1-25-2023

Driver and Bicyclist Comprehension of Blue Light Detection Confirmation Systems

Douglas P. Cobb
Oregon State University

Hisham Jashami
Oregon State University

Christopher Monsere
Portland State University, monsere@pdx.edu

Sirisha Kothuri
Portland State University, skothuri@pdx.edu

David S. Hurwitz
Oregon State University

Citation Details

Published as: Cobb, D. P., Jashami, H., Monsere, C., Kothuri, S., & Hurwitz, D. S. (2023). Driver and Bicyclist Comprehension of Blue Light Detection Confirmation Systems. Transportation Research Record, 0(0). https://doi.org/10.1177/03611981221148481

Driver and Bicyclist Comprehension of Blue Light Detection Confirmation Systems

Douglas P. Cobb, Ph.D., PE, PTOE, RSP2I
Graduate Research Assistant
School of Civil and Construction Engineering
Oregon State University
101 Kearney Hall, 1501 SW Campus Way, Corvallis, OR 97331, USA
Tel: 541-602-6736; Email: douglasc@oregonstate.edu

Hisham Jashami, Ph.D., RSP1 (Corresponding Author)
Assistant Professor (Sr Res)
School of Civil and Construction Engineering
Oregon State University
101 Kearney Hall, 1501 SW Campus Way, Corvallis, OR 97331, USA
Tel: 541-602-6736; Email: hisham.jashami@oregonstate.edu

Christopher Monsere, Ph.D., PE (OR)
Professor
Department of Civil and Environmental Engineering
Portland State University
PO Box 751
Portland, OR 97207-0751
Tel: 503-725-9746; Email: monsere@pdx.edu

Sirisha Kothuri, Ph.D.
Senior Research Associate
Department of Civil and Environmental Engineering
Portland State University
PO Box 751
Portland, OR 97207-0751
Tel: 503-725-4208; Email: skothuri@pdx.edu

David S. Hurwitz, Ph.D.
Professor and Director
School of Civil and Construction Engineering
Oregon State University
101 Kearney Hall, 1501 SW Campus Way, Corvallis, OR 97331, USA
Tel: 541-737-9242; Email: david.hurwitz@oregonstate.edu

Word count: 5930 text + 6 tables x 250 (1,500) = 7,430 words

Submission Date: August 1, 2022, Revised November 17, 2022, Final December 8, 2022

ABSTRACT

This study analyzed motorist and bicyclist understanding and preference of positive confirmation of detection of a bicycle by the traffic signal infrastructure using a blue light detection confirmation (BLDC). The research analyzed results of an online survey of 1,123 respondents and intercept survey of 337 respondents. The study initially found that participants of the survey did not understand the meaning of the blue light itself, but comprehension of the system rose by 40% to 50% when supplemental signs were used. Respondents overwhelmingly indicated that they preferred the sign option that included symbols, text, and a representation of the blue light, in comparison to the sign options that only included symbol and text or text and blue dot. Additionally, respondents indicated that they "Strongly Agree" that the supplemental signage helped with understanding the purpose of the detection confirmation devices, that they would support the system at intersections, and that it made them feel better about waiting at an intersection with light. Including supplemental signage with the symbol, text, and blue dot could potentially improve the riding experience for users, as it was strongly preferred among the alternative sign options that were tested, however further evaluation on sign configurations may be warranted .

Keywords:

Bicycle facilities, Bicycle crossings, Traffic control devices, Bicycle Detection

BACKGROUND

Signalized intersections, which have historically been designed and operated to promote the efficient movement of vehicular traffic, present an increased crash risk for bicyclists and are a location of elevated stress. Currently, at signalized intersections, bicyclists are primarily detected by in-pavement inductive loops, often by the same loops used for vehicle detection. While vehicles are almost always detected due to their size and predictable stopping location, that is not the case for bicycles. If bicyclists do not position themselves for optimal detection, there can be failures in detection resulting in unnecessary delays. These delays lead to a lower quality experience and may lead to increased risk-taking behavior (i.e., signal non-compliance). A blue light detection confirmation (BLDC) system can provide positive confirmation to the bicyclists that they have been detected. In the typical application, a small blue light is placed on the far side of the intersection near the signal head that the bicyclist is monitoring for information (either a vehicular or bicycle signal head). When bicyclists are detected and a call is placed, the blue light illuminates. Because most of the public does not understand how traffic signals operate, it is critical to present a message that is comprehended by most people.

The objective of this paper is to investigate the use and comprehension of a BLDC system in the US context. An online survey and survey of intercepted bicyclists at signalized intersections with various BLDC systems installed were conducted to determine the general public's comprehension and preference of the BLDC system and three supplemental sign alternatives.

Detection systems have been evaluated and studied by researchers and practitioners to determine their effectiveness and comprehension with both motorists and bicyclists. In 2015, Boudart et al. first evaluated the impacts of a BLDC at one signalized intersection in Portland, OR (*1*). Video data were collected in three phases – before condition, after blue light installation, and after blue light and informational sign installation. In the before condition, bicyclists primarily used the pushbutton to be detected, despite the presence of 9C-7 pavement detector marking (the R10-22 sign was absent). After the blue light and informational sign installation, a statistically significant decrease in bicyclists using the pushbutton was observed (*1*). Boudart et al. continued their work and tested the modified UM-Columbia pavement marking (includes bicycle symbol, "wait here for green" text, and green dot) along with the BLDC at two intersections in Portland, OR (*2*). A postcard intercept survey was also administered at the two sites, with the postcard containing a link to an online survey. A total of 213 respondents responded to the online survey. The findings of the survey revealed differences in comprehension regarding the BLDC at the two sites, 86% and 58% (*2*). The authors hypothesized that the higher comprehension at one site could be related to the longer length of time the BLDC had been active at that location compared to the other location (*2*).

Recently, ODOT conducted an experiment at the intersection of Commercial and Union Streets in Salem, OR with the BLDC (*3*). In the before test, a bicycle stencil (MUTCD Bicycle Lane Symbol Marking) was located on the westbound approach to indicate where bicyclists should position themselves. In phase 1, a BLDC was installed on the eastbound and westbound approaches. In phase 2, an explanatory sign was placed next to the BLDC. In each phase including the pre-installation phase, 40 bicyclists were observed via video footage. The findings revealed, that in phases 1 and 2, higher rates of the call being held until the bicyclist entered the intersection (31% before, 42% phase 1, 47% phase 2). More bicyclists were also observed to arrive and wait within the video camera's detection zone after phases 1 and 2. An alternative to far-side BLDC would be to place BLDC on the nearside, perhaps more easily visible to the waiting bicyclist. In

Christchurch, New Zealand a nearside indication device has been in use for some time. As described on the "Cycling in Christchurch" blog, the city adopted the standard pedestrian pushbutton confirmation device to work for bicycles. The button is dark when the call is not active but lights up red when bicycles are detected.

While crossing an intersection against a red indication can contribute to bicyclist-motor vehicle collisions (*4*), there is limited literature on bicyclist compliance at signalized intersections. Some studies have found that non-compliance by bicyclists is considered common behavior by drivers (*5-7*). Richardson and Caulfield examined the compliance of bicyclists in Dublin City, Ireland, using an observational survey and an online questionnaire (*8*). The results from the observational study revealed a non-compliance rate of 61.9%, with males demonstrating a higher likelihood of non-compliance (*8*). Overall, 49% of survey respondents stated that they would not comply with the signal indication (*8*). Thus, indicating that without detection feedback, users often indicated or were observed not complying with the signal indication; however, if technology could be used to provide feedback to users, this could help to improve operations, safety, and the overall cycling experience.

METHODOLOGY

The research consisted of an online survey, as shown in Figure 1, and a survey of intercepted bicyclists at signalized intersections that had various BLDC systems installed. The survey, distribution methods, and record handling were reviewed and determined exempt by the Institutional Review Board (IRB) of Portland State University (PSU) (196376-18).

Figure 1 Online survey flow chart

Survey Instruments

Both surveys began with respondents certifying that they are over 18 years old and acknowledging an informed consent statement. The surveys began with open-ended questions and then presented multiple-choice and Likert-Scale questions. Each survey ended with demographic questions on the respondent's income and education levels, cycling and driving habits, and eyesight.

The online survey began with open-ended questions, which asked participants to report their understanding of a BLDC placed on the backplate of a traffic signal head. In this section, the survey randomly branched into two options: 1) the user was assumed to be a bicyclist (i.e., bicycle is provided in the foreground of the image) or 2) the user was assumed to be a driver (i.e., car is provided in the foreground of the image). Participants were initially presented a computer image of an intersection from either a bicyclists' or driver's perspective and were asked to indicate their meaning of the BLDC on the signal head, without supplemental signage included (Figure 2-left). Next, they were asked the same question but with signage this time (Figure 2-right).

FIGURE 2 Image used for open-ended question on BLDC for bicyclist's perspective (Top) and driver's perspective (bottom) with and without signage

Three supplemental signs were tested in the survey such that all participants were randomly presented with one version of the three possible sign options. After completing these items, participants were asked to indicate which of the three sign options (shown in Figure 3) conveyed the best meaning for the BLDC and to provide feedback regarding their perspective of the use of the signage. The closing of the survey consisted of close-ended multiple-choice demographic questions on the participant's income and education levels, cycling and driving habits, and eyesight.

FIGURE 3 Images used sign options with BLDC for bicyclist's perspective (left) and driver's perspective (right)

The intercept survey was conducted to determine the bicyclists' comprehension of the BLDC at traffic signals equipped with the preferred accompanying sign. Two versions of the signs were designed – one in which the blue light was embedded in the sign, and the other where the blue light was located in the signal separate from the sign, as shown in Figure 4.

FIGURE 4 BLDC in Traffic Signal Housing with Accompanying Sign (left) and BLDC Embedded in Sign (right)

Table 1 shows the six intersection locations along with the 12 approaches where the BLDC were installed along with the accompanying signs. The intercept survey was administered at these six intersections.

TABLE 1 BLDC Locations and Type of Accompanying Sign

Location	Approach	Detection Device Type	Number of Lanes	Type of Lane	Speed Limit (mph)
N Ainsworth St. and N Interstate Ave.	N Ainsworth St. WB	Embedded Sign	1	Shared Left, Thru, Right	20
NE US Grant Pl. and NE 33rd Ave.	NE US Grant Pl. EB	Embedded Sign	1	Shared Left, Thru, Right	20
NE 53rd Ave. and NE Glisan St.	NE 53rd Ave. SB	Supplemental Sign	2	Left, Shared Thru and Right	20
SW Terwilliger Blvd and SW Capitol Hwy	SW Terwilliger Blvd SB	Supplemental Sign	2	Shared Left, Thru, Right, Bike Lane	25
Monroe St. and W 6th Ave.	Monroe St. NB and SB	Embedded Sign	1	Shared Left and Thru (NB), Shared Thru and Right (SB)	20
W 5th Ave. and Blair Blvd	W 5th Ave. EB and WB	Embedded Sign	1	Shared Left, Thru, Right	25

The intercept survey asked the respondents to first enter one of six letter codes (AA-FF) and a number code (001-300) from the postcard that they were handed at the intersections. Two branches of the survey (blue light embedded in the sign or blue light presented separately from the sign in the traffic signal backplate) were developed, depending on the letter code that was entered by the respondent. Within each of these branches, respondents were asked if they had observed the blue light and sign at the intersections previously and whether they had read any media articles about the blue lights. There were also open-ended questions, which asked respondents to report their understanding of a BLDC when it was ON and OFF, with the supplemental sign included. Respondents were also asked to describe how they could activate a blue light and their perspective regarding the inclusion of BLDC at signalized intersections. Finally, respondents were asked close-ended multiple-choice demographic questions regarding income and education levels, cycling, and driving habits, and eyesight.

Recruitment Methods

Two methods were used to recruit subjects for the online survey: 1) a postcard recruitment to household addresses in Oregon and 2) an online social media-based recruitment. For the postcards, an expected survey response rate of 6–8% was assumed based on a previously conducted postcard/online design on previous research (*9-11*). A sampling scheme was designed based on the proportion of the population in each medium/large city in Oregon. Only cities were chosen for the postcard mailing because of the higher prevalence of bicycling in urban areas. Postcards were mailed to 10,003 addresses. A total of 568 respondents clicked the online link to respond to the survey. A total of 271 postcards were returned as undeliverable, resulting in a response rate of 5.8%.

A social media post was provided on Facebook with pertinent information regarding the study and an online link to the survey. A total of 1,550 respondents clicked the online link to begin

the survey; 555 respondents completed the survey. The calculated response rate was 35%. Figure 5 shows the geographic distributions of respondents for the postcard and social media surveys.

FIGURE 5 Geographic distribution of postcard survey respondents in Oregon (left) and social media survey respondents in the United States (right)

A recruitment postcard containing information about the survey objectives and an online link was handed out by researchers to cyclists on 12 approaches of the six intersections studied. A total of 337 postcards were handed out with 151 responses, resulting in a response rate of 45%.

Open-Ended Question Coding

The primary questions in the online and intercept surveys to determine the comprehension of the BLDC were open-ended. In the online survey, respondents were presented with the following wording, with either "bicycle" or "vehicle" interchanged based on the respondent's branch:

> *"Imagine that you are waiting at an intersection on/in a bicycle. What does the BLUE LIGHT (to the left of the arrow) mean to you? Please type your response in the box below and be as descriptive as possible."*

In the intercept survey, respondents were presented two scenarios (i.e., one with the BLDC OFF, one with the BLDC ON) of the location they experienced and were asked the following:

> *"If you are waiting at the intersection and the blue light is ON/OFF, what does the sign pointed to by the red arrow mean to you? Please type your response in the box below and be as descriptive as possible."*

Responses to the questions were reviewed and classified as correct, partially correct, or incorrect based on the following error coding of open-ended comprehension responses:

- Online Survey: BLDC Intersection Scenario (with/without signage) with car or bicycle
  - Correct: Blue light indicates that either the bicyclist or vehicle has been "detected" at the intersection
  - Partially correct: Blue light indicates that a car or bike has been "detected" nearby or that that traffic signal has been triggered.
  - Incorrect: Anything else
- Field Installation: BLDC ON
  - Correct: Blue light indicates that either the bicyclist or vehicle has been "detected" at the intersection
  - Partially correct: Blue light indicates that a car or bike has been "detected" nearby or that that traffic signal has been triggered.
  - Incorrect: Anything else

RESULTS

Demographics

Of the 1,340 people who responded to the survey (568 postcard, 772 social media), 1,064 people provided some or all the requested demographic information (see Table 2). The responses from the social media survey were further categorized by zip code into those from Oregon vs. the rest of the US. The type of recruitment method used (postcard, social media, intercept) yielded different in demographics.

The postcard recruitment resulted in a sample that was overrepresented by older, educated white males compared to the 2010 census estimates for Oregon. Male respondents from the postcard survey had the highest overrepresentation (60% male compared to 49% male for the total population in both Oregon and US). Survey respondents were slightly older than the general population, with overrepresentation in the 55–64 and 65+ years categories, for data collected from Oregon (48.5% postcard survey, 34.4 social media (OR)) as compared to census estimates (29.9 (OR); 27.6% (national)). The social media survey administered nationally yielded a larger representation in the 25-34 year category (32.8%) as compared to the census (13.7%). Postcard respondents were 81% White/Caucasian (vs. 77% reported in the census) and overrepresentations were seen with both social media national and Oregon data. Proportions of higher income respondents ($100,000 or greater) on both postcard and social media surveys were overrepresented when compared with census estimates (34.2% (postcard), 33.3% (social media Oregon), 38% (social media national) vs. 26.2% (national) and 23.8% (social media Oregon). Respondents with a Bachelor's degree were overrepresented on all forms of the survey as compared to the census proportions.

Respondents from Oregon via the postcard tended to cycle far less than 5 miles per week (74%) in comparison to respondents from Oregon on social media who tended to cycle over 10 miles per week (74%). Furthermore, respondents from Oregon via the postcard had a lower propensity of using a bike ride for either fun/exercise or for transportation within the last month (28% for fun/exercise and 15% for transportation), in comparison to respondents from Oregon and nationally on social media who had higher propensity to use a bike ride for fun/exercise or for transportation within the last month (86% for fun/exercise and 73% for transportation for Oregon social media; 65% for fun/exercise and 38% for transportation for national social media).

TABLE 2 Demographics Summary of Survey Respondents

Category	Demographic variable	Post Card (Oregon) (n=529)	Social Media (Oregon) (n=90)	Intercept Survey (n=151)	Census (Oregon)	Social Media (USA) (n=465)	Census (USA)
Gender	Male	59.6	47.8	65.6	49.5	51.6	49.2
	Female	38.0	48.9	32.5	50.5	42.2	50.8
	Prefer not to answer	1.5	0.0	1.30	-	1.5	-
	Prefer to self-describe	0.6	3.3	0.6	-	1.9	-
Age	18–24	1.0	3.3	1.3	12.7	7.3	13.6
	25–34	12.9	16.7	14.6	13.9	32.0	13.7
	35–44	22.3	22.2	33.8	13.1	12.9	12.7

	45–54	15.1	23.3	25.8	12.8	14.2	13.4
	55–64	19.6	21.1	15.9	13.5	20.2	12.7
	65+	28.5	13.3	8.6	16.4	10.1	14.9
Race	American Indian or Alaska Native	0.8	1.1	0.0	0.9	0.0	0.7
	Asian	3.0	1.1	2.0	4.1	2.6	5.3
	Black or African American	0.8	1.1	2.0	1.8	2.8	12.3
	Hispanic or Latino/a	2.3	6.7	2.0	12.7	6.0	17.6
	White or Caucasian	80.9	82.2	88.7	76.5	76.6	61.5
	Other	3.2	3.3	1.3	4.1	2.8	2.7
	Prefer not to answer	8.5	4.4	4	-	5.8	-
Income	Less than $25,000	4.4	6.7	9.3	21.3	6.9	21.4
	$25,000 – $50,000	14.4	10.1	9.3	23.5	12.9	22.5
	$50,000 – $75,000	16.6	15.6	10.6	18.5	14.0	17.7
	$75,000 – $100,000	15.3	22.2	10.6	12.9	15.3	12.3
	$100,000 – $200,000	26.3	28.9	40.4	18.8	27.5	19.9
	$200,000 or more	7.9	4.4	11.9	5.0	9.2	6.3
	Prefer not to answer	14.6	12.2	7.9	-	10.8	-
Education	Some High school	1.1	0.0	1.3	6.0	0.0	7.2
	High School/equivalent	4.9	1.1	1.3	23.4	2.4	27.3
	Some college	13.2	11.1	6.6	25.8	10.3	20.8
	Trade/Vocational	4.5	2.2	1.6	-	1.1	-
	Associate degree	7.4	12.2	6.0	8.7	4.7	8.3
	Four Year Degree	32.0	37.8	41.7	20.1	40.2	19.1
	Master's degree	24.2	28.9	34.4	12.2	26.5	11.8
	Doctorate degree	8.9	5.6	7.3		8.8	
	Prefer not to answer	3.2	1.1	0.0	-	2.6	-

Note: Percentages for categories may not total 100% due to missing responses.

In the intercept survey, older, educated white males were overrepresented as survey respondents compared to 2010 Census estimates for Oregon. Survey respondents were generally older than the general population, with larger representation in the 55–64 and 65+ years categories, for data collected from Oregon (60.78%) as compared to the census estimates (29.9%). The respondents were 89% White/Caucasian (vs. 77% reported in the census). Proportions of higher-income respondents ($100,000 or greater) surveys were overrepresented (52.32%) when compared with census estimates (23.8%). Respondents with a Bachelor's and higher (Masters and Doctorate) degrees were overrepresented as compared to the census proportions.

Respondents on average reported using the bicycle for 22 days in a month. Overall, 93% of respondents possessed a driver's license. Fourteen percent of the respondents reported that they did not drive a car for transportation, and 45% reported driving less than 5,000 miles in a year. A

small percentage of respondents (1%) indicated that they were colorblind. Majority of the respondents indicated that they used corrective glasses or contacts for vision (58%).

BLDC Comprehension

Responses were coded following the convention in the method section for both the online and intercept survey. Figure 6 and Tables 3 and 4 presents the results of the analysis for the online survey, both without and with signage, and intercept survey at six locations.

Results of the online survey analysis of the responses are shown in Figure 6, which was answered by 1,084 respondents (548 with bicycle scenario and 536 with vehicle scenario). Most respondents, approximately 90% average of all three sources, indicated that they did not know what the blue light meant or provided a response that was not accurate. Of the respondents who correctly answered the question, Oregonians, both from the postcard and social media sources, generally showed higher rates of correctness (7.6% for post card-OR and 23.3% for social media-OR) compared to the national respondents (4.3% for social media social media-US). For the social media respondents from Oregon, 29.7% had a correct response to the blue light.

FIGURE 6 Responses to open-ended question on BLDC (without signage)

Table 3 summarizes the findings for the same question but with signage presented. For Sign Option #1 (i.e., Symbol without Blue Dot), respondents generally were split between correct and incorrect responses (44% for correct vs. 45% for incorrect responses) for the understanding of the BLDC. In comparison, respondents with the bicycle scenario were more likely to correctly respond (47% average of three sources) versus respondents with the vehicle scenario who had a lower propensity to answer correctly (40% average of three sources). Another 10% were coded partially correct because they did not provide additional detail on the location of detected vehicle or only indicated that signal was triggered.

Like the Sign Option #1, Sign Option #2 (i.e., Symbol with Blue Dot) respondents generally were split between correct (44%) and incorrect (45%) understanding of the BLDC. In comparison, respondents with the bicycle scenario were more likely to correctly respond (48% average of three sources) versus respondents with the vehicle scenario who had a lower propensity to answer correctly (41% average of three sources). An additional 11% were coded partially correct because they did not provide additional detail on the location of detected vehicle or only indicated that the signal was triggered.

For Sign Option #3 (i.e., Text with Blue Dot), respondents indicated more incorrect (49%) responses to correct (41%) responses. However, compared to the first two signs, the use of text indicated a decline in comprehension rates from respondents in both scenarios (41% average vs. 44% for Sign Options 1 and 2). An additional 10% were coded partially correct because they did not provide additional detail on the location of detected vehicle or only indicated that the signal was triggered.

To better understand respondents' comprehension scores, two binomial proportion tests were used for both vehicle and bicycle scenarios to test whether the additional signage, regardless of the sign option (e.g., symbol without blue dot, symbol with blue dot, text with blue dot) and survey mode (e.g., postcard versus social media), could increase the probability of getting less

incorrect responses (12, 13).

For respondents who were presented the vehicle scenario, results showed that the proportion of correct responses by participants increased from 6% when the sign was not presented to approximately 51% when it was presented, which is statistically different and significant (P-value < 0.001). However, for respondents who received the bicycle scenario, similar test was used, and the results showed that the proportion of obtaining correct responses by participants increased from 6% when the sign was not presented to approximately 47% when it was presented, which is statistically significant (P-value < 0.001). Based on these results, there is evidence that the additional signage helped participants understand the meaning of the BLDC.

TABLE 3 Responses to open-ended question on BLDC (with signage)

RESPONSE	BICYCLE (n=548)			VEHICLE (n=536)			TOTAL (n=1084)		
	Post Card	Social Media (Facebook)		Post Card	Social Media (Facebook)		Post Card	Social Media (Facebook)	
	OR	OR	USA	OR	OR	USA	OR	OR	USA
Sign Option #1 (Symbol without Blue Dot) (n=191 for Bicycle; n=189 for Vehicle)									
Correct	58.6%	35.7%	37.8%	50.0%	44.4%	30.1%	54.3%	40.6%	34.1%
Partially Correct	9.2%	7.1%	14.4%	5.7%	0.0%	12.0%	7.4%	3.1%	13.3%
Incorrect	29.9%	51.7%	44.4%	44.3%	55.6%	57.8%	37.1%	56.3%	50.9%
Did not Respond	2.3%	0.0%	3.3%	0.0%	0.0%	0.0%	1.1%	0.0%	1.7%
Sign Option #2 (Symbol with Blue Dot) (n=178 for Bicycle; n=191 for Vehicle)									
Correct	52.2%	25.0%	45.0%	46.7%	16.7%	40.7%	49.5%	19.2%	42.9%
Partially Correct	5.6%	12.5%	10.0%	10.9%	22.2%	13.6%	8.2%	19.2%	11.8%
Incorrect	42.2%	62.5%	45.0%	42.4%	61.1%	45.7%	42.3%	62.5%	45.3%
Did not Respond	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Sign Option #3 (Text with Blue Dot) (n=177 for Bicycle; n=158 for Vehicle)									
Correct	39.2%	46.7%	35.4%	45.3%	35.3%	42.4%	41.9%	40.6%	38.9%
Partially Correct	9.3%	6.7%	18.5%	4.0%	11.8%	12.1%	7.0%	9.4%	15.3%
Incorrect	51.5%	46.7%	46.2%	50.7%	52.9%	45.5%	51.2%	50.0%	45.8%
Did not Respond	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

For the intercept survey, overall, most of the respondents understood the purpose of the BLDC correctly and comprehension rates were high regardless of whether the blue light was ON or OFF (Table 4). Comprehension was higher at the intersections of N Ainsworth St and N Interstate Ave and NE US Grant Pl and NE 33rd Ave compared to the other locations when the blue light was ON.

Respondents were asked if there was anything that they could do as a bicyclist to activate the blue light. Respondents who chose “yes” as their response were asked to describe the actions

they would take. Sixty-six percent (66%) overall thought they could take actions to activate the blue light, while 33% were not sure.

TABLE 4 Blue Light Detection Confirmation (BLDC) Comprehension

Category	Response	N Ainsworth St and N Interstate Ave	NE US Grant Pl and NE 33rd Ave	NE 53rd Ave and NE Glisan St	SW Terwilliger Blvd and SW Capitol Hwy	Monroe St and W 6th Ave	W 5th Ave and Blair Blvd	Overall
BLDC ON	Incorrect	3.7	5.7	4.35	11.1	4.6	23.5	7.3
	Partially Correct	3.7	3.8	13.04	11.1	18.2	17.7	9.3
	Correct	92.6	90.6	52.61	77.8	77.3	58.8	83.4
BLDC OFF	Incorrect	11.1	3.8	4.35	0.0	13.6	29.4	9.3
	Partially Correct	11.1	3.8	8.70	33.3	9.1	11.8	9.3
	Correct	77. 8	92. 5	86.96	66.7	77.3	58.8	81.5

Sign Preferences

Following the comprehension questions in the online survey, respondents were presented all three sign options based on whether they were initially presented the intersection scenario as a bicyclist or vehicle, as shown in Figure 3. Respondents were then asked to choose the sign that conveyed the most comprehensible meaning to them and to provide justification for their choices. Figure 7 summarizes results for this question, which was answered by 1,084 respondents (548 with bicycle scenario signage and 536 with vehicle scenario signage). Respondents who were provided the bicycle scenario signage, as shown in Figure 7, generally indicated that Option #2 (67% for postcard vs. 81% for social media-OR vs. 68% for social media-US) conveyed the best meaning, followed by Option #3 (24% for postcard-OR vs. 8% for social media-OR vs. 20% for social media (US)). Similarly, respondents who were provided the vehicle scenario signage, as shown in Figure 7, generally indicated that Option #2 (57% for postcard vs. 60% for SMO vs. 55% for social media (US)) conveyed the best meaning, followed by Option #3 (35% for postcard vs. 60% for SMO vs. 35% for social media (US)); however, overall, there was a higher propensity for respondents with the vehicle scenario signage to indicate that Option #3 was viable, in comparison to respondents with bicycle scenario signage.

FIGURE 7 Blue Light Detection Confirmation (BLDC) Comprehension (percentages selecting a particular sign option)

Experience and Familiarity

Online survey respondents were asked whether they had experienced the BLDC at an intersection before. Figure 8 summarizes results for this question, which was answered by 1,084 respondents (545 with bicycle scenario and 539 with vehicle scenario). Respondents generally had not

experienced the BLDC at the intersection before (89% average of all three sources). However, in both scenarios presented, respondents nationally from social media had a higher proportion of "No" (97%) responses for experiencing this system in comparison to the respondents from Oregon via the postcard (86%) and social media (70%).

FIGURE 8 Responses to "Experience at Intersection" Regarding Blue Light Detection Feedback

Intercept survey respondents were shown a photo of an intersection like the one where they were handed the postcard and asked if they had noticed the blue light and the sign at the intersection that they traveled through. A follow-up question asked about their familiarity with media articles explaining the purpose of blue lights at intersections. Table 5 shows the responses. Overall, 84% of respondents indicated that they had observed the blue light at the intersection, and generally, the percent of respondents who observed the blue light was higher at the Portland locations than Eugene locations. Additionally, within the Portland locations, the percent of respondents who indicated that they had observed the blue light was higher at the locations where the blue light was embedded in the sign than at locations where it was separate. Seventy percent (70%) of the respondents did not read media articles on BLDC.

TABLE 5 Blue Light Detection Confirmation (BLDC) Familiarity

Category	Response	N Ainsworth St and N Interstate Ave	NE US Grant Pl and NE 33rd Ave	NE 53rd Ave and NE Glisan St	SW Terwilliger Blvd and SW Capitol Hwy	Monroe St and W 6th Ave	W 5th Ave and Blair Blvd	Overall
Observed BLDC at Intersection	Yes	96.3	92.5	69.6	88.9	72.7	70.6	84.11
	No	3.7	7.6	30.4	11.1	27.0	29.4	15.9
Read Media Articles on BLDC	Yes	37.0	34.0	43.5	44.4	9.1	5.9	29.8
	No	63.0	66.0	56.5	55. 6	90.9	94.1	70.2

The most common response from those who said they could take action to activate the blue light was to reposition their bicycle on/close to the bike pavement marking, if present, or on/close to the loop detector.

Attitudes and Perceptions

Respondents in both the online survey and intercept surveys were then provided a Likert scale to evaluate their level of "agreement" with designated statements.

Table 6 summarizes the results for the three Likert questions in the online survey, which were answered by 1,084 respondents (548 with bicycle scenario and 536 with vehicle scenario). For Question 1, respondents generally indicated that they "Strongly Agree" (57% average of all three sources) followed by "Agree" (27% average of all three sources) that the addition of the sign helped with their understanding of the purpose of the blue light. Similarly, for Question 2, respondents generally indicated that they "Strongly Agree" (45% average of all three sources) followed by "Agree" (29% average of all three sources), that they would support the use of the BLDC at some intersections in their community.

For Question 3, respondents were spread evenly, indicating that they "Strongly Agree" (34% average of all three sources), followed by "Agree" (27% average of all three sources) and "Indifferent" (21% average of all three sources), that they would feel better about waiting on a bicycle at an intersection if a BLDC was present.

In the intercept survey, each respondent was asked to state their level of agreement with four multiple choice questions to explore their attitudes and perceptions regarding the visibility and utility of the BLDC. Overall, 78% of the respondents felt that the blue light and sign were clearly visible to them at the intersection. Two intersections NE 53rd Ave at NE Glisan St and W 5th Ave at Blair Blvd had lower proportions, 57% and 64%, respectively, stating that the blue light and sign were clearly visible. The level of disagreement (either somewhat or strongly disagree) with the statement that the blue light and sign were clearly visible varied between 7% and 26%.

Seventy-two percent (72%) of all respondents either somewhat or strongly agreed with the statement that the meaning of the blue light is easily understood at the intersection, while 24% somewhat or strongly disagreed. The highest levels of disagreement were seen at the intersections of NE 53rd Ave and NE Glisan St in Portland (35%) and W 5th Ave and Blair Blvd in Eugene (35%). Eighty-one percent (81%) of the respondents overall stated that they felt better about

waiting at the intersection with the blue light and sign, while 10% either somewhat or strongly disagreed. The proportion of respondents who disagreed with this statement was highest at NE 53rd Ave and NE Glisan St in Portland (17%). Eighty-eight percent (88%) of the respondents felt that having information that they have been detected by the traffic signal was useful, while 7% somewhat or strongly disagreed with the statement. The high levels of agreement with this statement across all intersections reveals that respondents like having feedback from the traffic signal regarding their detection status.

TABLE 2 Responses to "Level of Agreement" of Statements Regarding BLDC

RESPONSE	BICYCLE (n=548)			VEHICLE (n=536)			TOTAL (n=1084)		
	Post Card	Social Media (Facebook)		Post Card	Social Media (Facebook)		Post Card	Social Media (Facebook)	
	OR	OR	USA	OR	OR	USA	OR	OR	USA
Q1: The addition of the sign helped with my understanding of the purpose of the blue light.									
Strongly Disagree	7.3%	8.1%	3.8%	8.2%	9.4%	9.1%	7.8%	8.9%	6.5%
Disagree	3.7%	5.4%	3.8%	7.1%	3.8%	4.3%	5.3%	4.4%	4.1%
Indifferent	4.0%	16.2%	3.4%	5.1%	7.5%	5.2%	4.5%	11.1%	4.3%
Agree	27.5%	24.3%	25.6%	25.5%	39.6%	25.1%	26.5%	33.3%	25.4%
Strongly Agree	57.5%	45.9%	62.4%	54.1%	39.6%	55.8%	55.8%	42.2%	59.1%
Did not Respond	0.0%	0.0%	0.9%	0.4%	0.0%	0.4%	0.2%	0.0%	0.6%
Q2: I would support the use of the blue light system at some intersections in my community.									
Strongly Disagree	12.1%	5.4%	6.4%	8.2%	11.3%	9.9%	10.2%	8.9%	8.2%
Disagree	5.5%	5.4%	3.4%	7.0%	3.8%	4.3%	6.2%	4.4%	3.9%
Indifferent	12.1%	5.4%	10.3%	5.1%	13.2%	17.2%	8.7%	10.0%	13.8%
Agree	27.5%	27.0%	29.6%	25.4%	30.2%	33.6%	26.5%	28.9%	31.6%
Strongly Agree	42.5%	56.8%	49.4%	53.9%	41.5%	34.1%	48.0%	47.8%	41.7%
Did not Respond	0.4%	0.0%	0.9%	0.4%	0.0%	0.9%	0.4%	0.0%	0.9%
Q3: I would feel better about waiting on a bicycle at an intersection if a blue light system was present.									
Strongly Disagree	11.4%	5.4%	6.9%	13.7%	7.5%	10.8%	12.5%	6.7%	8.8%
Disagree	4.4%	5.4%	5.2%	12.1%	7.5%	7.8%	8.1%	6.7%	6.5%
Indifferent	16.1%	13.5%	15.0%	25.8%	32.1%	24.1%	20.8%	24.4%	19.6%
Agree	27.5%	29.7%	30.0%	20.7%	28.3%	31.0%	24.2%	28.9%	30.5%
Strongly Agree	39.9%	45.9%	42.1%	27.0%	24.5%	25.4%	33.6%	33.3%	33.8%
Did not Respond	0.7%	0.0%	0.9%	0.8%	0.0%	0.9%	0.8%	0.0%	0.9%

DISCUSSION

Concerning the BLDC, the online survey revealed that most respondents (approximately 94% average of all three sources) indicated that they did not know what the blue light meant or provided a response that was not accurate. The American National Standard Criteria for Safety Symbols, as produced by American National Standards Institute, has indicated a minimum threshold of 85% comprehension for a traffic control device (ANSI Z535.1). Based on this standard, a 94% incorrect response rate falls well below acceptable comprehension rates for traffic control devices. Of the respondents who correctly answered the question, Oregonians, both from the postcard and social media sources, generally showed higher rates of correctness compared to the national sample. This could be a result of respondents in Oregon, particularly in Portland, being familiar with the BLDC systems. In general, the addition of supplemental signage increased the comprehension rates for both bicycle and vehicle scenarios. The correct response rates increased from 40 to 50% with the addition of an accompanying sign. Based on this significant increase in comprehension, supplemental signage would be both beneficial and recommended as part of the traffic control device system. Additional variations of the sign may need to be explored as the word "detection" may not be clear to the public. There was a strong preference for sign option #2 (i.e., symbol with blue dot).

For the intercept survey, overall, 84% of the respondents had observed the blue light and sign at the intersection and generally, the percent of respondents who observed the blue light was higher at the Portland locations than Eugene locations barring one exception. This was likely due to the familiarity of Portland bicyclists with the blue light devices. Additionally, within the Portland locations, the proportion of respondents who noticed the sign was higher at the embedded locations rather than at the locations where the blue light was separate from the sign. Although the sample size is small, this may indicate that the design where the blue light is embedded in the sign is more visible. In terms of educational campaigns, seventy percent (70%) of the respondents also did not read previous media articles on BLDC, although more respondents at the Portland locations read the articles compared to the respondents in the Eugene locations, and possibly due to their familiarity with one of the major articles being published on bikeportland.org.

The comprehension of the BLDC and sign was 83% and 81% when the light was ON or OFF, respectively. Sixty-six percent (66%) overall thought they could take actions to activate the blue light, while 33% were not sure. A high percentage of respondents (92%) were sure that they could activate the blue light at the intersection of NE US Grant at NE 33rd Pl, possibly because they were familiar with the operation of a BLDC as it was already present at this location prior to the installation of the embedded blue light in the sign as part of this study. The most common response from the people who said they could take actions to activate the blue light was to reposition their bicycle on/close to the bike pavement marking if present, or on/close to the loop detector.

CONCLUSION

This paper summarizes the use and comprehension of a BLDC system in the US context. An online survey and survey of intercepted bicyclists at signalized intersections with various BLDC systems installed were conducted to determine the general public's comprehension and preference of the BLDC system and three supplemental sign alternatives. The online survey was distributed based on a mixed method of postcard and social media, and overall, a more balanced sample was received

as a result. This approach reduces the bias that may come from one source that favors specific demographics.

All these results collectively reveal that users strongly prefer to have information from the signal system that they have been detected and feel better about waiting on a bicycle at the intersection equipped with blue light and sign. While comprehension rates are high with the accompanying sign, 24% of the respondents still did not understand the meaning of the blue light and sign easily. Therefore, BLDC and sign installations may help in further increasing comprehension rates.

There were a few limitations associated with these surveys. Both surveys showed an overrepresentation of older, educated white males. In addition to the demographic bias, the surveys were designed in a stated-preference format, which requires respondents to answer questions in non-real-world conditions. While stated-preference surveys serve as an economical, easy, and accessible method to collect data, they are subject to the design of the survey and the questions, which could lead respondents to understand and answer questions differently than how the surveyor intended them to be comprehended and completed. Additionally, the recruitment for social media attracted more persons who cycle. We suspect that many of the samples are familiar with the blue light through experience or education in Portland.

With regards to the intercept survey, the surveys were conducted at only a few locations in Eugene and Portland, heavily occupied with bicyclists, which could indicate that users are more likely to both adhere and respond positively to bicycle infrastructure changes.

Additional research is needed to continue to explore how this BLDC system can be implemented and tested in communities that are not currently heavily occupied by cyclists to see how individuals comprehend and react to them. Additionally, it could be beneficial to explore different colors of the indication light, the size of the letters on the supplemental signage, the location of the blue light device (e.g., nearside versus far side), and evaluating it at different roadway contexts (e.g., urban vs. rural). Nearside installations are also feasible and can be further explored.

ACKNOWLEDGMENTS

The research was sponsored by the Oregon Department of Transportation (SPR 825).

AUTHOR CONTRIBUTION STATEMENT

The authors Cobb (DC), Jashami (HJ), Monsere (CM), Kothuri (SK), Hurwitz (DH), and confirm contribution to the paper as follows: study conception and design: CM, DH, SK, DC; data collection: DC, SK, and HJ; analysis and interpretation of results: DC, CM, DH, SK and HJ; draft manuscript preparation: DC, SK, HJ, CM, and DH All authors reviewed the results and approved the final version of the manuscript.

REFERENCES

1. Boudart, J., Liu, R., Koonce, P., and L. Okimoto. (2015). “An Assessment of Bicyclist Behavior at Traffic Signals with a Detector Confirmation Device”. Transportation Research Record, Journal of the Transportation Research Board, No. 2520, Transportation Research Board of the National Academies, Washington D.C., pp.21-26.

2. Boudart, J., Foster, N., Koonce, P., Maus, J., and L. Okimoto. (2017). "Improving Bicycle Detection Pavement Marking Symbols to Increase Comprehension at Traffic Signals." ITE Journal, pp.29-34.
3. ODOT (2018). Progress Report for 4(09)-065 E Detector Confirmation Lights.
4. Watson, L. and M. Cameron. (2009). "Bicycle and Motor Vehicle Crash Characteristics." Final Report. Accident Research Center, Monash University.
5. O'Brien, S., Tay, R., and B. Watson. (2002). "An Exploration of Australian Driving Anger." Road Safety Research, Policing and Education Conference, Adelaide, South Australia.
6. J. Kidder. (2005). "Style and Action: A Decoding of Bike Messenger Symbols." Journal of Contemporary Ethnography, 34(2), pp. 344-367.
7. B. Fincham. (2006). "Bicycle Messengers and the Road to Freedom." The Editorial Board of the Sociological Review, pp. 209-222.
8. Richardson, M., and B. Caulfield. (2015). "Investigating Traffic Light Violations by Cyclists at Dublin City Centre." Accident Analysis and Prevention, Vol. 840, pp. 65-73.
9. Kothuri, S., Monsere, C., Jashami, H., & Hurwitz, D. S. (2020). Online survey of driver comprehension of the flashing yellow arrow for right-turn signal indications. Journal of transportation engineering, Part A: Systems, 146(7), 04020058.
10. Hurwitz, D., Monsere, C., Kothuri, S., Jashami, H., Buker, K., & Kading, A. (2018). Improved safety and efficiency of protected/permitted right-turns in Oregon (No. FHWA-OR-RD-18-14). Oregon. Dept. of Transportation. Research Section.
11. Currans, K., Gehrke, S., and K. Clifton (2015). Visualizing Neighborhoods in Transportation Surveys: Testing Respondent Perceptions of Housing, Accessibility, and Transportation Characteristics. Proceedings of the 94th, Annual Meeting of the Transportation Research Board, Transportation Research Board of the National Academies, Washington DC.
12. Monsere, C., Kothuri, S., Hurwitz, D., Cobb, D., & Jashami, H. (2021). Assessment of Bicycle Detection Confirmation and Countdown Devices (No. FHWA-OR-RD-21-18). Oregon. Dept. of Transportation. Research Section.
13. Cobb, D., Monsere, C., Hurwitz, D. S., Kothuri, S. & Jashami, H., (2022). User Comprehension of Bicycle Signal Countdown Timers. Transportation research record.