intended to be used similarly to motor vehicle roadways (Architectural and Transportation Barriers Compliance Board, 2011), slower moving path users travel on the right-hand side, while passing path users do so on the left-hand side. The pattern is reversed in countries such as Australia and the United Kingdom, where motor vehicles travel on the left-hand side of the road. When located near roadways, shared-use paths may be separated with marking or barriers

(Architectural and Transportation Barriers Compliance Board, 2011). Signage and/or road markings can be used to explain rules or separate opposite traveling path users.

Shared-use paths are used extensively across the United States. For example, shared-use paths were part of a 90-city study conducted by Buehler and Pucher (2012). They can also be found in Australia, Denmark, Ireland, New Zealand, and the United Kingdom (Ker et al., 2006).

Sources

The research team identified a total of 12 studies relevant to this review, but could not obtain the full-text versions of 2 sources (De Rome et al., 2011; Skartland, 2016). Of the 10 sources that were obtained, 2 originated in the United States, United Kingdom, and Australia (each); 3 originated in Canada; and 1 was a joint effort undertaken by researchers in China and Canada.

- Quenault (1982) discussed the results of studies conducted in the United Kingdom, where researchers observed road user behavior and gathered perceptions of bicycle routes. Shared-use paths were incorporated into portions of the bicycle routes.
- Nearly two decades later, Jordan and Leso (2000) observed path user behavior on a shared-use path in Philadelphia, before and after center line and arrow markings were painted onto the path.
- Aultman-Hall and LaMondia (2005) used surveys to gather self-reported collisions and falls of pedestrians, bicyclists, and in-line skaters at three shared-use paths in Connecticut.
- In Australia, Ker et al. (2006) conducted stakeholder interviews with State governments, local governments, user groups, and users regarding conflicts on shared-use paths.
- Hunt and Abraham (2007) conducted a survey-based, bicyclist preference experiment in Edmonton, Canada. Questionnaires presented hypothetical bicycle routes to respondents and asked them to choose the preferred option.
- Teschke et al. (2012) interviewed bicyclists who were injured using various types of bicycle facilities, including shared-use paths, in Vancouver and Toronto.
- Atkins (2012) observed pedestrians and bicyclists using separated and non-separated shared-use paths in the United Kingdom. Researchers also conducted intercept surveys to gather path user perceptions.
- A few years later, Hatfield and Prabhakharan (2016) observed pedestrian and bicyclist behaviors during passing events on three shared-use paths in Sidney, Australia. They conducted surveys at the study locations to gather pedestrian and bicyclist beliefs and experiences.
- More recently, Gkekas, Bigazzi, and Gill (2020) conducted intercept surveys at the University of British Columbia in Vancouver, to gather perceptions of safety and comfort regarding shared-use paths.
- Zheng, Sayed, and Guo (2020) explored factors related to pedestrian and bicyclist lane use compliance on the Brooklyn Bridge.

Table 20 provides a chronological overview of these sources and the road users and components present in the literature.

Table 20. Overview of Sources Relevant to Shared-Use Paths

Source	Bicyclists	Motorists	Pedestrians	Use, Comprehension, Safety	Attitudes, Beliefs, Perceptions	Education Strategies	Knowledge, Comprehension
Quenault, 1982	✓	✓	✓		✓		
Jordan & Leso, 2000	✓		✓	✓			
Aultman-Hall & LaMondia, 2005	✓		✓	✓			
Ker et al., 2006	✓		✓		✓		
Hunt & Abraham, 2007	✓				✓		
Atkins, 2012	✓		✓	✓	✓		
Teschke et al., 2012	✓			✓			
Hatfield & Prabhakharan, 2016	✓		✓	✓	✓		
Gkekas et al., 2020	✓		✓	✓	✓		
Zheng et al., 2020	✓		✓	✓			

Note: A ✓ indicates that the source does address this road user or component.

Use, Compliance, and Safety

The sources reviewed indicated that bicyclists reduced their speeds as pedestrian volumes increased on shared-use paths, but did not consistently warn them when passing. Several studies examined lane position and compliance with centerlines among various road users. Safety was primarily examined via surveys.

Researchers documented a decrease in maximum bicyclist speeds as pedestrian flows increased on shared-use paths in the United Kingdom, suggesting that bicyclists "moderate their behavior in the presence of pedestrians" (Atkins, 2012, p. 5). Hatfield and Prabhakharan (2016) refined this statement with the finding that only 3% of bicyclists reduced their speed when passing pedestrians from behind and 6% reduced speed when passing in the opposite direction. When bicyclists and pedestrians share the same space, communication can help the two groups co-exist safely. Hatfield and Prabhakharan (2016) inspected safety related behaviors on shared-use paths, finding that only 2% of bicyclists warned pedestrians before passing from behind. No bicyclists were observed warning pedestrians before passing in the opposite direction.

Jordan and Leso (2000) observed pedestrians, bicyclists, in-line skaters, and runners before and after centerlines were painted onto a shared-use path. Dashed white lines and directional arrows were also applied at driveways and road crossings. The proportion of path users traveling on the wrong side was reduced from 30% to 10% following the addition of centerline markings and arrows; painting a yellow centerline at blind corners reduced the proportion of path users traveling on the wrong side from 35% to 15%. When comparing different types of path users, Jordan and Leso (2000) observed that runners traveled on the correct side of a shared-use path to a greater degree than bicyclists, pedestrians, and roller-skaters. Roller skaters traveled on the wrong side of the path in greater proportions than the other path users. Researchers hypothesized the observation was the result of relatively more horizontal space skaters took up when moving, as oscillating sideways movements were required for forward travel. Pedestrians varied in the side of the shared-use path they used. Researchers noted that pedestrians seemed to be concentrating less on where they were going than other path users as "the wrong-side pedestrians seemed oblivious to any danger" (p. 19).

Research conducted by Hatfield and Prabhakharan (2016) supported these findings. Ninety-three percent of pedestrians traveled on the correct side when there was a centerline, compared to 76% when there was no centerline present. Similarly, 93% of bicyclists traveled on the correct side when there was a centerline, compared to 83% when there was not a centerline present. When comparing their findings to those of Jordan and Leso (2000), Hatfield and Prabhakharan concluded that the centerline may have been effective in keeping shared path users on the correct side, even without directional arrows. Atkins (2012) also observed higher rates of pedestrians (83% to 100%) traveling on the correct side of shared-use paths with centerline markings than bicyclists (82% to 94%).

Zhen et al. (2020) explored factors associated with centerline compliance on the Brooklyn Bridge promenade. Researchers did not manipulate the shared-use path, but used video footage to observe pedestrians and bicyclists and compare compliant and non-compliant users. Forty-seven percent of pedestrians and 32% of bicyclists were found to be non-compliant with the centerline. Statistical modeling indicated that pedestrians were more likely to be non-compliant when they were headed to Brooklyn (compared to Manhattan), exercising, when in the presence of other pedestrians going the same direction, or when in the presence of a bicyclist going in either direction. The presence of vendor booths and garbage bins also significantly increased the likelihood of violation. Bicyclists were found more likely to be non-compliant when heading toward Brooklyn, and less likely to violate the centerline when in the presence of pedestrians traveling in either direction. They conclude that the significance of the direction of travel (toward Brooklyn or toward Manhattan) underscores the importance of clear guidance on path use.

Three studies used questionnaires to investigate injuries on shared-use paths. Interviews with injured Canadian bicyclists suggested that shared-use paths may have been associated with a small reduction in the risk of injury (collision with a motor vehicle, route infrastructure, a person or animal; or falling) compared to routes with major streets, parked cars, and no bicycle facilities (Teschke et al., 2012). However, the difference in risk between the two route types was not deemed statistically significant.

Aultman-Hall and LaMondia (2005) gathered self-reported incidents from pedestrians, bicyclists, and in-line skaters on three shared-use paths. Incidents included both falls and collisions with other path users; collisions with motorized traffic were not considered. Researchers found skaters had the highest incident rates (0.26 incidents/1,000 miles), bicyclists had the second highest (0.15 incidents/1,000 miles), and pedestrians had the lowest (0.04/1,000 miles).

Gkekas et al. (2020) gathered incident experiences from pedestrians and bicyclists on a university campus that included shared-use paths. Similar to Aultman-Hall and LaMondia (2005), incidents were more prevalent among bicyclists than pedestrians; 19% of respondents who bicycled on campus at least occasionally reported at least one incident within the last year, while 15% of respondents who walked on campus at least occasionally reported at least one incident within the last year. Notably, the most common type of incident occurred between bicyclists and pedestrians (from both path users' perspectives), compared to incidents with non-moving permanent objects or motor vehicles. Twenty-two percent of the incidents reported by respondents resulted in an injury of some kind.

Atkins (2012) used both video footage and questionnaires to explore conflicts and injuries. Zero collisions took place during the video footage, but five marginal conflicts (instances where a bicyclist or pedestrian slowed down or changed direction for another path user in a calm, controlled manner) were observed on non-separated shared-use paths. Responses to the questionnaire indicated that 3% to 4% of pedestrians and bicyclists had experienced a collision on the shared-use path where they were handed the questionnaire. Researchers suggested that lane width played a role, as the non-separated paths were narrower that the separated ones. However, these findings were derived from shared-use paths only, while the findings from Gkekas et al. (2020) may have arisen from other locations, as questions were asked about experiences on a university campus.

When comparing separated and non-separated shared-use paths, Atkins (2012) found the difference in the potential for conflicts to be minimal. Hatfield and Prabhakharan (2016) observed five near-collisions between shared-path users, but no statistical associations could be drawn due to the low occurrence of the event.

Attitudes, Beliefs, and Perceptions

The literature reviewed did not evaluate attitudes toward shared-use paths, but did attempt to ascertain beliefs and perceptions regarding shared-use path users.

On-site surveys conducted at shared-use paths revealed the majority of pedestrians believed that "quite a lot" or "nearly all" bicyclists keep to the left (in Australia) when using the facility (Hatfield, & Prabhakharan, 2016). Approximately 90% of pedestrians found passing bicyclists' warnings helpful but the majority felt that they "rarely" or "never" actually gave warnings. The majority of pedestrians also believed that "few" bicyclists or "almost none" travel too fast. However, other research found that 54% of pedestrians who experienced an incident believed excessive bicycling speeds was a contributing factor (Gkekas et al., 2020). A smaller proportion of bicyclists who also experienced incidents (13%) shared this belief. Approximately 20% of both pedestrians and bicyclists believed bicyclist inattention was a contributing factor for incidents involving pedestrians.

Hunt and Abraham (2007) used a stated preference experiment to explore route choice in various hypothetical situations. Responses indicated that traveling on shared-use paths was less desirable for bicyclists than traveling on dedicated bicycle paths. Researchers hypothesized that bicycling alongside pedestrians may have been viewed as more dangerous than using a dedicated facility or that bicyclists may have felt confined to travel at lower speeds in the presence of pedestrians. While having to adjust speeds may have played a role in bicyclist perceptions of pedestrians, Hatfield and Prabhakharan (2016) found that approximately half of surveyed bicyclists believed that "quite a lot of" or "nearly all" pedestrians traveled in the intended direction, suggesting positive perceptions. However, a similar proportion believed that pedestrians "often" or "almost always" fail to sufficiently supervise children or animals. For pedestrians and bicyclists who were involved in incidents, 52% of pedestrians and 70% of bicyclists believed pedestrian inattention was the primary cause (Gkekas et al., 2020).

Gkekas et al. (2020) found that 70% of respondents who were involved in incidents “somewhat” or “strongly” agreed that pedestrian-bicyclist conflicts on a university campus that included shared-use paths were a safety issue. Notably, these conflicts were believed to be more of an issue than pedestrian-motorist or bicyclist-motorist conflicts. The researchers also found that respondents who had at least one incident within the prior year had 270% greater odds for having safety concerns regarding pedestrian-bicyclist conflicts, and pedestrians who never bicycle had 47% lower odds. The most common additional factor that respondents believed contributed to their incidents was overcrowding: 76% believed so when the incident involved a pedestrian and 79% believed so when the incident involved a bicyclist.

Research conducted in the United Kingdom suggests that perceptions of shared-use paths and users of said paths were generally positive. Quenault (1982) reported that bicycle routes that included shared-use paths were well received, perceptions of safety improved from before the routes were installed, and acceptance was high. Importantly, the assessment covered multiple facilities, not shared-use paths alone.

Atkins (2012) found pedestrians and bicyclists were generally comfortable using shared-use paths with and without centerline marking separation, even though other users were perceived to be non-compliant with the centerline markings. Researchers also found that pedestrians and bicyclists perceived each other as more considerate on non-separated shared-use paths than on separated ones, concluding that behavior is more considerate where the requirement to interact with other user types is clearer. In contrast, Ker et al. (2006) conducted surveys with groups of pedestrians and bicyclists who stated that they experienced bicyclists failing to give sufficient warning to slower moving bicyclists or pedestrians. In addition, respondents reported experiences of bicyclists not giving way to pedestrians, and pedestrians and bicyclists traveling side-by-side, blocking the shared-use path. Survey responses also revealed that speed differences between bicyclists and pedestrians caused pedestrian discomfort as they felt vulnerable to collisions.

Education Strategies

None of the sources reviewed investigated education strategies regarding shared-use paths.

Knowledge and Comprehension

None of the sources reviewed knowledge or comprehension regarding shared-use paths.

Gaps in Literature

Research has investigated the sides that path users take when traveling on shared-use paths. Evidence suggested that centerline markings can influence path users to travel on the appropriate side, especially when used with directional arrows. However, formal research has not evaluated explanatory signage. Path users may travel on the appropriate side of shared-use paths when signs direct them to do so. Educational strategies that explain appropriate use may increase path users’ compliance with centerline markings.

While research has evaluated perceptions of shared-use paths, user comprehension has yet to be measured. Shared-use paths are designed to be used like motor vehicle lanes, with passing dictated by the country's laws for motor vehicles. Research could help to determine if similarities exist in user understanding between motor vehicle lanes and shared-use paths.

Questionnaires indicated that collisions and injuries occur on shared-use paths. Findings suggested path users believed inattention or excessive bicyclist speeds may have been contributing factors. These unsafe behaviors may be reduced by law enforcement presence on shared-use paths. Path users may be more inclined to adopt safe behaviors when law enforcement is present. Future research may help quantify this relationship.

Summary and Conclusions

Shared-use paths were generally well received although some bicyclists were observed using an adjacent roadway instead of a shared-use path. Centerline markings appeared to influence path users to travel on the appropriate side of shared-use paths, especially when used with directional arrows, with different user groups complying at various rates. Questionnaires indicated that collisions and injuries occurred on shared-use paths. Although beliefs regarding contributing factors to these collisions and injuries differed among path users, the literature indicated generally positive perceptions of shared-use paths.

Pedestrian and Bicyclist Wayfinding

Pedestrian and bicyclist wayfinding, also referred to as *wayshowing* (Alotaishan, 2017), is a navigational system comprised of signs and/or pavement markings that help pedestrians and bicyclists determine their locations and guide them to destinations along preferred routes (America Walks & Sam Schwartz Engineering, n.d.; NACTO, 2014). Wayfinding systems can include destinations, distance, or time to reach destinations, and/or directional arrows (NACTO, 2014). For bicyclists, wayfinding can help to familiarize users with bicycle networks, identify the best routes, and minimize overestimations of travel times. In addition, they indicate to motorists the potential presence of bicyclists. For pedestrians, wayfinding can help overcome the hurdle of distance perception and increase foot traffic. Pedestrian and bicyclist wayfinding can be found along streets or facilities where either road user travels. While wayfinding can incorporate web connectivity or mobile applications, the focus of this review is on traditional sign and pavement marking wayfinding systems. In addition, the research team omitted studies on wayfinding systems designed for interior spaces. Figure 21 shows bicyclist wayfinding signs.

Figure 21. Bicyclist Wayfinding in Seattle, Washington (NACTO, 2014)

Pedestrian wayfinding systems are used extensively across the United States. Example cities include Charlotte; Kailua, Hawaii; and New York City (America Walks & Sam Schwartz Engineering, n.d; Keliikoa et al., 2018). In addition, pedestrian wayfinding systems are found in Australia and the United Kingdom (America Walks & Sam Schwartz Engineering, n.d; Vaez et al., 2019). Bicyclist wayfinding systems are also used extensively across the United States. For example, bicyclist wayfinding systems can be found in Albuquerque, Baltimore, Berkeley, Chicago, Davis and Emeryville (California), Kailua, New York City, Oakland, Portland, San Francisco, Seattle, Washington, DC., Cambridge, and Austin (NACTO, 2014; Keliikoa et al., 2018).

Sources

The research team identified three relevant sources. The research team considered several other sources related to wayfinding but marked the research as outside the scope of this report. Of the three sources reviewed, 2 originated in the United States while the third originated in Australia.

- Using the ZouSim Bicycle Simulator, Brown et al. (2017) studied bicyclist reactions to wayfinding signs and pavement markings. A post-simulator survey also explored bicycling habits and preferences.
- Keliikoa et al. (2018) gathered pedestrian and bicyclist perceptions regarding bicyclist wayfinding signs that were installed in Kailua as part of wayfinding signage plans.
- A year later, Vaez et al. (2019) compared wayfinding strategies of pedestrians in Brisbane, Australia, using GPS devices, paper maps, and those relying on the local signage system.

Table 21 provides a chronological overview of these sources and the road users and components present in the literature.

Table 21. Overview of Sources Relevant to Pedestrian and Bicyclist Wayfinding

Source	Bicyclists	Motorists	Pedestrians	Use, Comprehension, Safety	Attitudes, Beliefs, Perceptions	Education Strategies	Knowledge, Comprehension
Brown et al., 2017	✓			✓	✓		
Keliikoa et al., 2018	✓		✓	✓	✓		
Vaez et al., 2019	✓		✓	✓			

Note: A ✓ indicates that the source does address this road user or component.

Use, Compliance, and Safety

The research indicated that pedestrians unfamiliar with an area adopted different strategies when using local signage than those who used GPS devices or paper maps. Nonresident and resident pedestrians and bicyclists appeared to differ in their use of wayfinding signs. The types of wayfinding signs and pavement markings presented on a simulated roadway appeared to have influenced bicyclist behaviors.

Vaez et al. (2019) evaluated wayfinding behaviors of pedestrians in an unfamiliar area. Researchers found that these pedestrians adopted edge following (walking along a road, for example, until new information was found), compassing (walking in a cardinal direction), aiming (orienting based on landmarks, especially a nearby river), and screening (evaluating the environment for the desired destination) to a greater degree than those who used a GPS device or paper map. When thinking out loud, they also made fewer anticipatory comments (prediction of what would happen or be seen) and fewer positive or rehearsal statements (route planning before beginning the journey) than those using a paper map. In addition, pedestrians who used only local signage asked others for confirmation to know if they had reached their desired destination.

Keliikoa et al. (2018) surveyed pedestrians and bicyclists about their use of wayfinding signs that were installed as part of a wayfinding signage plan in Kailua. They evaluated residents and nonresidents to account for tourists who had less familiarity with the area. They found that nonresidents were more likely to report using the signs than residents: 58% of nonresidents reported using any of the installed signs compared to 19% of residents. They also found that women were more likely to report using them than men: 46% and 36%, respectively. In addition, bicyclists were found to be approximately 4.5 times more likely to use the signs than pedestrians.

Brown et al. (2017) evaluated bicyclist behaviors while interacting with wayfinding signs and pavement markings in a simulated environment. Researchers compared established MUTCD signage (D11-1 with M7-2 plaque, shown in Figure 22) to experimental pavement markings. The pavement markings featured a bicycle icon with “Route” written underneath, enclosed within a circle, below a forward-pointing arrow. The study evaluated both uncolored and greenback ground versions. Participants perceived and reacted to the pavement marking with green background sooner than the alternatives; fewer navigational errors were also associated with this marking. They did not provide any theoretical explanation for these findings.

Figure 22. MUTCD Signage used in Brown et al. (2017)

Attitudes, Beliefs, and Perceptions

The literature suggested that pedestrians and bicyclists, both residents and nonresidents, believed wayfinding to be beneficial. Reasons for traveling on routes delineated by wayfinding signs appeared to differ between pedestrians and bicyclists. Findings indicated that pedestrians and bicyclist also differed in their perceptions of wayfinding signs. Simulator research suggested that bicyclists perceived wayfinding signs and pavement markings differently.

Researchers surveyed residents and nonresidents while walking or bicycling. When describing their attitudes toward wayfinding signs, the majority of residents (83%) and nonresidents (87%) thought the signs were beneficial to the community (Keliikoa et al., 2018). Only 9% of residents believed the signs were not beneficial to the community, while less than 1% of non-residents believed so. The most common reason reported for selecting a route defined by a sign was the belief that the indicated route was the most direct one. This belief was held by more pedestrians (65%) than bicyclists (39%).

Education Strategies

None of the sources reviewed investigated education strategies regarding pedestrian or bicyclist wayfinding.

Knowledge and Comprehension

None of the sources reviewed investigated knowledge or compression regarding pedestrian or bicyclist wayfinding.

Gaps in Literature

Research has explored perceptions of bicyclists and pedestrians using *bicyclist* wayfinding signs. Including a bicycle symbol appeared to influence some pedestrians to disregard the signs, although they were capable of using them. Further research could probe pedestrians' willingness to use wayfinding systems without bicycle symbols, or with pedestrian-specific symbols or wording. Caution should be exercised if bicycle symbols are omitted, as it may negatively influence bicyclist use.

While research evaluated pedestrian and bicyclists use and decisions to use wayfinding systems, it is currently unknown how they understand or comprehend the facility. Bicyclists traveling on a dedicated bicycle facility—such as a cycle track or bicycle lane—may misinterpret signage, potentially believing that it allows them to travel in the motor vehicle lane. In addition, research has yet to inspect wayfinding systems from the motorist's perspective. Motorists may be more likely to adopt lower speeds when seeing wayfinding signs or markings.

Summary and Conclusions

Pedestrians using wayfinding signs tended to adopt different strategies than those using GPS or paper maps. Wayfinding signs were generally well received by resident and nonresident bicyclists and pedestrians. The literature indicated that bicyclists tend to notice and use wayfinding signs to a greater degree than pedestrians. However, Keliikoa et al. (2018) noted that a higher proportion of signs in their study were directed toward bicyclists than pedestrians. Some pedestrians appeared to disregard wayfinding signs with bicycle symbols, even though they could use them. The types and colors of wayfinding signs and markings appeared to have influenced bicyclist behavior, perceptions, and likelihood of following a route.

Current Practices in Outreach

The preceding sections discuss what is known regarding specific innovative pedestrian and bicycle facilities in terms of use, compliance, safety, attitudes, beliefs, and perceptions. Research into education and enforcement strategies was also sought. The literature review indicated that many of these education and enforcement strategies were not reliably evaluated. This review included only those that were evaluated, thus creating gaps in knowledge about what might be effective at improving the understanding and use of facilities. However, there were considerable efforts by practitioners, enforcement, and others to improve access and safety through education.

Approaches to Learning and Behavior Change

To more fully understand how pedestrians and bicyclists are taught about and use facilities, we reviewed outreach efforts aimed at educating the public about pedestrian and bicyclist facilities. The review focused on a sampling of public agencies and advocacy groups at various levels – national, State, and local. The scan not only considered how the entities educate different segments of the public, but also how they teach countermeasures to industry practitioners (e.g., engineers, planners, State, and municipal staff), who typically introduce facilities to the public themselves. As part of the scan, the research team examined the outreach medium, the level of accessibility to the medium (i.e., whether the material was publicly available or restricted), the material's content, and the source for the content. The scan also encompassed a review of relevant studies evaluating the effectiveness of outreach campaigns.

The review resulted in the identification of differences in how national organizations communicate roadway treatments compared to State and local agencies. In addition, content produced by industry organizations and State departments of transportation tends to be more detailed and technical, compared to the more education-focused materials often produced by local organizations. Ready-made material provided by State health departments, cities, and local agencies, such as manuals and reports, focused more broadly on safety education, safe travel habits, and proper equipment use, rather than specific countermeasures. In general, manuals and reports displayed the content more visually, relying on infographics and photographs to support the material. As a whole, organizations and agencies also tended to use social media presence and websites to post instructional videos, including live action demonstrations, animations, and verbal instructions. This could reflect developments in graphic design, as well as changing beliefs about teaching and learning design.

Advocacy organizations engage (use, produce, and distribute) in pedestrian and bicycle safety education material at many different levels. The content produced by advocacy groups tends to be general, focused on simple education efforts. In particular, the research team found that public health agencies were focused on broad campaign messages. Their focus was on general practices as opposed to specific countermeasures, which may be more useful to State or industry groups. Many cities and other locally focused agencies tended to publish and display messages and campaigns from other towns and cities. City websites often displayed educational material from other municipalities, as well as material from the Federal or State level. This could suggest that local agencies are doing a good job at synthesizing safety material from a broad range of sources for their residents.

The following is a summary of the outreach and education findings from the national, State, and local levels.

National-Level Activities

National-level activities include those that are managed by professional associations and institutes, Federal agencies, and national advocacy organizations. Each of these is discussed in the following sections.

National Professional Associations and Institutes

To develop a focused sample, the research team identified national professional organizations that were known for developing facility design standards for the transportation industry and educating practitioners about new facilities. We focused this search on industry organizations with a national focus, such as the NACTO, ITE, and AASHTO. The research team generally focused on outreach efforts developed within the previous 10 years, though it did not discount campaigns more than 10 years old if they were the only educational source on a specific topic. The research team collected data by directly visiting the organization websites. Table 22 summarizes which agencies engaged in each activity.

Table 22. Overview of National-Level Associations and Activities

Association	**Manuals**	**Webinars, In-Person Courses**
NACTO	✓	
ITE	✓	✓
AASHTO	✓	
Pedestrian and Bicycle Information Center		✓

Note: ✓ indicates that the source has material in this medium.

Manuals

Transportation industry practitioners serve as educational resources by introducing the public to new bicycle and pedestrian treatments, and by providing technical advice to local advocacy groups or organizations. Since industry roadway and facility design manuals impart transportation industry practitioners with the practical knowledge for creating roadway treatments, the project team examined the content and accessibility of design manuals and guidebooks.

NACTO published the *Urban Bikeway Design Guide* (NACTO, n.d.), which provides guidance on the design of bicycle-related treatments for urban settings. The document educates professionals about best practices in the design of bicycle facilities, including intersection treatments, cycle tracks, bicycle lanes and boulevards, and universal design. The manual is accessible online through the NACTO website for free. It was also available in print form for purchase.

ITE similarly published the *Recommended Design Guidelines for Accommodating Pedestrians and Bicycles at Interchanges* (Mitman & Ridgway, 2016). The manual provides practitioners with guidance on designing interchanges for the safe accommodation of bicyclists and pedestrians. The 29-page guidebook is available in print form only at a cost of $150 for non-members.

ITE also published *Designing Walkable Urban Thoroughfares: A Context Sensitive Approach* (Daisa et al., 2010). The guidebook teaches practitioners how to apply the principles of context sensitive solutions to the design of walkable arterial and collector roads. This includes incorporating bicycle and pedestrian facilities into major thoroughfares. The 216-page manual is available online through the ITE website for $50 for non-members.

AASHTO's *Guide for the Development of Bicycle Facilities, Fourth Edition* was released in 2012 (AASHTO, 2012). It offers bicycle planning and design guidelines for roadways, shared-use paths, and bikeways. These guidelines are intended to meet the needs of all road users, not just bicyclists. The guide is available online through the NACTO website for free. An update to the guide is currently in the AASHTO balloting process. (For status updates status see the NCHRP project site, https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3873.)

AASHTO also published the guidebook *A Policy on Geometric Design of Highways and Streets, 7th Edition, 2018* (AASHTO, 2018). This guide is commonly referred to as the Green Book. It provides information on geometric design current research and practices. The updates include more multimodal and performance-based design guidelines to meet the needs of all road users. The guidebook is available for purchase both online and in print form from the AASHTO website.

Webinars, In-Person Courses

Transportation professionals may attend trainings, either in-person or virtually, to supplement their knowledge of roadway treatments. For this study, the research team's sample included trainings developed by ITE and the Pedestrian and Bicycle Information Center (PBIC – which is funded by FHWA and NHTSA).

ITE, in agreement with FHWA, offers a series of training modules geared toward pedestrian and bicyclist safety in small localities (professionals from counties with a population of 100,000 or less, or from cities or towns with a population of 50,000 or less) and tribal governments (ITE Training Module Series, www.ite.org/professional-and-career-development/free-small-community-and-tribal-government-webinars/). The course topics range from the fundamentals of safety to an introduction to specific countermeasures or treatments that may be new to the locations the practitioners serve. At the time of this study, eligible transportation professionals could access webinars for designing for bicyclist safety, advisory bike lanes, uncontrolled pedestrian crossings, protected bikeways, and changes to traffic calming measures in the previous 20 years. ITE and FHWA offer the courses online at no cost to eligible professionals.

PBIC offered a webinar series about accommodating blind and low vision pedestrians in roadway design practices (Pedestrian and Bicycle Information Center, 2020). The course content was tailored for practitioners as well as advocacy groups and the public and is an example of how practitioners are trained on ADA concerns in bicycle and pedestrian planning. Recordings of the webinar series are available online for free as well as a number of other relevant webinars.

Key Takeaways

The review of the manual and webinar content revealed several common themes in the way national organizations communicate roadway treatments to practitioners.

Compared to educational material for the public, the content produced by industry organizations was more technical, detailing information such as treatment dimensions, construction materials, and placement. The technical language reflected the practical needs of the audience, who are professional planners, engineers, and designers. The technical descriptions were often accompanied by graphics and figures to spatially illustrate facility dimensions and use.

Manuals also widely used case studies to demonstrate treatment application. The case studies illustrated real-world scenarios of where and how treatments are applied. The case studies also provided an understanding of the impact of the treatment on road user safety. Many manuals also described the advantages of specific facilities or countermeasures, helping the planner or designer to select the right treatment.

Federal Agencies

We sought to identify educational outreach efforts by national agencies to understand how Federal agencies communicate information about pedestrian and bicycle facilities. The findings would also provide insight into the safety messages that Federal agencies believed were most important for public safety. Table 23 summarizes which agencies engaged in each activity.

Table 23. Overview of Federal Agencies and Activities

Agency	**Marketing & Outreach**	**Manuals**	**Reports**	**Videos**
NHTSA	✓		✓	
CDC	✓			
FHWA and National Highway Institute		✓	✓	✓
U.S. Access Board			✓	

Note: ✓ indicates that the source has material in this medium.

Marketing and Outreach

NHTSA has several websites addressing specific transportation topics. The *Traffic Safety Marketing* website (U.S. DOT, n.d.), provides ready-made marketing material on a wide range of transportation safety topics, including impaired driving, rail grade crossing, seat belts, senior drivers, and pedestrian and bicyclist safety. The marketing mediums vary by topic. For bicycle safety, NHTSA offers a toolkit that targets bicyclist and driver education (NHTSA, n.d.-a). The toolkit employs a variety of mediums to communicate safe bicycling behaviors, including printed brochures and advertisements, sample newspaper editorial pieces, and a traffic safety fact sheet. The toolkit also provides several items to engage audiences on social media (e.g., web banner ads, sample Facebook and Twitter posts, and web videos). The material contains language tailored for the general public, with at least one brochure specifically written for youth. NHTSA also offers a Spanish version of its material for distribution. The content of the material focuses on proper equipment use (e.g., proper helmet fitting) and safe riding behavior, such as using verbal and non-verbal communication while riding a bicycle.

To promote pedestrian safety, similar mediums are used to communicate safe walking behaviors (NHTSA, n.d.-b). The website offers a brochure geared toward providing youth with safe walking tips, traffic safety fact sheets, sample newspaper editorial pieces about anti-safe behavior, as well as tools for promoting safe pedestrian behaviors on social media (e.g., sample Facebook and Twitter messages, web banner ads, web videos, social media infographics).

NHTSA also provides a curriculum on pedestrian safety for students - grades Kindergarten through 5th grade (NHTSA, n.d.-c). Lesson plans include agendas, sample scripts, age-appropriate graphic display material (e.g., cartoon illustrations), and parent tips and at-home activities. Material is also available in Spanish.

NHTSA's marketing material is available for download through the campaign websites at no cost.

CDC provides basic tips and problem overviews for pedestrian and bicyclist safety (see www.cdc.gov/transportationsafety/ for more information). These websites are geared to adults and those seeking additional resources and CDC publications on the issue. CDC also maintains a helmet safety website with information on 11 different types of helmets including bike helmets and videos relaying the importance of wearing a helmet and proper fit (CDC, 2020).

Manuals

In addition to providing marketing toolkits, Federal agencies also publish manuals to communicate design standards for pedestrian and bicyclist facilities in different settings. In *Accessible Shared Streets: Notable Practices and Considerations for Accommodating Pedestrians with Vision Disabilities* (Elliott et al., 2017), FHWA provides guidance on how to design roadways for the vision impaired and those with low vision. The guidance document helps practitioners understand the challenges people with vision-impairments face when navigating streets, and outlines roadway surface treatments for accommodating their needs. The document does not specifically address countermeasures but examines treatments that could be incorporated into facility designs. The guidebook is available online at no cost.

FHWA also published a manual on creating multimodal networks, *Achieving Multimodal Networks: Applying Design Flexibility and Reducing Conflicts* (Porter et al., 2016a). The manual, aimed at planners and designers, focuses on leveraging design flexibility to reduce multimodal conflicts. The document communicates design strategies through descriptions and visualizations. The guide also provides case studies demonstrating locations where the treatments have been applied and how. The manual features several facilities including shared streets, traffic calming strategies, and separated bike lanes. The manual is available online through the FHWA website at no cost.

In *Small Town and Rural Multimodal Networks* (Dickman et al., 2016), FHWA, in partnership with Blue Cross Blue Shield, provides practitioners in small towns and rural areas with guidance on designing pedestrian and bicyclist facilities in a rural context. The guide discusses common challenges for small towns and rural areas, and introduces each treatment by providing a description, a diagram illustrating the treatment geometry, an explanation of its benefits, associated markings and signs, tips for implementation, accessibility for other modes, and case studies. The guide is available online through FHWA's website for free.

FHWA published another guide for designing accessible treatments, *Designing Sidewalks and Trails for Access (Best Practices Design Guide)* (Kirschbaum et al., 2001). The guide is older than most manuals reviewed in the research sample and contains a much simpler format, with mostly written text and comparatively simple black and white diagrams. It is available online for free.

FHWA administers the MUTCD (FHWA, 2009). This manual provides uniform standards for traffic control devices. These devices include "all signs, signals, markings, and other devices used to regulate, warn, or guide traffic, placed on, over, or adjacent to a street, highway, pedestrian facility, bikeway, or private road open to public travel…" (p.1-1). The 2009 edition was last revised in 2012 and the next edition is directed to be updated by no later than May 15, 2023, and at least every 4 years thereafter. The current MUTCD is available on the FHWA website at no cost.

FHWA also provides course content for university level bicycle and pedestrian transportation trainings. The *Federal Highway Administration University Course on Bicycle and Pedestrian Transportation* covers a wide range of pedestrian and bicyclist issues from planning and designing facilities to supporting programs and international approaches (Turner et al., 2006). This second iteration of the course follows the work conducted by Toole et al. (n.d). The course workbook and instructor guide are available online from the FHWA website.

NHI is the training division of FHWA and provides training to Federal, State, and local planning and design professionals, as well as decision makers, on pedestrian and bicycle facility design (Pedestrian Facility Design National Highway Institute, n.d.). The courses aim to educate practitioners on pedestrian and bicyclist needs, identify opportunities for integrating pedestrian and bicyclist-friendly facilities, and apply universal design concepts to an existing location or new location. NHI offers the courses through in-person instruction, web-based training, or web-conference training, all for a fee.

Reports

The U.S. Access Board is the Federal agency charged with promoting accessibility in the built environment and developing accessibility design standards. The agency published a set of guidelines, *Accessible Public Rights-of-Way Planning and Design for Alterations* (Markesino & Barlow, 2007), to provide technical guidance for pedestrian accessibility. The guidelines are focused on how to incorporate accessible design through alterations to existing rights-of-way. The guidelines help engineers and designers determine how to integrate accessibility and to know when they have reached maximum accessibility. The document is highly technical, walking through various common accessibility constraints that engineers may encounter, and proposing solutions. The document communicates mostly through text with some illustrations. The report is available online for free.

NHTSA's *Advancing Pedestrian and Bicyclist Safety: A Primer for Highway Safety Professionals* summarizes infrastructure treatments and behavioral programs that address specific pedestrian and bicycle safety problems and describes how to combine and implement approaches (Brookshire et al., 2016). The primer also provides State Highway Safety Officials, partners, and grantees information on collaborative approaches and funding strategies for more comprehensive programs. The document is technical but written in an approachable manner, providing definitions of common terms, acronyms, and key concepts.

Videos

FHWA offers a website, *Pedestrian Safer Journey*, that disseminates safe walking skills for children age 5 to 18 (FHWA, Pedestrian Safer Journey). The website contains videos, with quizzes and discussion guides to test learning after viewing the videos. The site is publicly accessible online.

Key Takeaways

In general, ready-made outreach material focused on general safety education, safe travel habits, and proper equipment use, rather than specific facilities. The focus on behavioral aspects of safety speak to the broader reach of the agencies. Sample editorials provided through toolkits were educational, providing statistics about pedestrian fatalities and/or describing how to use facilities (U.S. DOT, n.d.). Some ready-made material focused on negative behaviors that may impact pedestrian and bicyclist safety such as distracted driving, communicate the consequences of not following safety practices.

The manuals and reports published by agencies were technically focused, conveying knowledge about how to adapt facilities for specific settings, or how to make design decisions to maximize pedestrian accessibility. Handbooks dedicated to pedestrian accessibility and universal design discussed design principles, user considerations, legislation, and legal requirements. The technical nature of the documents reflects their target audience, who are planners, designers, and engineers. The research team observed that the older manuals in the sample group (Kirschbaum et al., 2001) were less visual than recently published manuals. The increase in the visual nature of manuals over time could reflect developments in graphical design and desktop publishing software. It may also provide insight about agencies' beliefs about how teaching and learning design concepts have evolved over time.

National Advocacy

We also reviewed education campaigns conducted by national advocacy organizations, such as the League of American Bicyclists and Smart Growth America. Table 24 summarizes which groups engaged in each activity.

Table 24. Overview of National Advocacy Groups and Activities

Advocacy Group	Marketing & Outreach	Written Case Studies	Webinars & Training
The National Center for Safe Routes to School	✓		
Safe Routes Partnership	✓		
Rails-to-Trail Conservancy	✓		
The League of American Bicyclists	✓		
The Vision Zero Network		✓	
Smart Growth America			✓
PeopleforBikes			✓
AAA (American Automobile Association)			
America Walks		✓	✓

Note: ✓ indicates that the source has material in this medium.

Marketing and Outreach

In its review of safety campaigns by national advocacy groups, the project team identified several entities that engage in safety education. The National Center for Safe Routes to School, often shorthanded as SRTS (http://www.walkbiketoschool.org/), a division of the UNC Highway Safety Research Center, provides communities with tools to support pedestrian and bicyclist safety among youth. The organization's programming features an educational component. The organization coordinates Walk to School Day and Bike to School Day, which provides children with experiential learning about pedestrian and bicyclist facilities. The National Center provides event organizers with kid-friendly, downloadable fliers and banners to market the days (National Center for Safe Routs to School, 2020). The National Center's website indicates that it also provides marketing resources in support of the Federal Safe Routes to School program, but it does not outline what they are. Though not cited, material on the National Center's website was similar to the material provided by the Safe Routes to School National Partnership, with the exception of classroom curriculums referenced on the site which are sourced to other active transportation organizations (e.g., the Active Transportation Alliance, Marin County Bicycle Coalition, NHTSA, Safe Routes to School National Partnership). The National Center and HSRC work collaboratively on the effort and some material may be sourced to HSRC.

Similar to the National Center, the Safe Routes Partnership also promotes youth pedestrian and bicyclist safety through a number of initiatives and its website (Safe Routes Partnership, n.d.). The program includes an education component, geared toward educating school administrators and community members on how to implement a local Safe Routes to School program. The material takes the form of fact sheets, reports, webinars, and newsletters. They focus on the benefits of launching an initiative and are developed jointly with other partners such as the CDC. The material is available through the Safe Routes Partnership website for free.

The Rails-to-Trail Conservancy operates *Share the Trail* (Rails-to-Trails Conservancy, n.d.), a campaign aimed at increasing safety for all trail users. The campaign uses a number of mediums to educate trail users about general pedestrian and bicyclist safety behaviors. The campaign focuses on six topics for successfully sharing the trail: speed, passing, standing aside, minding pets, being alert, and knowing the rules of the local trail. The rules are communicated through web animations, downloadable posters, graphics, and a blog. The content is available for free on the Rails-to-Trail website in English and Spanish.

The League of American Bicyclists (2019) offers the Smart Cycling Program (League of American Bicyclists, 2019), which provides a suite of classes and course material for learning safe bicycling behaviors while riding in vehicular traffic and on trails. While the material is focused on general safe bicycling principles, some content is specific to how to use bicycle lanes. The program educates bicyclists through manuals, quick reference guides, illustrations, articles on its website, web videos, and in-person classes. The program also offers a certification program to train course instructors. Program articles and videos are free, but the manuals, illustrations, and guides are for purchase and the cost of bicyclist skills classes depends on the locality.

Written Case Studies

The Vision Zero Network (2020) serves as a forum for municipal representatives and transportation safety advocates to exchange information about Vision Zero initiatives. The campaign's education efforts are focused on teaching decision-makers how to successfully develop, adopt, and/or implement Vision Zero strategies to support bicyclist and pedestrian safety, rather than how to use pedestrian and bicycling facilities. The campaign shares information through case studies, reports, and sample action plans. The content of the material targets decision-makers rather than bicyclists and pedestrians, and it provides examples for establishing policies to support bicyclist and pedestrian safety. The material is available through the Vision Zero Network website for free. Case studies and sample action plans are sourced to the communities that developed them.

Webinars and Training

Smart Growth America (2020) offers the *Safe Streets Academy* to provide technical assistance to jurisdictions. The Academy is comprised of in-person workshops and distance-learning sessions focused on several topics, including countermeasures to reduce speed and promote safety. The Smart Growth America website does not specify the kind of countermeasures the trainings cover. The courses are offered to jurisdictions that met certain criteria and can raise funds or provide in-kind donations to support the project.

PeopleforBikes (People for Bikes Foundation, n.d.) also offers various webinars about trends in the bicycling industry, including safety. The webinars are geared toward bike businesses and those working to advance bicycle access and infrastructure. They discuss industry trends, but only select webinars focus on general safe routes promotion. The webinars are available online for free.

Websites

AAA (2017) offers resources through a section of its website dedicated to pedestrian safety, *Pedestrian Safety*. The content is aimed at educating the general public on pedestrian safety. While not a coordinated campaign, the website offers tips to communicate general pedestrian safety measures, specifics on child and mature pedestrians, and resource links to additional information.

Key Takeaways

Advocacy organizations engage in pedestrian and bicyclist safety education at several levels. Many of the organizations identified through the sampling for this literature review focus their educational efforts on advocates and decision-makers. Their material addresses how to develop and implement policies to support bicyclist and pedestrian safety (Safe Routes Info, 2020; Safe Routes Partnership, n.d.; Vision Zero Network, 2020). Where agencies target the general population, the content is relatively general, focusing on safe travel habits, proper use of equipment, sharing the roadway/trails, and understanding laws and user rights, rather than specific countermeasures.

State- and Local-Level Activities

This section describes State- and local-level activities related to outreach and education about pedestrian and bicyclist facilities. This includes activities in transportation, public health, and advocacy. Each is described in the following sections.

State Departments of Transportation

We reviewed material produced by State Departments of Transportation on facility design and use, that may be shared in the industry. Similar to its search of design material developed by national organizations, the research team identified DOTs known as leaders in the field and selected cities with higher than average bicyclist and pedestrian active communities. We generally focused on content that was developed within the previous 10 years. Table 25 summarizes which DOTs engage in each activity.

Table 25. Overview of State DOTs and Activities

Agency	Manual	Guide
Minnesota DOT	✓	
New York State DOT	✓	
Delaware DOT		✓
Virginia DOT		✓

Note: ✓ indicates that the source has material in this medium.

This review includes manuals published by State DOTs that address bicycle and pedestrian facilities. While the manuals are produced for use by practitioners within the State, some manuals are shared across the industry, extending the reach of the manual's content. The manuals range in age, with some published in the 1990s, but with individual chapters updated through the late 2010s. The Minnesota DOT (MNDOT) roadway manual (Barnes et al., 2020) includes chapters that date back to 2006 (Pavement Designment) but most chapters were updated between 2018 and 2020.

Manuals

MNDOTs *Bicycle Facility Design Manual* provides practitioners with guidance on developing bicycle facilities along State highways (Barnes et al., 2020). The manual is based on the AASHTO's *Guide for the Development of Bicycle Facilities*, FHWA's *Separated Bikeway Planning and Design Guide*, and FHWA's *Bikeway Selection Guide*. It is available online through the MNDOT website for free.

MNDOT also provides practitioners with guidance on the design of pedestrian facilities. The guidance is incorporated into the agency's overall roadway design manual (Minnesota Department of Transportation, 2020), with sections dedicated to pedestrian facilities where appropriate. MNDOT's *Road Design Manual* is accessible online through the MNDOT website for free.

Guides

New York State DOT (NYSDOT) also published bicycle and pedestrian facility design guidelines as part of its Highway Design Manual (New York State Department of Transportation, 2020). The manual presents minimum design standards and educates planners on NYSDOT-specific policies. The manual is accessible through the NYSDOT website at no cost.

Delaware DOT (DelDOT) published a guidebook that provides public and private transportation planners with direction on minimum and desired standards for pedestrian accessibility (Delaware Department of Transportation, 2018). The guidebook contains original source material inspired by the U.S. DOT's *ADA Standards for Transportation Facilities* (2006) and the U.S. Department of Justice's *ADA Standards for Accessible Design* (2010). The manual is available through DelDOT's website at no cost.

Virginia DOT (VDOT) created a guide for pedestrians, bicyclists, and motorists to safely navigate the State's roadways (Virginia Department of Transportation, 2015). The guide lists State laws and describes how these laws are implemented by highlighting information on key safety tips. The guide also describes general education, from defining facility types (e.g., bike lanes, sharrows) to discussing and illustrating how to make turns and pass vehicles while bicycling. At the end of the guide, there are links to other national (e.g., America Walks, FHWA, League of American Bicyclists) and State-specific agencies (e.g., Bike Arlington, Virginia Department of Motor Vehicles) for more information. The guide is available online through VDOT's website at no cost.

Key Takeaways

Similar to the material published by industry organizations, the content presented in the State DOT manuals was more technical compared to the educational material for the public. The technical language reflects the target audience for the handbooks, who are professional planners and engineers. Several of the manuals were designed to be used in conjunction with industry-wide manuals and feature comparatively more written descriptions.

The State DOTs also tended to discuss minimum State design standards rather than introduce new treatments. Certain facilities are common to State DOT manuals, however. These included:

- Separated bike lanes.
- Protected intersections.
- Contraflow bike lanes.
- Two-stage turn box.
- Bike left-turn only box.

State Departments of Public Health

To conduct the targeted sampling, the research team identified State Departments of Public Health and Public Safety that were known as leaders in the field. In previous years, the CDC and Prevention Communities Putting Prevention to Work program supported communities tackling obesity through the built environment. The research team identified States representing the communities with the understanding the agencies had previously promoted active transportation. Many of the State public health organizations coordinated with their State DOT in the educational campaigns, which may have overlapped with results from the State DOT search. Therefore, the research team limited the search to focus on products produced and supported by the public health agency alone. To balance the search, the research team randomly selected up to four other States in the same approximate region as the targeted locations. Table 26 summarizes which Departments of Public Health engaged in each activity.

Table 26. Overview of State Departments of Public Health and Activities

State	Curricula & Guidance	Marketing & Outreach
California	✓	
Vermont	✓	✓
South Carolina	✓	✓
Mississippi	✓	
North Carolina		✓

Note: ✓ indicates that the source has material in this medium.

Curricula and Guidance

Workbooks were designed to provide teachers, instructors, and parents with lesson plans and structured activities to educate children and young adults on bicycle and pedestrian safety. Topics were typically general and provided instructions on the basic concepts of riding, signaling, crossing, helmet usage, and other introductory information.

The California Health Kids Resource Center (California Healthy Kids Resource Center, n.d.) provides links to purchase workbooks to assist trainers and educators teach pedestrian and bicycle safety. The Bucklebear (*Walking with Bucklebear, Bucklebear Gets Ready to Go)* series is geared toward children 2 to 5 years old and the kits provide tools for teachers to reinforce safety behaviors. This series is available for purchase through the California Health Kids Resource Center.

The *California Pedestrian and Bicycle Safety Curriculum for Grades 4 and 5* teaches students pedestrian and bicycle safety skills, including rules of the road, helmet safety, and hand signals (California Healthy Kids Resource Center, n.d.). Lessons are taught in the classroom and meet the approved curriculum standards. The curriculum is available for download online at no cost.

The train-the-trainer material resulting from this search typically included books, manuals, and presentations. Target audiences ranged from in-class educators to community members and advocates. The California Pedestrian Safety (PedSafe) Program's *Communication for Pedestrian Safety: Risk, Response, and Change* is a training workbook for promoting risk communication practices and norm change strategies related to pedestrian safety (California Department of Public Health, 2020). The workbook is aimed at people interested in their community's pedestrian safety or who have direct responsibility for safety such as elected officials, local transportation officials, local law enforcement, local public health departments, and community advocacy groups. Key messages are conveyed through case study examples, worksheets to identify audiences and messages, guidance on developing messaging, and guidance on stakeholder and partner engagement.

The California PedSafe Program also developed the *Action Response Kit,* which details how community members can respond locally to a pedestrian collision (California Department of Public Health, 2020). The guide provides seven tips for improving community safety and provides links to resources for additional research. All material is available by request via email to the California Department of Public Health, which are promoted on the PedSafe website.

Vermont Center for Health & Learning's guide *Walksmart/Bikesmart Vermont! Critical Content, Concepts and Skills for Pedestrian & Bicycle Safety* is directed toward adults teaching children about safe walking and bicycle safety concepts (Tarallo-Falk et al., n.d.). The curriculum targets first and second grade and second to sixth grade and outlines required material, assessment criteria, and follow-on material to send to parents and community members. Key concepts include walking safely in traffic, crossing roads, exiting cars and buses, helmet safety, proper attire, bicycle maintenance, and rules of the road. The full curriculum is available online for download at no cost.

In-class educational material identified in this research built off the train-the-trainer material and included workbooks, games, and manuals for both students and instructors. The Vermont Center for Health & Learning's *Walksmart/Bikesmart Vermont!* is an example where the in-classroom curriculum supplements the available train-the-trainer material (Tarallo-Falk et al., n.d.).

The Palmetto Cycling Coalition, Bikelaw, and the South Carolina Department of Public Safety all partnered on *Safe Streets Saves Lives*—a curricula for safer roadways for bicyclists intended for the classroom but which can be taught by anyone (Palmetto Cycling Coalition, n.d.). Activities varied in length—ranging from 14 minutes to 1 and half hours—and target all ages, grades 3 to 12, and grades 5 to 8. Topics include measuring bicycle ridership, bicycle and right-of-way rules, bicycle laws, road hazards, strategies for safer bicycling, and developing a travel plan. Curricula material provide instructions on required material, sample images and graphics, step-by-step instruction, and recommended practices. There were also four videos on bicycle laws and safe riding practices. All lessons are available for download at no cost on the *Safe Streets Saves Lives* web page.

Safe Routes STARS (Students Taking Active Routes Safely), supported by the Mississippi State Department of Health, provides pedestrian and bicycle safety instruction to second and fifth grade students, parents, schools, and community members. The curriculum includes classroom instruction, hands-on skills training, and school and community-based outreach events (Mississippi State Department of Health, n.d.). The Mississippi State Department of Health provides the services for free and workshops for parents, school officials, and community members.

Marketing and Outreach

Public health agencies identified in this research partnered with transportation agencies to promote educational safety campaigns, marketing, and general outreach material.

The most common safety campaign, Watch for Me, was derived from North Carolina's Watch for Me NC, first launched in 2012. *Watch for Me, VT*—supported by the Vermont State Highway Safety Office, Vermont Department of Health, and State of Vermont Safe Streets—was modeled after and credited *Watch for Me NC* and *Watch for Me CT* (neither were reviewed in the random sampling). The campaign's focus was to reduce injuries and deaths on Vermont roadways, specifically people who walk and bicycle. It includes an education and enforcement aspect; promotes safety tips for walking, driving, and bicycling; references reports and resources; and links to social media content and images replicable by interested parties. The website also provides links to videos on bicycle commuting, driving safely around pedestrians and bicyclists, animated crash scenarios, and most notably, the only source identified in this search that provides information on pedestrian safety countermeasures (State of Vermont, n.d.).

South Carolina's Department of Public Safety campaign *Be Safe. Be Seen.* is a pedestrian safety campaign that provides drivers and pedestrians information on stopping distances, where and how to walk, and supporting videos (South Carolina Department of Public Safety, n.d.). The California Department of Public Health and California Office of Traffic Safety teamed up on the campaign *It's Up to All of Us.* The campaign is a public education campaign focused on promoting pedestrian safety. A 2014 guide details directions for using and deploying media messaging. Topics include behaviors, awareness and alertness, shared responsibility for the road, and respect for other users—all of which are promoted through five campaign slogans targeting drivers, pedestrians, and community members through flyers (California Department of Public Health, 2020).

Key Takeaways

This search identified public health and non-transportation agencies that developed general campaigns with messages focusing on broad safety-related topics—laws, traffic codes, visibility, helmet usage, and other similar information. Their focus was on general practices rather than specific to types of facilities or types of roadways they may experience while out walking or bicycling. Mentions of pedestrian-specific facilities was limited to a general understanding and awareness of the roadways, where to walk, how to recognize signals and signs, and intersections.

Agencies used workbooks, flyers, media campaigns, videos, and presentations to reach the target audiences, which included elementary aged students, parents, and general community members. The education was family-focused to reach broader audiences. When sourced, the lead agencies linked to Federally sponsored reports, data, and guidance (e.g., FHWA) or to other cities and towns with similar campaigns. Most material was produced in early 2000s through mid-2010s and are nearly all available for download for no cost.

Local Agencies

We sought to identify facilities on a more localized level to understand how local agencies communicate messages about infrastructure to the community. To conduct the scan, the research team first searched large cities with reputations as innovators or early adopters and large cycling and pedestrian communities known to have extensive bicycle and pedestrian networks. We also applied a second approach by searching for specific facilities known as innovative to the United States or emerging (more commonly accepted within the last 5 to 7 years). Table 27 summarizes which agencies engaged in each activity.

Table 27. Overview of Local Agencies and Activities

Agency	Videos	Diagrams/ Drawings	Maps	Definitions/ How-To	General Education	In-Person Training	Resources
City of Roanoke, Virginia	✓						
City of Boulder, Colorado	✓						
City of New Orleans, Louisiana	✓		✓	✓			✓
City of Little Rock, Arkansas	✓	✓		✓	✓	✓	
City of Lincoln, Nebraska		✓					✓
City of Santa Monica, California	✓	✓					
New York City, New York State		✓	✓	✓	✓		
City of Columbus, Ohio		✓	✓	✓			✓
City of Seattle, Washington		✓	✓	✓	✓		✓
City of Raleigh, North Carolina			✓		✓		
City of Denver, Colorado			✓				
City of Charlottesville, Virginia			✓				✓

Agency	Videos	Diagrams/ Drawings	Maps	Definitions/ How-To	General Education	In-Person Training	Resources
City of Boston, Massachusetts				✓			
City of Burlington, Vermont				✓			
City of Oklahoma City, Oklahoma					✓		
City of Cambridge, Massachusetts					✓		✓
City of Sacramento, California					✓		
City of Orlando, Florida							✓
City of Bowling Green, Kentucky	✓						
City of Pittsburgh, Pennsylvania	✓						

Note: ✓ indicates that the source has material in this medium.

Videos

Agencies commonly used videos to convey important messages. Roanoke, Virginia, produced a video on how to use RRFBs where a law enforcement officer presented facility locations, instructions for both vehicles and pedestrians on how to use the facility, and emphasized the improved safety impacts (City of Roanoke, 2019). The video is on the city web page as well as the city's Facebook page.

Speakers also include local staff—engineers and planners—as subject matter experts presenting the information. When Boulder, Colorado, introduced a contra-flow bike lane, it developed a video with the city's bicycle and pedestrian transportation planner to explain the purpose of the bike lane, how it works, and why the design was selected (StreetFilms, 2008). The video was produced by an organization that produced short films on the impact of design and policy on communities. The video is no longer available on the StreetFilms web page but can be found on other web locations.

Other videos were presented as public service announcements capturing residents navigating the facility with voice over descriptions of locations and instructions for all users. Examples include Pittsburgh's *How To Use Contra Flow Bike Lane* and *How to Use the 2-Stage Bike Turn Box* (BikePGH, 2017, 2019) and Bowling Green, Kentucky's, *RRFB Crosswalk* PSA video (City of Bowling Green, KY, 2017). All three examples show live action pedestrians, vehicles, and bicyclists maneuvering the facilities with views from different angles. The video narrative also describes the maneuvers and provided supplemental information such as specific locations, need identification, and justification for the selected facility to address the needs. The Pittsburgh videos are embedded on the Bike PGH! website and Bowling Green's video is embedded in the city website, tagged as a public service announcement.

Santa Monica, California, has a website dedicated to three strategies the city is investing in to support pedestrian safety. One strategy is installing LPIs. The city's Facebook page hosts a video showing both pedestrians and motor vehicles navigating an intersection where an LPI is installed. There is no voice-over, but rather the video relies on watching and observing real-time signal timing and maneuvers (Santa Monica Planning, 2017). Santa Monica's pedestrian education also includes a video on an all-way pedestrian scramble. The video shows a person activating the signal by pushing a button, which signalized an all-way pedestrian phase with real-time pedestrians and motor vehicles.

The New Orleans Department of Public Health developed a YouTube video on bicycle safety. The video displays adults on bicycles on local roads with spoken narrative explaining the safety information, such as where to ride, hand signals, advice on visibility, and laws. The video is posted on its bicycling web page (New Orleans Regional Planning Commission & Louisiana Department of Transportation and Development, 2015). Similarly, Little Rock, Arkansas, posted a 22-minute video on essential bicycling skills produced by the League of American Bicyclists (2010).

Drawings and Diagrams

This research identified local agencies that used drawings and diagrams to describe specific pedestrian facility types. The City of Lincoln (Nebraska) Traffic Engineering website provides detailed instructions on how to use an RRFB. In addition to statistics supporting the facility implementation and video PSA, the website provides a colorful diagram displaying a mid-block crossing. The image includes clear arrows and text boxes describing travel directions and instructions for pedestrians, bicyclists, and motor vehicles. Supplementary narrative provides additional details and instructions as well locations where the city had previously installed RRFBs as well as plans to install new RRFBs (City of Lincoln, n.d.).

Santa Monica’s LPI education also includes two diagrams of an LPI at an intersection: one of the pedestrian phase and one of the through and turning vehicle phase. Both include arrows highlighting travel paths and are supplemented with text describing the phase length (Maximous, 2017).

New York City’s *Bike Smart: The Official Guide to Cycling in NYC* includes diagrams for several safety issues: mixing zones (interactions between bicycles and motor vehicles), biking near large vehicles, turning when pedestrians and motor vehicles are present, and turning using a bike box (NYC DOT, n.d.). All diagrams are colorful illustrations with arrows and step-by-step breakdowns of where the bicyclist should travel, for example when using the two-stage turn box.

Columbus (Ohio) hosts a web page dedicated to information on bicycling, with several links to specific information on protected bike lanes and turn boxes (City of Columbus, n.d.-a). Similar to New York City’s Bike Smart guide, the diagrams are colorful illustrations that include measurements and step-by-step numbers of where the bicyclist should travel when using a turn box. The diagrams also highlight the difference between a bicyclist navigating a turn box and a bicyclist making a standard left turn.

Little Rock, Arkansas’ online education includes diagrams for bicyclists “taking the lane” (moving to the center of a lane when it is safe) and vehicular right turns (City of Little Rock, n.d.). The diagrams use color to highlight real-word scenarios with arrows indicating a bicyclist’s movement and a motor vehicle’s movement. The diagrams compare the right and wrong ways for bicyclists to navigate each situation.

Seattle’s website on Protected Bike Lanes includes a GIF animation for drivers on how to park next to a protected bike lane. The GIF shows a two-lane roadway with a parking lane to the left, followed by a protected bike lane to the left of the parking lane, and two bike lanes to the left of the parking lane. The GIF simulates, along with text to clarify, the correct way for a motor vehicle to travel along the roadway and move into the parking lane. The simulation is followed by an incorrect movement of a second motor vehicle that parks on the bike lane.

Maps

Local agency web pages often provide links or embed maps (both PDF and interactive) illustrating facility locations, commuting routes, and other useful information for bicyclists and pedestrians. For example, the Seattle, Columbus (Ohio), Raleigh (North Carolina), and the Denver each provide a map detailing key intersections or routes where facilities like bike lanes, bike-shared lanes, protected bike lanes, and sharrows are currently installed and identify locations of planned future facilities (City of Seattle, 2020; City of Columbus, n.d.-a; City of Raleigh, 2020; City of Denver, n.d.). The City of Columbus (n.d.-b) also identifies turn box locations for bicyclist and motorist awareness.

Charlottesville (Virginia) provides several useful map resources for bicyclists and pedestrians. The Charlottesville Trails Map details paved and unpaved bicycle and pedestrian friendly trails, as well as locations of recreation centers, parks, and schools (Charlottesville Trails, 2020). The Bicycle and Pedestrian Plan-Level of Traffic Stress Map color codes city streets based on vehicular traffic, illustrating which routes may be less heavily trafficked and more bicycle and pedestrian friendly (City of Charlottesville, 2015). The Columbus Metro Bike Map details all existing bicycle routes and rates them on level of comfort and type of trail surface (Mid-Ohio Regional Planning Commission, 2016). The New York City Bike Smart Guide helps riders plan routes using connected lanes (NYC DOT, n.d.), and the New Orleans Bicycle Network Map also highlights routes that supported bicycles and categorized routes based on path types (City of New Orleans Department of Public Works, 2019).

The Charlottesville Bike and Ped Map was the most comprehensive identified in this search, providing locations for the following facilities: bike lanes, contraflow bike lanes, climbing bike lanes, signed shared roadways, low-stress connections, challenging connections, limited access, bicycle routes, trails, bicycle racks, fixit stations, pedestrian mall, bicycle shops, schoolgrounds, public restrooms, and even marked bike routes with steep uphill grades (City of Charlottesville Bike and Ped, n.d.-a).

Definitions and "How To"

Many agencies provide definitions of facilities on their web pages to explain the how and why they are used (e.g., intended user, directionality, rules, specifications like widths and pavement markings). These definitions are often detailed, yet brief, providing less technical explanation so a lay person can understand the technical name. The City of New Orleans (2020) provides definitions for shared lane, shared-use path, buffered bike lane, protected bike lane, bicycle boulevard, and bike rack. Each definition is accompanied by a photograph from local installations. The City of Columbus (2020a) also provides a definition for bike box and turn box. The definitions are more detailed than the City of New Orleans and also include photographs of installations.

New York City's *Bike Smart: The Official Guide to Cycling in NYC* provides short definitions for protected bikes lanes, bike lanes, shared lanes, signed routes, sharrows, terms when navigating lanes, and what different dashed lines indicated (e.g., dashed bike lanes, mid-block dashed lines, dashed lines with chevrons, and two-way bike lanes) (NYC DOT, n.d.). Each definition, similar to Columbus and New Orleans, include photographs that illustrate a bicyclist within the facility. For terms like sharrows and taking the lane, the *Bike Smart* guide also includes illustrations of a roadway and the correct and incorrect ways for a bicyclist to navigate the roadway when sharrows and turning motor vehicles are present.

The City of Boston's (2020) website defines traffic-calmed local streets, protected bike lanes, buffered bike lanes, separated bike lanes, flex posts, contraflow bike lanes, buffers, dooring, offset intersections, bike signals, intersection conflict markings, bike boxes, two-stage turn boxes, and signed routes. Beyond providing the definitions, the city explains how updating existing bicycle facilities with the infrastructure makes facilities more comfortable for people bicycling along streets and through intersections. Each definition and explanation include a photograph of a bicyclist using the countermeasure in a local installation.

Little Rock and Seattle include detailed definitions for bike lanes and how they are used (City of Little Rock, n.d.; City of Seattle, 2020). Both cities include explanations for how to use a protected bike lane from a bicyclist and driver perspective, accompanied by a visual, either a photograph or video of a bicyclist using the facility. Seattle provides additional explanations for how to use a bike lane from a pedestrian perspective and from the perspective of someone using a wheelchair.

Burlington, Vermont, devotes an entire web page to a protected bike lane installed in one location. The web page provides a brief definition of a protected bike lane and background on where and how the city will install the bike lane (City of Burlington, n.d.-b). An explanation on why the city was installing a protected bike lane with highlights of previous demonstration projects are also included. Burlington provides additional photographs beyond just one of a bike lane. The web page includes photographs of completed bike lane projects, the installation process, and of a demonstration project.

General Education

This research identified general education strategies, which provide free, fast, and easy access to information listed on agencies' home web pages. The general education primarily includes tips for drivers to navigate the roadway when bicyclists and pedestrians are present. For example, New York City's *Bike Smart: The Official Guide to Cycling in NYC* and Raleigh's BikeRaleigh web page both include a section on general tips when biking (NYC DOT, n.d.; City of Raleigh, 2020). The general tips include bicycling laws specific to the city, the proper way to wear a helmet, safety tips (visibility and alertness), and turning styles.

Little Rock's web page includes general education on bicycle and pedestrian laws, formal programs, and topics for drivers, pedestrians, and bicyclists (City of Little Rock, n.d.). Each topic includes a clickable link where the user could learn more information. The bicycle and pedestrian laws explain the State and city laws for bicyclists and pedestrians so they can navigate the streets safely. The formal education opportunities list seven different programs/courses offered throughout the city that range from teaching bicyclists to safely use the streets to partnering with local after-school programs to teach students about pedestrian and bicyclist safety. Under the different education topics, the city's web page includes safety tips specific to pedestrians and bicyclists for co-existing with cars as well as safety tips for drivers when co-existing with pedestrians and bicyclists.

Similarly, Oklahoma City's Department of Planning launched Watch for Me OKC. This campaign focuses on safety tips for pedestrians, bicyclists, drivers, and scooters providing laws, infographics, and safety information. Although not cited, the graphic look and content is similar to that of North Carolina, Connecticut, and Vermont's campaigns (City of Oklahoma City, n.d.).

As with Little Rock, Oklahoma City, and New York City, the Cambridge web page contains highlights and resources for bicyclists (City of Cambridge, 2011). The highlights section includes links to mode-specific plans, and a list of current and planned projects. The resources section provides a list of upcoming meetings, safety tips, maps, and laws. For pedestrians, the city's web page provides safety tips and maps. Specific to drivers, the web page contains safety tips for drivers to follow to safely coexist with pedestrians and bicyclists.

Several agencies highlight crash data as part of general education. The City of Little Rock (2015) also includes information on the crash data and the city's 2015 *Pedestrian/Bicyclist Crash Analysis*. The analysis provides information on risk groups, geographic areas, crash conditions, and recommendations to study additional locations. The City of Cambridge (2011) also provides a copy of their *Bicycle Crash Summary*, which provides a detailed explanation of bicyclist crash data and actions that could be taken to address the crashes.

In-Person Training

Some agencies include in-person training, which is oftentimes available through links on their web page, or through specific programs, such as the Safe Routes to School program. There are quite a few of these types of programs, the ones included here are a sampling of what is actually available throughout the country.

Little Rock provide detailed information on a local school's after school bicycle education program (Landosky et al., 2017). The after-school program consists of surveying students and parents, conducting a SMART Cycling class, teaching 15 sessions to students, procuring bicycles for all students in the program, and hosting a Bike to School event.

In addition to the after-school elementary program, Little Rock includes other formal education opportunities (City of Little Rock, n.d.) for bicyclists. The League of American Bicyclist SMART Cycling Class is offered by the Bicycle Advocacy of Central Arkansas. The full-day class teaches bicyclists about safety in a classroom setting and on the road. Community mentoring is another in-person option where members of the community convene for educational rides. The educational ride targets novice riders looking to learn more about bicycling safely on the road. The city also provides contact information for those interested in participating in a bike rodeo.

Similar to the courses offered by Little Rock, Sacramento offers an in-person Urban Bicycling and Scooting 101 Class (City of Sacramento, 2020). The free 1-hour class is offered monthly as an introduction or refresher course to bicyclists. The course covers laws pertaining to cyclists, navigating on the roadway and through intersections, and how to safely avoid crashes.

Specific to drivers, Little Rock offers the Friendly Driver Certification Program, which is an in-person course for drivers to learn how to safely navigate roads when bicyclists and pedestrians are present (City of Little Rock, n.d.). The course also instructs drivers how to safely travel around new bicyclist and pedestrian facilities.

Resources

Many agency web pages and documents provide links to source material published by FHWA and PBIC to validate the content. National design guidelines and standards are commonly cited as source material for technical content, such as design elements and definitions. Seattle, Cambridge, and New Orleans reference NACTO's *Urban Bike Guide* as reference material (City of Seattle, n.d.; City of New Orleans, 2020; City of Cambridge, 2011; National Association of City Transportation Officials, n.d.). New Orleans also references AASHTO's (2012) *Guide for the Development of Bicycle Facilities*. Little Rock links to NHTSA's Prevent Pedestrian Crashes: Elementary School and Pre-School (City of Little Rock, n.d.; National Highway Traffic Safety Administration, 2008). Referencing these national guidelines provides readers with other sources to explore and collect more information and validate the technical information the agency presented to the broader community.

City-supported planning-level documents also provide the background information or supported bicycle and pedestrian infrastructure. Several cities provide links to web pages or allow the user to download PDFs of master plans, thoroughfare plans, or other such documents detailing existing and planned infrastructure, highlighting priority corridors are areas, and having a large community engagement element that supports the decision-making process (City of Seattle, 2020; City of Charlottesville, n.d.-b; City of Columbus, n.d.-a).

In other situations, cities and towns reference national organizations with a more public-facing or advocacy element. These sources are written more toward the general public and are therefore useful tools when communicating with and educating the broader community. The League of American Bicyclists is another national resource site used for content and references. Several cities embed videos on intersections and bike lanes supported by the American League of Bicyclists (City of Little Rock, n.d.; City of Columbus, n.d.-a; City of New Orleans, n.d.).

Other cities link to peer cities or towns. For example, the City of Lincoln (n.d.) links to Bellevue, Washington, and Columbus, Ohio, for their how-to-use videos featuring RRFBs. Columbus's web page also includes a link to a turn boxes video from Salt Lake City, Utah (City of Columbus, n.d.-c). Other agencies provide resources like the Charlottesville link to State references, such as Virginia's *Share the Road VA Guide*. Orlando also links to other web pages for peer counties and organizations within the State like Bike/Walk of Central Florida, Orange County's pedestrian/bicycle safety, and FDOT's Pedestrian Safety (City of Orlando, n.d.).

Cities and towns provide links to additional resources that supported continued education or promoted walking and bicycling. New York City's *Bike Smart: The Official Guide to Cycling in NYC* (NYC DOT, n.d.) provides links to several national cycling groups (Bikes Belong, Black Girls Do Bike, League of American Bicyclists, and National Center for Bicycling and Walking), local cycling education and advocacy organizations, and useful City of New York resources. Similarly, the Columbus provides links to local and national advocacy organizations, local cycling clubs, information on local parks, fundraising organizations that support bicycling, and statewide and other local trail systems (City of Columbus, n.d.-c).

Key Takeaways

As the research team conducted the scan, a search for one facility type often resulted in a city or town providing information on several other bicycle or pedestrian facilities. For example, a search for cities with bike lanes led to Boston's web page that lists many other bicycle facilities

(City of Boston, 2020). The cities with the most infrastructure also provide the most comprehensive listings of facilities, definitions, and often supporting photographs. To support the facilities listed on the web pages, several local agencies also provide maps, interactive maps, street names, and intersection names where facilities are installed (City of Burlington, n.d.-b; City of Seattle, 2020; City of Charlottesville Bike and Ped, n.d.). Cities and towns often focus educational information on instructions on how to navigate a specific facility type. These facilities are often newer or non-traditional designs the community may not have been exposed to yet, such as the turn box in Pittsburgh (BikePGH, 2017) and the contraflow bike lanes in Boulder (StreetFilms, 2008). Videos and written material often target all users, providing separate instructions for bicyclists, pedestrians, and drivers. However, how-to educational material often focuses on bicyclists, with driver information coming in second, and very little information available for pedestrians.

Many of the agencies include diagrams that illustrate travel behaviors for pedestrians, bicyclists, and motor vehicles. The diagrams are typically from an aerial perspective (City of Lincoln, n.d.; Santa Monica Planning, 2017) and include arrows showing step-by-step different user's travel paths. The aerial—and often also used side-view—allow the user to see a more comprehensive view (City of Columbus, n.d.-b; City of Little Rock, n.d.). The diagrams are often focused on one user's perspective at a time (Maximous, 2017). The diagrams illustrate from a motor vehicle's perspective and then from a pedestrian or bicyclist perspective. Several diagrams also include measurements and descriptions of who travels in what lane to make the diagrams more digestible for a lay person (City of Columbus, n.d.-b).

Another theme of the material is content on laws and rules of the road. Content is clear with concise messaging and often uses infographics or illustrations to convey the key messages (City of Little Rock, n.d.; NYC DOT, n.d.). Again, however, more information is available on bicycling laws and rules with very little content specific to pedestrians.

Despite the lack of pedestrian-specific facilities, one key theme for many local agency-developed material is the emphasis on promoting multiple perspectives for any facility. Messages toward motorists focus on awareness of other users, what to look for when driving near bicycle or pedestrian facilities, and how to navigate the facilities. In addition to how to navigate facilities, bicyclist-specific messaging promotes tips for safe commuting and selecting the best routes to destinations. Education on how and where to park and general awareness and safety of others on the road is directed to all users. Generally, many local agencies promote co-exist messaging, focusing on how all users can navigate roadways safely at the same time. More focused educational messages display how emergency vehicles can navigate certain facilities, combating common negative public perceptions and demonstrating facility effectiveness and appropriateness (City of Burlington, n.d.-b).

Local agencies also post more general educational information on city web pages and social media accounts. Some include safety impacts of the facilities or relevant statistics related to bicycle and pedestrian crashes. This message leans toward the more positive outcomes such as the lives saved, and the number of crashes prevented. Other safety messaging promotes the appropriateness of a selected facility for both the roadway (context) and the users (demand) and intended outcomes such as addressing specific crash types.

The research team identified the following facilities in this search. While not an exhaustive examination of all facilities installed by local agencies, this following illustrates common facility types.

- Advisory bike lanes (City of Burlington, n.d.-a)
- Audible pedestrian buttons (Maximous, 2017)
- Bicycle lanes (City of New Orleans, 2020)
- Bicycle signal (City of Cambridge, 2011; Austin Transportation Department, 2014; Kendall, 2017)
- Buffered bike lanes (City of Boston, 2020; City of New Orleans, 2020).
- Contraflow bike lane (StreetFilms, 2008; City of Boston, 2020; BikePGH, 2019; City of Cambridge, 2011)
- Cycle track (City of Portland, 2020)
- Flashing beacons (Maximous, 2017)
- Green bike lanes (City of Raleigh, 2020; Minneapolis Public Works Department, 2012)
- Green shared lanes (Minneapolis Public Works Department, 2012)
- Left-side bike lane (Portland Bureau of Transportation, 2017)
- LPI (Maximous, 2017)
- Multimodal thoroughfare/bike boulevard (City of New Orleans, 2020)
- Protected bicycle lanes (quick build and permanent) (City of Columbus, n.d.-b; City of Seattle, 2020; City of Burlington, n.d.-b; City of New Orleans, 2020)
- Raised cycle track (City of Cambridge, 2011)
- RRFB (City of Lincoln, n.d.; City of Bowling Green KY, 2017; City of Roanoke, n.d.)
- Separated bike lanes (City of Boston, 2020)
- Shared lane markings (City of Columbus, n.d.-b; City of New Orleans, 2020)
- Shared-use path (City of New Orleans, 2020)
- Signage – share the road (2022 Bikes, 2009)
- Traffic calming (City of Boston, 2020)
- Turn box (BikePGH, 2017; City of Columbus, n.d.-c)
- Two-way separated bike lane (City of Cambridge, 2011)

Local Advocacy

While searching for facilities at the local level and State health agencies, the research team identified advocacy groups disseminating relevant information. The groups were associated with statewide, regional, and local transportation or health agencies and support pedestrian and bicycle activities. More details on the search terms that produced the results can be found in State DPH and Local Agencies sections. We then conducted a subsequent general search for tactical urbanism on the local level. Tactical urbanism is an action-oriented, scalable, and low-cost intervention on the neighborhood scale led by cities, organizations, and community-led groups. Many of the publicized efforts are associated with local government agencies such as transportation and business development or local bicycle and pedestrian advocacy groups. Table 28 summarizes which groups engaged in each activity.

Table 28. Overview of Local Advocacy Groups and Activities

Agency	Grant Programs	Pedestrian Facilities	Bicycle Facilities	Roadway Redesign
Fayetteville, Arkansas Sustainability Office and Engineering Department	✓			
Snellville, Georgia Downtown Development Authority, Development Authority, Urban Redevelopment Authority, and Planning and Development	✓			
The Miami Foundation	✓			
Nashville, Tennessee	✓			✓
Utah (Statewide and in Pravo)		✓		✓
Denver, Colorado		✓		✓
San Francisco Vision Zero		✓		
Macon Connects (Georgia)			✓	
Wichita, Nebraska			✓	
Boston, Massachusetts			✓	
Orlando, Florida				✓

Note: ✓ indicates that the source has material in this medium.

Grant Programs

In several cases, city or local agencies funded application-based tactical urbanism programs. In these cases, projects were driven by the communities but approved, overseen, and managed by the local staff. The Fayetteville, Arkansas Sustainability Office and Engineering Department jointly supported a program where citizens proposed projects. Applicants were encouraged to read city-supported guidelines (City of Fayetteville, n.d.) and complete a permit application where they detailed their organization type and detailed installation and removal dates, design and location criteria, and supporting material. The web page linked to examples around the country and the world, and emphasized the Street Plans guide.

Similarly, Snellville, Georgia's collaboration between the Downtown Development Authority, Development Authority, Urban Redevelopment Authority, and Planning and Development supported a Tactical Urbanism Program. Snellville developed a Tactical Urbanism Program Project Guide detailing types of tactical urbanism (traffic calming, public art or installations, streetscape improvements, and pedestrian improvements), steps to apply, guidance on selecting a site location, how to identify project essentials, and links and contact information (City of Snellville, GA, 2020). The web page also suggested applicants review the *Tactical Urbanist's Guide to Materials & Design (*Lydon et al., 2016) for more information and guidance and then provided links for the application and property owner consent.

In other instances, local agencies or foundations hosted tactical urbanism efforts. For instance, the Miami Foundation (Florida)—an organization that awarded grants to address community needs—funded the Public Space Challenge. This effort invested funds to improve mobility for pedestrians, bicyclists, streets and sidewalks, and public transit. Individuals, for-profits or groups, and government entities were all eligible to apply and projects were encouraged to focus on how residents moved around, in, and out of Miami. Winning projects in 2019 included bike lanes and signage to improve pedestrian safety, lighting improvements to improve pedestrian safety, and Miami-themed crosswalks at public schools (The Miami Foundation, n.d.).

TURBO (Tactical Urbanism Organizers) is a local organization in Nashville that falls under the umbrella of the Civic Design Center's Reclaiming Public Space initiative (Obara, 2013). The group was largely driven by input from community organizations and neighbors on changes to address identified issues. Those parties interested in redesigns completed an online application for TURBO's assistance. TURBO then explored the scope, feasibility, and interest in the project and if implemented would lead the design. While the organization did not implement projects—community leaders were expected to take on the responsibility—TURBO did provide assistance throughout the project lifespan (TURBO, n.d.)

Pedestrian Facilities

Some tactical urbanism efforts focused primarily on improving pedestrian experiences. As part of the Utah Chapter of the American Planning Association's Spring Conference in 2019, participants engaged in a pop-up crosswalk project in Price, Utah. The project's purpose was twofold—build capacity among conference attendees and give back to the community in a way that increased awareness of pedestrians. As a result, the group collaborated, designed, and painted a crosswalk with brightly colored shapes and spirals (Robinson, 2019).

WalkDenver implemented a pedestrian wayfinding project named Great Paths in one neighborhood in Denver. This project installed 50 signs that guided people to destinations with the amount of time it would take walking. WalkDenver also installed a high-visibility mural at a busy intersection to slow traffic and improve pedestrian experience (Sachs, 2015). In San Francisco, a non-profit called Build Public released "traffic zebras"—adults dressed in zebra costumes that assist pedestrians crossing intersections. This effort is duplicative of a program in Bolivia with the same purpose and was implemented in San Francisco to promote the City's Vision Zero campaign (Rudick, 2017).

Bicycle Facilities

In response to a nationwide competition to improve cities, Macon, Georgia, sought ideas from residents and the broader community. Its award-winning submittal—Macon Connects—was the world's largest pop-up bike network (Kotala, 2017). Over the course of one weekend, volunteers installed temporary bike lanes with pavement markings, promoted share the road messages, and hosted a street festival. The installation stayed in place for one week and included bike counts along the network and public survey on riding behaviors and desires.

In a true tactical urbanist move, an unknown person placed plungers on the lane markings either side of bike lanes to create a buffered bike lane in Wichita, Nebraska. The intent was to prevent drivers merging into bike lanes at intersections, a problem not unique to the city (Dovey, 2017). Boston installed orange traffic cones on the roadways to convert a parking lane and bike lane into a bus lane to improve transit time. Bicycles were still allowed to use the lane (Schmitt, 2017).

Roadway Redesign

Often, tactical urbanist projects are broader and address both bicycle and pedestrian improvements. For example, Orlando installed temporary road "diets" that resulted in reduced travel lanes and the addition of bicycle lanes in both directions. The project also installed new crosswalks. This was a city-funded yet temporary project to test the project feasibility and gauge community buy-in (Planetizen, 2018). The project resulted in a decrease in travel time (from 6 minutes to 1 minute), reduction in drivers speeding (from 59% to 28%), and an increase in bicyclist and pedestrian use (Spear, 2018). While there were several reductions as a result of the project, side streets saw an increase in daily vehicle traffic. As a result, the public criticized the project and a permanent re-design has not yet been put in place (Spear, 2018).

Denver developed a neighborhood plan with pedestrian improvements, bicycle infrastructure, car sharing, and examples of small park designs. During a demonstration project, the city taped and duct-taped stripes for crosswalks, showed examples of how the city could plan and design bike lanes in different ways for the neighborhood, and then collected resident feedback on the designs (Global Site Plans-The Grid, n.d.).

In response to pedestrian fatalities in Provo, a local advocacy group temporarily redesigned a major connector street to slow traffic and improve bikability and walkability. Installations included temporary curb extensions to narrow pedestrian crossings at intersections, crosswalks that encourage safe walking, a pop-up roundabout to slow motor vehicles, and painted sharrows to encourage bicycle traffic (Taylor, 2019).

The Nashville Civic Design Center developed a plan, *Reclaiming Public Space in Downtown Nashville*, which listed projects throughout Tennessee and the nation that have been redesigned to improve walkability, bikability, and connectivity within communities (Obara, 2013). The plan described eight projects in downtown Nashville where different facilities were redesigned by adding crosswalks and pedestrian signs to improve walkability between greenways. The plan also proposed eight locations to undergo redesign. One of the proposed projects included adding a pedestrian bridge from a neighborhood to downtown. The plan also included resources to evaluate a space and a toolbox of resources.

Key Takeaways

Since generally associated with a State or local agency, the messages mirrored those found in both of those searches. These are the sources directly linked to by the local agency and, therefore, the primary source of information for those communities. So, while they are "advocacy" or independent groups, they are looked to as the experts.

Tactical urbanism is often linked to and supported by the local transportation agency (Global Site Plans-The Grid, n.d.). Funding or general support/technical assistance comes national or local advocacy groups and business development or similar city initiatives (Austin Transportation Department, n.d.; Kotala 2017.; The Miami Foundation, n.d.; Sachs, 2015; TURBO, n.d.).

While several of the cities and towns developed guidance and toolkits, applications for project ideas, and permitting processes (City of Snellville, GA, 2020; City of Fayetteville, n.d.), many efforts referred to StreetPlans' *Tactical Urbanism: Short-term Action for Long-term Change* (Lydon et al., 2016) as the primary guide for all-things tactical urbanism. All efforts identified, however, emphasized the importance of community engagement in the decision-making process and piloting for long term investments. Responding to community needs, at the core, is the essence of tactical urbanism.

Additionally, tactical urbanism efforts focused on low-cost and temporary solutions. Demonstration projects *showed* residents and decision-makers how proposed projects would look and how all users would navigate the infrastructure. This built confidence and buy-in. Therefore, projects communicated the impacts to multiple perspectives (e.g., motor vehicle drivers, pedestrians, bicyclists) and often communicated co-exist messaging. In some cases, other factors like parking and emergency vehicle navigation was also discussed to address concerns from all vehicles.

Common tactical urbanism facilities identified in this scan included the following.

- Bike lanes (City of Fayetteville, n.d.; Lydon et al., 2016; Kotala, 2017)
- Bulb-outs (TURBO, n.d.)
- Curb extensions (City of Fayetteville, n.d.; Lydon et al., 2016)
- Mini-roundabouts (Lydon et al., 2016)
- Painted crosswalks (Robinson, 2019; Lydon et al., 2016; Robinson, 2019; TURBO, n.d.)
- Protected lanes with orange cones, barriers, toilet plungers (Schmitt, 2017; Keenan, 2019; Dovey, 2017)
- Sharrows (Lydon et al., 2016; Kotala, 2017)
- Temporary road diet (Planetizen, 2018)
- Traffic calming with intersection art (TURBO, n.d.)
- Wayfinding (Sachs, 2015; Rudick, 2017)

Evaluation of Campaigns

As described earlier, the literature review identified a limited amount of research evaluating education to improve the understanding and use of specific pedestrian and bicycle facilities. However, there are a significant number of campaigns that broadly target pedestrian and bicyclist safety. Often these are associated with a particular multi-dimensional program in a region or area that broadly focus on awareness of pedestrian and bicyclist safety.

In order to be comprehensive in our discussion of improving facility use, we also reviewed research on pedestrian- and bicyclist-focused campaigns in the United States from 2000 to 2020. This produced a limited number of studies evaluating the effectiveness of campaigns and how to use facilities. We identified only one study that evaluated bicyclists' perception of facilities and provided recommendations for ways to improve educational campaigns based on the results. Table 29 provides an overview of these sources and the road users and components present in the literature.

Table 29. Overview of Campaign Evaluations

Source	**Bicyclists**	**Motorists**	**Pedestrians**	**Use, Comprehension, Safety**	**Attitudes, Beliefs, Perceptions**	**Education Strategies**	**Knowledge, Comprehension**	**Law Enforcement**
Watkins et al., 2020	✓	✓		✓	✓		✓	
Mondschein et al., 2017		✓	✓	✓	✓			
Zegeer et al., 2008	✓	✓	✓	✓	✓	✓	✓	✓
Floerchinger-Franks et al., 2000	✓	✓	✓	✓	✓	✓	✓	
Dunckel et al., 2007		✓	✓	✓	✓	✓	✓	✓
Lewis and Lane, 2007		✓	✓		✓	✓		✓
Sandt et al., 2016		✓	✓		✓	✓	✓	✓
Nuworsoo et al., 2012	✓	✓	✓		✓			

Note: A ✓ indicates that the source does address this road user or component.

The majority of the published research was conducted by State Departments of Transportation and researchers on behalf of State DOTs to evaluate the effectiveness of nationwide, State, and local programs. This included a focus on the implementation and results of different pedestrian and bicyclist campaigns. Each study focused on one particular campaign/program and the associated effects instead of comparing campaigns to one another.

Watkins et al. (2020) held focus groups to determine how bicyclists perceived different facility types. In addition to focus groups, the study included three treatment areas in Alabama and Tennessee and three control areas in Alabama where the study team collected data on bicyclist use of different facilities. Beyond the focus groups and observations, the study team also sent out two waves of surveys to collect information on the public perception of the facilities. Based on the results, Watkins et al. concluded respondents preferred facilities that created more separation between modes (e.g., protected/separated bike lanes and shared-use paths). Protected/separated bike lanes were also found, among those interviewed/surveyed, to decrease negative perceptions of a roadway. Also, most notably, among the findings are bicyclist's preferred facilities that were more intuitive. When planning for future implementations, Watkins et al. identified the need to protect bicyclists by adding protected/separated lanes when motorists are present and to provide clear delineations on multi-use paths when pedestrians are present.

Mondschein et al. (2017) reviewed current road user education to determine if the practices were effective. The evaluation reviewed in literature, interviewed 18 practitioners across the United States, and reviewed bicyclist and pedestrian educational videos available on YouTube. Mondschein et al.'s results found a lack of guidance for Federal and State agencies regarding educational material. This is further explained through the interviews with practitioners, where it became evident many practitioners were not clear on the definition of each of the 5Es (education, engineering, enforcement, encouragement, and evaluation and planning) which are supported by the League of American Bicyclists, a developer and coordinator of adult bicyclist education programming. The difference between education and encouragement produced the most difficulty.

Zegeer et al. (2008) evaluated the effectiveness of campaigns in Miami-Dade County, Florida over the course of 9 years. Zegeer et al. partnered with the Miami-Dade Safe Kids Coalition, the Injury Prevention Coalition, Florida Department of Transportation, local communities within the county, the University of Miami School of Medicine, the WalkSafe Program Task Force, the Miami-Dade MPO, the public schools in the area, and the Department of Public Works. Zegeer et al. worked with these safety partners to implement 16 education, engineering, and enforcement efforts. The education efforts were the most exhaustive and included community-based programs, print material (e.g., handouts, flyers, bi-lingual booklets, posters), and multi-media advertisement PSAs. For the evaluation, the study collected data from the Florida Department of Motor Vehicles and Pedestrian and Bicycle Crash Analysis Tool . The data analysis showed a reduction of 360 pedestrian crashes in 2003 and 2004 (the first 2 years of the study), with the largest reduction occurring among adult pedestrians.

Floerchinger-Franks et al. (2000) evaluated a safety and bicyclist-focused competition sponsored by the South Central Idaho Health District. The competition was offered to 44 elementary schools in the 8 county health district of Idaho in partnership with the local Safe Kids Coalition. Nine of the elementary schools participated. As part of the competition, more than 2,500 students raised money to purchase bicycle helmets and competed in other outreach activities. Two schools even implemented helmet policies. Florechinger-Franks et al. (2000) collected baseline data and follow-up data. The data most applicable to this current research was bicycle-helmet use. Following the contest, bicycle helmet use increased significantly ($p = 0.0134$). Florechinger-Franks et al. cited using "an inter-school contest to increase … bicycle helmet use was an efficient mechanism for providing injury prevention activities, with little funding" (p. 120).

Similar to Zegeer et al. and Floerchinger-Franks et al.'s research, Dunckel et al. (2007) analyzed the effectiveness of a Pedestrian Safety Initiative in Montgomery County, Maryland. The particular initiative combined education, engineering, and enforcement activities. The engineering side of the initiative consisted of conducting 10 Road Safety Audits (RSAs) and, as an outcome of those RSAs, implemented engineering countermeasures like curb extensions, refuge islands, road diets, and modified edge lines. Dunckel et al.'s findings were similar to Mondschein et al.'s (2017). The educational programs implemented as part of the Pedestrian

Safety Initiative that Dunckel et al. studied were tailored to specific areas and focused on different safety messages depending on the needs of that area. For example, one of the educational programs was designed for a high pedestrian crash area where there was a cultural issue due to the large immigrant population. The county implemented bilingual curb markers and brought in members from the community to help explain the curb markers in English and Spanish to pedestrians. In another area, an education campaign focused on engaging students in a high school on pedestrian safety. The school, along with parents, created a poster of a student's eyes, marketing staying alert for pedestrians.

Sandt et al. (2016) evaluated the effectiveness of the Watch for Me NC program, which is a community-based program that include involved with law enforcement and engineering improvements. The evaluation of the study looked at the effects of driver behavior based on the engineering countermeasures installed and law enforcement activities. Enforcement activities included issuing press releases, marketing material (i.e., signs and banners), and engaging the public through outreach events. The study found yielding rates improved at the 16 locations where an engineering countermeasure coupled with enforcement activities was implemented as part of the Watch for Me NC program.

Key Takeaways

Holistic programs, ones that used a wide variety of material (education posters on public transportation, coupled with an enforcement campaign and safety brochure), led to more effective programs (Zegeer et al., 2008; Nuworsoo et al., 2012). Zegeer et al. (2008) also identified the following important items to consider including for future programs.

- Reliable/quality data to identify target locations for outreach/countermeasure implementation.
- Defined objectives/goals of safety outreach and communicating those clearly to partner agencies.
- A broad stakeholder group to assist in implementing a multi-faceted and comprehensive campaign.

The most successful programs targeted multimodal transportation education locally (Mondschein et al., 2017). Reliable data was needed to create a campaign that is targeted to a location (Zegeer et al., 2008; Mondschein et al., 2017; Dunckel et al., 2017). The types of educational material that were successful in reducing crashes in one location may not be successful in another location. Instead of replicating a campaign, an agency could consider the following elements that lead to a successful campaign/program (Mondschein et al., 2017; Lewis and Lane, 2007).

- Understanding how transient the population is, which in turn affects the delivery of the message.
- Involving enforcement and agencies to provide positive message and support for the campaign.
- Defining clear roles between agencies to coordinate which agencies are responsible for what message.
- Identifying funding opportunities.

Along with the key elements that lead to a successful campaign, Mondschein et al. (2017) also identified several best practices when creating messaging for a campaign.

- Focus on the humanity aspect.
- Shift cultural norms.
- Market across a wide range of channels.

In addition to focusing on the humanity, Watkins et al. (2020) noted the importance of creating education programs that promoted positive messages and addressed negative attitudes. Focusing on the positive and shifting cultural norms can lead to a willingness for a larger demographic to participate in bicycling and walking (Watkins et al., 2020; Mondschien et al., 2017).

There is a need for more successful multimodal campaigns as the demand for bicyclist and pedestrian facilities continues to grow (Sandt et al., 2016; Mondschein et al., 2017). Mondschein et al. found in their practitioner interviews and literature review that many agency planners face challenges in determining the appropriate educational material to best fit the users' needs. To adapt with the growing demand of successful educational material, planning offices are hiring marketing staff to assist in the development of campaigns/marketing material or coordinating with other agencies that can spearhead education.

Additionally, the project team found a lack of published research into bicyclist and pedestrian campaigns that focus on specific facilities. There was also a lack of published research on the effectiveness of bicyclist-focused educational campaigns. The project team found while the published research did rarely include bicyclists, bicyclist safety was often coupled with pedestrian safety and focused on educating elementary-school aged children. This could be due to the lack of bicyclist-focused campaigns versus pedestrian-focused campaigns, or due to any new campaigns/programs not being evaluated yet.

Law Enforcement Agencies

This section describes law enforcement activities related to outreach and education about pedestrian, bicyclist, and general safety-related laws, and policies. This includes activities on the national and State level. Of the research identified in this search, few focused specifically on pedestrian and bicycle safety and rather focused more broadly on enforcement efforts related to general traffic safety. The following sections provide additional information on the topics.

National Organizations

NHTSA developed two training courses specifically for law enforcement—*Pedestrian Safety for Law Enforcement* and *Bicycle Safety for Law Enforcement* (NHTSA, n.d.-c; NHTSA, n.d.-a). The computer-based trainings educate law enforcement officers on the factors associated with pedestrian and bicycle crashes, developing meaningful countermeasures and enforcement strategies, and crash investigation and reporting. In addition, although not focused on the newer pedestrian and bicycle facilities presented in this report, NHTSA funded a high-visibility enforcement (HVE) campaign to increase driver compliance with pedestrian right-of-way laws at traditional crosswalks (Van Houten et al., 2013). Driver yielding to pedestrians increased significantly over the course of the yearlong HVE program with yielding maintained at a 4-year follow-up (Van Houten et al., 2017). Similar efforts could be employed to change behaviors around newer facilities.

NHTSA dedicates Section 405(h) funds for nonmotorized safety incentive grants. Eligible recipients may use the grants for training law enforcement on State bicycle and pedestrian laws (Governors Highway Safety Association, 2020). Several past recipients included the Colorado Office of Transportation, Connecticut Highway Safety Office, New Jersey Division of Highway Traffic Safety, New York Governor's Traffic Safety Committee, Nevada Office of Traffic Safety, Oregon Transportation Safety Division, Pennsylvania Bureau of Maintenance and Operations, and Washington Traffic Safety Commission (NHTSA, n.d.-b).

Connecticut's curriculum focused on specifics of pedestrian and bicycling laws and education on target behaviors contributing to crashes, injuries, and fatalities involving non-motorized road users. Similarly, New Jersey developed a standardized training for law enforcement agencies to understand the factors associated with crashes, develop countermeasures and enforcement strategies, and recognize the importance of complete and accurate crash reporting. Pennsylvania examined pedestrian data to identify and prioritize law enforcement agencies for training workshops.

The New York Governor's Traffic Safety Committee worked with the New York State Department of Transportation to develop and conduct a training for law enforcement titled *Pedestrian and Bicycle Safety: Law Enforcement Workshop* (n.d.) but it is unpublished. Throughout the course, participants received information on laws and common violations related to vehicles, pedestrians, and bicyclists; problem identification; effective education strategies; operations, enforcement, and adjudication; and how to spot an engineering problem. An optional mock operation followed the training where law enforcement agencies could practice the learned strategies. The training also connected to the statewide Pedestrian Safety Action Plan, a 5-year safety plan involving the 3Es (Engineering, Enforcement, Education) focused on reducing pedestrian fatalities and serious injuries. Additional New York programs funded under 405(h) program provided law enforcement with information on safely and effectively enforcing traffic violations involving specific types of vehicles. This more broadly applied to motorcycles and commercial vehicles, with some emphasis on pedestrians and bicyclists.

Using 405(h) funds, Oregon Transportation Safety Division developed a project to provide pedestrian safety enforcement operations and pedestrian safety education to law enforcement statewide. A non-profit organization and traffic safety partner administered the grant, funding 33 law enforcement agencies to promote pedestrian safety education and overtime enforcement. All agencies received training in 2019 on vulnerable road user safety and how to implement best practices in High Visibility Enforcement operations. The goals of the training were to educate and enforce crosswalk laws and encourage behavior change to road users who may not abide by the crosswalk laws (Thomas et al., 2019).

The Washington Traffic Safety Commission used a 405(h) grant to fund the Spokane Pedestrian Safety Zone (n.d.). The purpose of this project was to continue data driven pedestrian education through media, publicity, outreach, and high visibility enforcement in pedestrian/driver crash locations in the City of Spokane to reduce the high number of pedestrian fatal and serious injury crashes. Although the COVID-19 pandemic curtailed some enforcement activities in 2020, the project's media exposure yielded over 13 million impressions. Enforcement accomplishments included 500 contacts with vehicles resulting in 23 speeding citations, 395 contacts resulting in 10 seat belt citations, and 51 cell phone use citations.

Lakewood Police Department was the only law enforcement agency in Colorado allocated 405(h) NHTSA funding in 2021 (Colorado Office of Transportation, n.d.). Officers received hardcopy and electronic documentation about traffic enforcement related to pedestrian and bicycle safety. Content focused on existing laws, educational pamphlets, and additional training. Similarly, the Utah Department of Public Safety planned to fund one officer special training on pedestrian and bicycle enforcement (n.d.).

The Nevada Office of Traffic Safety supports several law enforcement efforts related to bicycles and pedestrians in Clark County, Nevada (n.d.). For example, officers conduct 3-foot enforcement for bicycles similar to pedestrian enforcement with a decoy officer on a bicycle with a laser that shows the 3-foot distance. The officer radios the non-compliance to officers along the route who make the stop. Additionally, two officers provided pedestrian enforcement training courses that included half-day training with in-the-field enforcement following. The State also provides safety classes for people who received a pedestrian citation (either motorist or pedestrian), which allows the courts to dismiss the fine and erase the points (PED SAFE Nevada, 2014).

Universities

University staff assisted other statewide organizations in developing training on accessing and analyzing data to make decisions and to evaluate the success of previous education efforts. Both example efforts are from Rutgers University.

The Rutgers University Center for Advanced Infrastructure and Transportation, with support from the New Jersey Division of Traffic Safety, hosts a three-day course titled *Data-Driven Countermeasures for Traffic Safety* (Rutgers, 2021). The intended audience is project managers and grant writers with the purpose of providing the tools needed to conduct data analysis for high crash locations and develop and submit grants to the Division of Highway Traffic Safety, which funds projects related to pedestrian and bicycle safety, roadway safety, and police traffic services. Attendees become familiar with the grant writing and application process and learn the technical skills to use the New Jersey Crash Analysis Tool.

The Rutgers University Alan M. Voorhees Transportation Center conducted an analysis of a statewide training programs to educate law enforcement officers on the application of the statewide vehicle code Title 39 to bicycles (Sinclair & Brown, 2015). Trainings reached 48 police officers from 22 different agencies and provided education on bicycles as roadway traffic, appropriate locations and directionality for bicycling, turning maneuvers, helmet and other safety equipment requirements, and laws related to traffic signals. The evaluation included a comparison of pre- and post-training tests and concluded that the training was effective in raising awareness of the code.

State Departments of Transportation

State Departments of Transportation have supported law enforcement education on bicycle and pedestrian through trainings focused on laws and recognizing violations for motorists, pedestrians, and bicyclists.

The New Hampshire Office of Highway Safety, with the New Hampshire Police Academy, developed an internal training to educate policy academy candidates on the rules of the road for bicyclists and pedestrians (New Hampshire Office of Highway Safety, n.d.). The course covers

State laws and associated infrastructure including control signals, signs, pavement markings, where on the roadway pedestrians and bicyclists are permitted to travel, and legal and illegal crossings. Information is also provided on driver behavior near bicycles, application of vehicle laws to bicyclists, and safety gear for bicyclists.

The Rhode Island Department of Transportation Office on Highway Safety (Rhode Island Department of Transportation, n.d.) developed an instructional presentation on how to enforce pedestrian and bicycle safety. The training presented statistical data on pedestrian and bicycle fatalities specific to the State and generally nationwide, where fatal crashes occurred, and contributing factors such as alcohol and age. The presentation went on to expand on State law definitions of a sidewalk and addressed how speed and vehicle type impact crash severity. The section on effective pedestrian safety enforcement provided detailed guidance on how to create and implement enhanced enforcement activities. Steps included selecting a location, notifying local judiciary of increased violations, engaging with the public, using media for more awareness, selecting the best dates and times, and the types of violations for drivers and pedestrians. The course also discussed implementation considerations like safety precautions, material, and locations. The training concluded with applicable laws for pedestrians and bicyclists.

State Departments of Law and Public Safety

Outside of transportation agencies and university research, State departments focused on law and public safety have the most opportunity to directly connect with law enforcement agencies and provide education and training. The New Jersey Office of the Attorney General hosts the Safe Stop website (State of New Jersey, n.d.) with the purpose of promoting educational information on safe traffic stops for law enforcement and drivers. The website hosts a series of videos with State experts, community leaders, and national celebrities providing public service announcements for drivers. The primary focus of these announcements are driver rights and responsibilities. Other methods of outreach include tips, frequently asked questions, guidance on filing a complaint, and relevant news stories. Training and training material for law enforcement are also available on the website.

Key Takeaways

Trainings, guidance, and other general education on bicycle and pedestrian facilities for law enforcement is very limited. The sources identified in this section are not exhaustive. However, the information derived from the small sample of law enforcement trainings and activities reveals several consistent themes. Available resources tend to focus more broadly on law enforcement’s role with vehicle and roadway safety with minimal focus on specific pedestrian or bicycle issues. The resources emphasize understanding laws as they relate to bicycles and pedestrians and safety data trends. State agencies developing training with NHTSA support were data-driven, both in terms of using bicycle and pedestrian data to identify municipalities with the most need for law enforcement education and also to train law enforcement on how to correctly collect crash reports. The one identified evaluation in New Jersey demonstrated the positive impact education for law enforcement on increased awareness and understanding of bicycle-related topics.

Conclusions

This literature review serves as a synthesis of what is known about how road users understand and use new pedestrian and bicycle facilities. The breadth and depth of research varies by facility. Much of the research identified focuses on use, compliance, and safety, while relatively little research directly explores education or enforcement strategies and their potential impacts on use and understanding. In addition to scientific literature, the team collected and reviewed a sampling of material from unevaluated outreach efforts.

Several conclusions and lessons learned can be drawn from this review, summarized below:

- Road users generally use new transportation facilities safely, if not entirely as intended. For example, motorists may not always yield when they should, but pedestrians and bicyclists take precautions to avoid injury regardless. Confusion can occur when expectations are defied, such as when movement patterns are changed by bike boxes or two-stage left turn boxes.
- Generally, and as expected, pedestrians and bicyclists express positive attitudes about pedestrian and bicycle facilities. These facilities are often designed to promote non-motorized traffic and, in doing so, increase pedestrians’ and bicyclists’ presence and improve their travel in some way (e.g., delay reduction or improved routing). Motorists share these sentiments unless they represent inconveniences or unexpected behaviors such as bicyclists riding in buffered or contraflow lanes.
- Surprisingly little published research has explored education strategies for specific facilities. Some facilities are more interactive than others and some road users may require guidance. It appears that the general practice is to use established signage rather than experimenting with a potentially more effective method, such as intuitive design principles or media campaigns.
- This review identified one study that evaluated the effects of enforcement activities on driver yielding rates. Enforcement—whether by visible patrol, citations, sting operations or otherwise—is likely to positively influence compliance among all road users. Law enforcement officers may know this, but the research community has yet to document it. Perhaps this is due to limited resources, obstacles preventing coordination with law enforcement agencies, or measurement difficulty.
- Local agencies and advocacy groups are responsible for much of the educational outreach to the public regarding pedestrian and bicycle facilities. Larger organizations tend to deliver more broad, general safety messages (e.g., safe habits, proper equipment use) or technical specifications and implementation guidelines. While these are important for planners, more localized organizations seem better positioned to deliver relevant messages to prospective users. These organizations are composed of members of the local community, which helps garner local support and engagement.
- Although little research directly evaluated education surrounding specific facilities, the team identified a small number of studies into broader educational campaigns. These studies indicate that multimode communication to a highly localized audience is the most successful strategy for improving safety through behavioral change. More research is needed to quantify the success of the educational campaigns.

- This research yielded little educational material directed toward educating law enforcement officers. Of those identified, the sources focused on general vehicle and roadway safety rather than on things specific to pedestrian and bicycle issues. The information identified also focused on educating law enforcement officers, rather than law enforcement agency educational material for the public.

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