Does the Bicycle Detector Symbol Change Cyclist Queuing Position at Signalized Intersections?

Stefan W. Bussey
Kittelson & Associates, Inc., stbussey@yahoo.com

Christopher M. Monsere
Portland State University, monsere@pdx.edu

Peter Koonce
Bureau of Transportation, City of Portland

Does the Bicycle Detector Symbol Change Cyclist Queuing Position at Signalized Intersections?

Paper # 15-2501

Stefan Bussey (corresponding author)
Kittelson & Associates, Inc.
610 SW Alder Street, Suite 700
Portland, OR 97205
503-535-7431 (phone) 503-273-8169 (fax)
sbussey@kittelson.com

Christopher M. Monsere
Department of Civil & Environmental Engineering
Portland State University
PO Box 751
Portland, OR 97201
503-725-9746 (phone) 503-725-5950 (fax)
monsere@pdx.edu

Peter Koonce
Bureau of Transportation
City of Portland
1120 SW 5th Avenue, Room 800
Portland, OR 97204
503-823-5382 (phone)
peter.koonce@portlandoregon.gov

Submitted for presentation and publication to the
94th Annual Meeting of the Transportation Research Board January 11-15, 2015

Submitted July 31, 2014

4,176 words + 4 figures x 250 + 5 tables x 250 = 6,426 words

ABSTRACT

The Manual of Traffic Control Devices (MUTCD) includes a bicycle detector pavement marking (Section 9C-05) and accompanying explanatory sign (R10-22) which may encourage cyclists to position themselves over detection at traffic signals. This paper presents the results of an observational and survey-based study evaluating the bicycle detector marking. Three minor actuated approaches at signalized intersections with significant bicycle volumes and without bicycle detector markings were selected for treatment. Three configurations were compared: 1) bicycle detector marking only 2) bicycle detector marking with the R10-22 explanatory sign, and 3) an alternative bicycle detector installed over a contrasting green rectangle. Analysis of 688 observations, gleaned from over 300 hours of before and after video data, indicate that while all three marking options influence cyclist stopping position, the effect of the marking is not substantial. For the marking only, 23.5% of cyclists waited over the space where the marking was installed. This improves to 34.8% with the addition of the explanatory sign and 48.4% when the marking is applied over the green rectangle. Analysis of survey responses of 227 cyclists indicates that only 45.4% of cyclists understand the roadway marking is meant to show where they should wait to be detected. An additional 11.5% understand that the marking indicates the recommended waiting location, but do not know that it is for the purpose of detection. Finally, survey respondents expressed concern about waiting in the travel lane and preference to wait closer to the curb (a position which usually prevents them from being detected).

INTRODUCTION

As municipalities seek to expand their cycling networks, many will consider the development of low stress routes for cyclists (also known as bicycle boulevards). These routes consist of connecting a grid of lower speed, low volume collector streets that provide a more comfortable and safe environment for riding a bike (*1*). At the signalized intersections, where these routes cross busier arterials, actuated signal timing with vehicle detection is often installed to place calls to the signal controller for the minor approach. Providing accurate detection and prompt service is a key feature for these intersections to function in a bicycle network. The most common form of detection—inductive loop detectors (often referred to as loops)—requires the bicyclist to stop over the loop to be detected. To encourage cyclists' stopping in locations where they will be detected, the Manual on Traffic Control Devices (MUTCD) suggests a road marking (see Figure 1a) that may be placed over the area of the loop where cyclists will be consistently detected. An optional explanatory sign may be installed at intersections with the road marking (see Figure 1b).

a) Section 9C-05 Bicycle Detector Symbol   b) R10-22 Sign

FIGURE 1: MUTCD Bicycle Detector Marking and Explanatory Sign

This study evaluates cyclists' understanding and use of the bicycle detector symbol and R10-22 sign as described in the MUTCD. Three installations were tested: 1) the MUTCD bicycle detector symbol installed alone, 2) the MUTCD bicycle detector symbol installed with an accompanying R10-22 sign, and 3) the MUTCD bicycle detector symbol installed over a one foot by two foot green rectangle. The evaluation of each installation includes approximately 100 hours of before and after video data with a minimum of 102 observations of cyclists' stopping positions at each location. A total of 688 before and after observations of stopping position were logged across all three test installations. Video data are supplemented with a survey completed by 227 people who identify as cyclists. Survey questions include comprehension of the bicycle detection symbol, self-reported stopping position at signalized intersections, reasons for choosing the reported stopping position and demographic information.

There is minimal published research on this topic. This study provides quantified insight on the effectiveness of the marking. While this study is limited to one field test per installation, it includes a large number of observations and incorporates both objective video data and self-reported survey data from cyclists. The combination of quantitative and qualitative data provides a more complete understanding of cyclist comprehension and use of the bicycle detector symbol by providing context to why cyclists choose to wait at specific locations at signalized intersections. The remainder of this paper begins with a presentation of prior research, followed by a description of the study sites, discussions on the data collection methodologies utilized, results and a concluding summary. Both the methodologies and results sections are broken into two subcategories; one for video data and another for survey data.

BACKGROUND

Inductive loop detectors take a variety of shapes and sizes but are most commonly square, rectangular, or circular in shape. Circular loops are formed with six foot diameters, square loops with six foot long sides, and rectangular loops are usually six feet wide and vary in length depending on the needed detection zone (*2*). Loops are typically centered in the motorized vehicle travel lane and the detection zone roughly spans the area enclosed by the loop (*3*). Large vehicles such as cars and trucks are usually detected by loops; however, cyclists are more difficult to detect (*2*). This is due to the higher level of sensitivity needed to detect the smaller mass of ferrous material in bicycles and that bike riders positioned in the middle of the loop may not be sensed (*2*). Also, the installation of loops in the center of the vehicle lane often does not coincide with the preferred path of travel taken by cyclists (*2*). While other forms of detection such as infrared, video, and radar are available, they have only recently been used to attempt to detect cyclists.

The bicycle detector symbol and R10-22 sign are believed to have been developed by the California Department of Transportation (Caltrans) in the late 1990s (Richard Moeur, unpublished data, personal communication, May 30, 2013). They were first recommended for use by the American Association of State Highway Officials' (AASTHO) 1999 guide for roadway design and adopted into the 2003 edition of the MUTCD. Adoption of both the road marking and sign into the MUTCD was based on recommendations by the National Committee on Uniform Traffic Control Devices (NCUTCD) and the Federal Highway Administration did not require a formal experiment for adoption (Kevin Dunn, unpublished data, personal communication, May 31, 2013). While a human-factors experiment was conducted to determine which sign design was most effective, no research was found on the effectiveness of the roadway marking prior to 2013 (Ron Van Houten, unpublished data, personal communication, May 31, 2013). A September 2013 report written by the Department of Psychology at Florida State University for the Florida Department of Transportation evaluated comprehension of 17 bicycle related signs and roadway markings, including the bicycle detector symbol (*4*). Participants were recruited from the Tallahassee, FL area, 17 of which were identified as cyclists (*4*). The study identified a cyclist as someone who rode a bicycle five or more miles a week. Of the 68 participants in the study, none correctly identified the meaning of the bike detector roadway symbol (*4*). Study authors acknowledge that this may in part be due to its infrequent use in the Tallahassee area and the lack of context given during the sign knowledge test (*4*).

Precedence exists for the evaluation of roadway signs and markings through before and after studies and surveys of roadway users (*5*). A 2008 pooled fund study evaluating driver comprehension of experimental sign symbols included an intercept survey of drivers at a local shopping mall (*5*). While the pooled funds study focused on determining sign recognition distance and road user comprehension, this study tests cyclist comprehension and the effect the bicycle detector symbol has on cyclists' queuing position.

STUDY SITES

Three study sites in Portland, OR were chosen from a preliminary inventory of approaches at 27 signalized intersections. To be considered for treatment, an approach needed to operate with actuated-based signal timing, use inductive loops for vehicle detection, be absent of any road markings or signage to indicate where cyclists should wait over the loop in order to receive a green indication and be a popular bike route. In order to reduce the potential influence of variations in intersection design on the cyclist stopping position, the three approaches with the most similar lane configuration, loop type, and distance from the curb to the edge of the loop were selected for use in the before-after study. Table 1 displays the characteristics of each study site and modification made after initial observations were recorded. All three approaches have a single vehicle travel lane with permissive left turns and utilize six-foot diameter inductive loop detectors. The approaches selected for the intersections of NE Dekum St. at NE MLK Blvd. (Site 1) and NE U.S. Grant Pl. at NE 33rd Ave (Site 2) both permit curbside parking, are 20-feet wide from the curb to centerline and have a distance of 10-feet between the curb and the edge of the loop detector. Curbside parking is prohibited along the approach selected for the intersection of NE Ainsworth St. at NE MLK Blvd. (Site 3), is 14-feet wide from the curb to centerline, and there are 4-feet between the curb and edge of the loop detector.

TABLE 1: Characteristics of Study Sites

Variable	NE Dekum St. at NE MLK Blvd. - WB Approach (Site 1)	NE Ainsworth at NE MLK Blvd. - EB Approach (Site 2)	NE U.S. Grant Place at NE 33rd Ave - WB Approach (Site 3)
Distance from Curb to Centerline	20'	14'	20'
Number of Travel Lanes	1	1	1
Movements Allowed	Thru, Left, Right	Thru, Left, Right	Thru, Left Right
Loop Type	6' Diameter Circle	6' Diameter Circle	6' Diameter Circle
Distance from Curb to Edge of Loop (ft)	10'	4'	10'
Modification Made After Initial Observation Period	Loop Stencil Added	Loop Stencil and R10-22 Sign Added	Loop Stencil over Green Background Added

METHODOLOGY

Data were collected through two methods; recorded video of cyclists' behavior at intersections before and after installation of the markings and a survey of road users administered both in person and online.

Video Data Collection

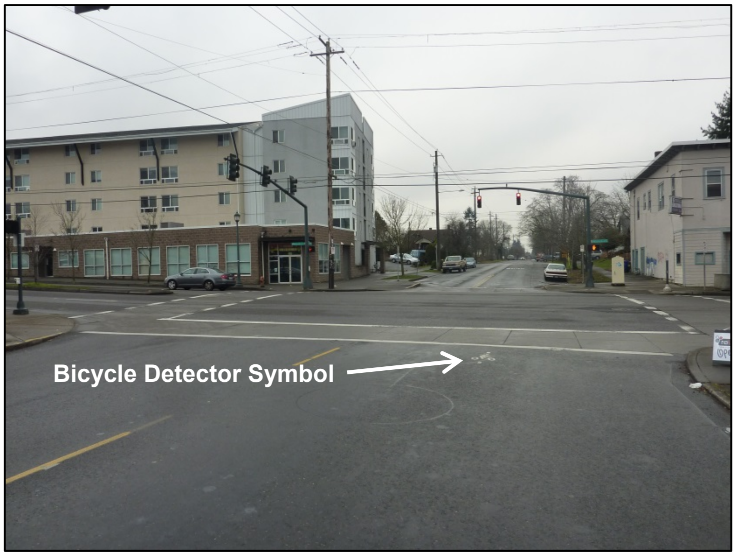
Portable video equipment was installed at each intersection to collect data on cyclists using each location. Initial observations were made of each study site without roadway markings or signage present to indicate where a cyclist should wait over a loop detector in order to receive a green. Once initial video data were recorded, modifications to each study site were made to help cyclists position themselves over the loop detector in order to receive a green indication. Each study site had a different modification made as described previously. Photographs of each intersection after modification are included in Figure 2.

Video observations were made over three consecutive days beginning before 7:00 AM on Sunday mornings and ending on Tuesday evenings. Equipment was programmed to record from 5:00 AM to 11:00 PM but recording on Tuesdays terminated prior to 11:00 PM due to limitations in battery capacity. Each observation period resulted in between 46 and 51 hours of video. Before data were recorded in April and May with average temperatures between 50 and 60 degrees Fahrenheit and small amounts of precipitation measured. After data were recorded in June and July with average temperatures between 60 and 70 degrees Fahrenheit and no recorded precipitation. Days of the week and recording times were chosen to capture the broadest sample of cyclists. This may include recreational riders likely to ride on weekends in addition to bike commuters who may be more likely to ride on week days. A total of 302 hours of before and after video were recorded across the three study sites, resulting in 688 observations of cyclist queuing position during a red signal indication.

Each approach recorded was divided into zones to categorize the stopping position of cyclists during video reduction. The dimensions of these stopping zones were measured and established with temporary markings (tape) placed on the roadway. The video recording was started and once the initial frames of the video included the markings, the tape was removed. Before beginning video data reduction, these zones were reestablished by using a dry erase marker to trace the taped regions onto a transparency placed over the monitor screen (see Figure 3b). This ensured consistent classification of stopping position throughout video reduction. The stopping zone was determined by where the wheels of the stopped bike met the pavement. An example of this process is shown for Site 1 in Figure 3b.

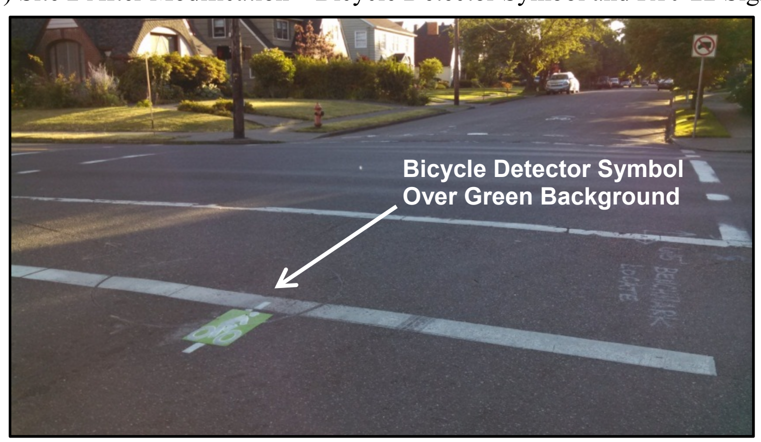
Sites 1 and 3 used the same zone configuration while zones for the study approach at Site 2 were different due to the smaller approach width. An example of the zones for Site 1 is illustrated in Figure 3a which depicts a plan view of the zones for the intersection.

The location, date, time, stopping zone, if the cyclist appeared to use the pedestrian push button, if the cyclist violated the red signal indication, the arrival of a motorized vehicle after the cyclist, group size, cyclist's travel direction and any unusual circumstances such as the presence of a dog with the cyclist were recorded.



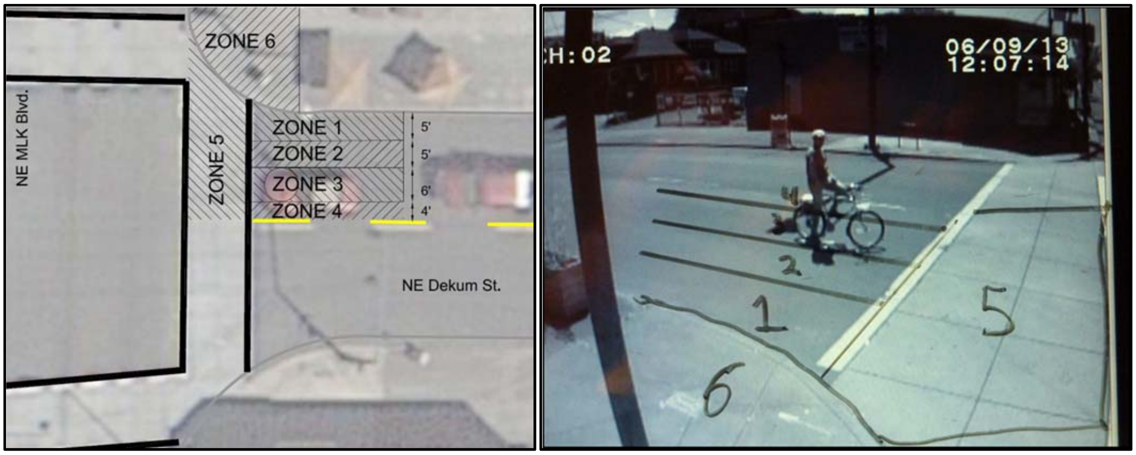
a.) Site 1 After Modification – Bicycle Detector Symbol

b) Site 2 After Modification – Bicycle Detector Symbol and R10-22 Sign



c) Site 3 After Modification Bicycle Detector Symbol with Green Background

FIGURE 2: Photographs of Intersections after Installation of Tested Marking



a) Plan View of Stopping Zones for Site 1 b) Example of Video Analysis

FIGURE 3: Illustration of Stopping Zones for Site 1.

Survey Data Collection

The objectives of the survey instrument were to assess road users' comprehension of existing signing and marking methods used to indicate where cyclist should wait over a detector, and to determine how and why cyclists choose where to wait for a green indication at a signalized intersection. The survey instrument was administered both as an in-person intercept survey and a self-administered online survey. Both of the survey instrument and protocol were reviewed and approved by Portland State University's Institutional Review Board. A total of 227 surveys were completed consisting of 81 in-person and 146 online responses. In-person surveys had a response rate of 94.2% (81 responses for 86 requests) while the online administered survey had a response rate of 16.1% (146 responses for 911 postcards).

The in-person survey administrators approached potential participants and asked if they were willing to participate in the study. Requirements for participation included being over the age of eighteen and riding a bike at least once a year. Participants that did not meet these requirements were not administered the survey. The survey administrator read questions to each participant and recorded responses using a survey data collection application on a mobile electronic device. Answers to questions were both categorical and open-ended. All categorical answers were read to each participant and the participant identified which category best describes his or her self. Survey administrators recorded responses to open-ended questions using the device's alpha numeric keypad.

Categorical questions included how often participants rode a bike, number of working bikes they owned, age range and gender. Five open-ended questions were asked. In the first, the participant was shown a laminated picture of the approach to a signalized intersection with a red signal indication displayed. The participant was then asked to use a dry erase marker to mark an X on the picture where they would stop as a cyclist to wait for a green indication. Three versions of this question were created but each survey participant was asked only one randomly chosen variation of this question. In each version the same picture of an intersection was shown but the road marking and signage was different. In the first variation, the only marking present was the bicycle detector symbol. In the second, the bicycle detector symbol was accompanied by a R10-22 sign mounted on the side of the roadway. The third variation was a modified bicycle detector symbol over a green background (see Figure 4).

a) Variation 1: Bicycle Detector Symbol

b) Variation 2: Bicycle Detector Symbol and R10-22 Sign

c) Variation 3: Bicycle Detector Symbol Over Green Background

FIGURE 4: Photographs Used in Survey of Stopping Position

The participant was then asked the reason for choosing to wait at the location. Comprehension of the bicycle detector symbol was tested by showing participants a picture of the bicycle detector symbol installed over a visible inductive loop detector and asking its meaning.

The online version of the survey was self-administered using an online survey platform. While the questions remained the same as the in-person survey, all questions were displayed on an electronic device. In the case where participants were asked to indicate their stopping position at an intersection, they were required to use a mouse and click where they would stop on the picture displayed. The variation of this question asked was chosen randomly by the survey software. Online participants were recruited by taping postcards with a link to the survey onto bikes parked on public property. Postcards were also distributed by handing the flyer to cyclists at large bike-related events that attracted a wide range of rider types. A summary of where both in-person and online recruitment occurred is given in Table 2.

TABLE 2: Survey Recruitment Locations

Event/Location	Survey Type
Portland Sunday Parkways, Northeast Portland	In-person
Portland Farmers' Market, Downtown	In-person
Portland Sunday Parkways, North Portland	Online
Portland Providence Bridge Pedal	Online
Portland Sunday Parkways, Southeast Portland	Online
Portland State University Campus Bike Parking	Online
Portland Timbers Soccer Games at Jeld-Wen Field	Online

RESULTS

Video

A total of 302 hours of before and after video were recorded resulting in 955 logged observations. After filtering, 688 observations remained for analysis. The 267 observations that were omitted in the analysis include instances when cars immediately followed a cyclist, groups of cyclists riding together, cyclists who violated the red indication, and unusual circumstances that may have influenced rider behavior such as the presence of a dog running next to the cyclists or the rider talking on a mobile phone.

Analysis indicates that the stencil with the green background is most effective at influencing cyclists to wait over the proper location of the loop in order to place a call to the signal controller. While only 23.5% of riders waited over the stencil as designed in the MUTCD, 48.4% waited over the stencil when a green background was added. Addition of an R10-22 sign also appears to improve the number of cyclists who wait over the stencil area. Observations at Site 2 showed an increase from 6.5% of riders waiting over the stencil area before to 34.8% after the installation of the stencil and R10-22 sign. In all cases, over half of cyclists did not wait over the installed roadway marking. A chi-square test of proportions determined that in all three cases, the change in stopping behavior could be attributed to the applied marking technique at the 95% significance level. Expected observations were calculated based on data collected before the marking was applied. Table 3 summarizes before and after observations and displays the chi-squared and p-values for the data.

TABLE 3: Cyclist Queuing Position Before and After Installation of Marking

Marking Variation and Test Site	Stopping Zone	Observations		Percent of Observations		Chi-Square Value (p-value)
		Before	After	Before	After	
Stencil Only Site 1	0'-10' from Curb	24	24	47.1%	47.1%	
	Over Loop (Not Stencil)	8	7	15.7%	13.7%	
	Over Stencil Area	6	12	11.8%	23.5%	
	Elsewhere	13	8	25.5%	15.7%	
	Total	51	51			8.1 (0.045)
Stencil with R10-22 Sign Site 2	0'-4' from Curb	68	51	73.9%	45.5%	
	Over Loop (Not Stencil)	9	11	9.8%	9.8%	
	Over Stencil Area	6	39	6.5%	34.8%	
	Elsewhere	9	11	9.8%	9.8%	
	Total	92	112			149.7 (0.000)
"Green Backed" Stencil Site 3	0'-10' from Curb	65	65	41.4%	28.9%	
	Over Loop (Not Stencil)	37	22	23.6%	9.8%	
	Over Stencil Area	36	109	22.9%	48.4%	
	Elsewhere	19	29	12.1%	12.9%	
	Total	157	225			90.7 (0.000)

Survey

A summary of the demographics is given in Table 4. Out of 227 survey participants, 60% of participants identified as male, 38% as female, and 2% preferred not to answer the question. The age of participants ranged from 18 to over 74 with the majority of people surveyed falling between the ages of 26 and 65. Forty-one percent rode a bicycle five or more days a week.

Across all three survey instruments, 57% of participants indicated they would wait over the bicycle detector symbol for a green signal indication, 22% would wait zero to five feet from the curb, 15% would wait between five and 10-feet from the curb and the remaining 4% would wait somewhere over the loop detector but not over the roadway marking. A chi-square test of proportions resulted in a chi-square value of 4.65 and a p-value of 0.794 (for 8 degrees of freedom) and indicates that there is not a significant difference in self-reported stopping positions across the three instruments of the survey.

TABLE 4: Survey Participant Demographics

Category	Response Option	Number of Responses (n)	Percent of Total[1]
Gender	Male	135	59%
	Female	86	38%
	Prefer not to answer	4	2%
	Blank	2	1%
	Total	227	
Age	18-25	37	16%
	26-39	80	35%
	40-65	98	43%
	66-74	5	2%
	74 +	2	1%
	Blank	5	2%
	Total	227	
Cycling Frequency	Less than 1 day a month	10	4%
	1-3 days a month	27	12%
	1-2 days a week	42	19%
	3-4 days a week	54	24%
	5 or more days a week	94	41%
	Total	227	

Note 1: Percentages are rounded to the nearest integer.

The self-reported reasons for choosing stopping positions were categorized into similar groups manually. They varied across each stopping zone. Those choosing to stop zero to five feet from the curb indicated that they did so primarily for safety/visibility or to stay out of the way of traffic. Of those who indicated they would wait five to 10-feet from the curb, 59% said they did so to stay out of the way of traffic. Within the group of participants who chose to wait over the bike detector symbol, 51% reportedly did so to trigger the signal, 31% reported they did so due to the marking but did not indicate they did so in order to be detected. Full results are displayed in Table 6.

Finally, when shown a picture of the bike detector roadway marking installed over a visible loop, 45.4% correctly identified that it was used to indicate the location a cyclist should wait in order to be detected. Of the remaining responses, 33.9% thought it indicated a bike lane, 11.5% the recommended location to wait while a red indication was shown, 6.5% did not know what it meant, 1.8% that bikes were allowed and 0.9% gave other answers.

TABLE 5: Stopping Position and Reason

Stopping Zone	Response Given	Number of Responses (n)	Percent of Total[1]
0’-5’ From Curb	To be able to step on the curb	2	4%
	Stay out of the way of traffic	27	56%
	Safety and/or visibility	19	40%
	Total	48	
5’-10’ From Curb	Stay out of the way of traffic	17	59%
	Safety and/or visibility	3	10%
	Marked spot	5	17%
	To trigger the signal	2	7%
	Out of the crosswalk	1	3%
	In-line with intended direction of travel	1	3%
	Total	29	
10’-16’ from Curb (Over the loop)	Stay out of the way of traffic	2	22%
	Safety and/or visibility	1	11%
	Marked Spot	1	11%
	To trigger the signal	1	11%
	Out of the crosswalk	2	22%
	In-line with intended direction of travel	2	22%
	Total	9	
Over the stencil	Stay out of the way of traffic	11	9%
	Safety and/or visibility	7	6%
	Marked Spot	39	31%
	To trigger the signal	64	51%
	Out of the crosswalk	3	2%
	In-line with intended direction of travel	1	1%
	Total	125	

Note 1: Percentages are rounded to the nearest integer.

CONCLUSION

As communities look to encourage cycling, improving traffic operations for these users takes on greater importance. Failure to receive a green indication due to improper positioning over loops can add to travel time and may discourage cycling (*6*). Recent legislation in California, requiring that the road network provide equal service to motorized and non-motorized vehicles, means accurately detecting cyclists is even more important. In answer to this paper’s title — Does the Bicycle Detector Symbol Change Cyclist Queuing Position at Signalized Intersections?—the answer is: Yes. However, the effect of the roadway marking itself is not large at the locations studied. In the absence of any markings, about 16% of cyclists positioned themselves over the area of the loop most likely to detect them (either by chance or by experience). When the detector marking was installed, this improved to 23.5% of riders waiting over this same space. When the curbside mounted R10-22 sign was added to the pavement marking, this improved to 34.8%. Finally, when the bicycle detector symbol was installed over a green contrasting background, this increased to 48.4%. Even though some of the shifts were small, the change in stopping position from when no marking was provided was statistically significant.

The results of the survey provide some insight on why the marking and sign were not overly effective. Over half of cyclists do not understand the meaning of the bicycle detector roadway marking. Further, many persons expressed a desire to not stop in the motor vehicle travel lane. Reasons given for not stopping over the stencil area were dominated by concerns for safety and a desire to stay out of the way of motorized vehicle traffic.

As with any study in a single jurisdiction, there may be limitations transferring the results to other locations. This study may present a best case for cyclist comprehension and use of the tested roadway markings. Portland has the one of the largest commute shares of bicycling of a large city and many survey and observed persons are regular bike riders compared to other American cities. The vast majority of survey respondents self-reported riding a bicycle more than once a week. Portland also has widespread use of the bicycle detector symbol within the city. For the specific treatments, the stencil with the added R10-22 sign did produce significant results but the location of the sign is likely an important factor. At the studied intersection location the installation was ideal—it was within three feet of the curb, had no obstructions, and few other signs were installed at the intersection. The green highlighting showed the largest shift but that may be related to the City of Portland's use of green to highlight areas of the roadway intended for cyclists. If the use of green marking is limited in a jurisdiction, results may not be the same. Finally, though a large number of observations were made, the numbers in some categories were small. Further research could include additional test locations and seek increased responses from infrequent bike riders.

The results of this study have some lessons for practice. First, the results of the study suggest that simply using the bicycle detector marking will not encourage the majority of people on bicycles to properly position themselves for detection. The addition of the R10-22 sign may help in some locations where a feasible mounting location is available. Though the installation cost of the marking and sign is low, there is a maintenance cost to weigh against the effectiveness. Accompanying the detector marking with green should be further explored (this may require an MUTCD experiment). The results suggest that if loops are to be used, installing bike specific loops or curbside push buttons for bikers could also be considered. Portland is exploring options for positive feedback on detection (blue indicator light) that might also improve appropriate bicycle queuing location. The use of detection that does not require such precise stopping locations such as radar, video or thermal detection is another option.

ACKNOWLEDGEMENTS

The authors of this study would like to thank the following people for their support and guidance. Rob Burchfield, Rodger Geller and Mark Haines from the City of Portland's Bureau of Transportation; Kevin Dunn from the Federal Highway Administration; Ron Van Houten from Western Michigan University; and Richard Moeur of the Arizona Department of Transportation, who is Chair of the NCUTCD Bicycle Technical Committee.

REFERENCES

1. Mekuria, M. C., P. G. Furth and H. Nixon. *Low-Stress Bicycling and Network Connectivity*. Report No. CA-MTI-12-1005. California Department of Transportation and U.S. Department of Transportation, 2012.
2. Maki, P.J. and P.S. Marshall. Accommodating Bicycles at Signalized Intersections with Loop Detectors: A Case Study and Example. Presented at Institute of Transportation Engineers 67th Annual Meeting, Boston, MA, 1997
3. California Manual on Uniform Traffic Control Devices, 2012 Edition. State of California Business, Transportation and Housing Agency Department of Transportation. http://www.dot.ca.gov/hq/traffops/signtech/mutcdsupp/ca_mutcd2012.htm. Accessed July 7, 2013.
4. Boot, W., N. Charness, C. Stothart, M. Fox, A. Mitchum, H. Lupton and R. Landbeck. Final Report: Aging Road User, Bicyclist, and Pedestrian Safety: Effective Bicycle Signs and Preventing Left-Turn Crashes BDK83 977-15. Prepared for the Florida Department of Transportation, September 2012
5. Katz, B.J., H.G. Hawkins, J.F. Kennedy and H.R. Howard. Traffic Control Devices Pooled Fund Study, Design and Evaluation of Selected Symbol Signs Final Report. May 2008.
6. Akar, G. and K.J. Clifton. Influence of Individual Perceptions and Bicycle Infrastructure on Decision to Bike. In *Transportation Research Record: Journal of the Transportation Research Board, No.*

2140, Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 165-172