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Simulator Study of Driver Responses to Pedestrian Treatments at Multilane Roundabouts

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Abstract

Previous studies have shown that roundabouts – especially multilane roundabouts - pose accessibility challenges to pedestrians with vision impairments, in part due to a lack of yielding by drivers, especially on multilane roundabout exit legs. In this study, three different treatments are assessed in terms of their propensity for increasing driver yielding rate using a driving simulator. These are stop bar and crosswalk relocation away from the beginning of exit leg, and two types of beacons, namely a Pedestrian Hybrid Beacon (PHB) and a Rectangular Rapid Flashing Beacon (RRFB). The study shows that installation of any kind of beacon (PHB or RRFB) with or without crosswalk relocation increases driver yielding rates significantly. Relocating the crosswalk does not provide a significant increase in driver yielding rate for the base case, but appeared to further enhance the effectiveness of the PHB and RRFB treatments. The results of using an eye tracker on drivers to track their gaze pattern while exiting the roundabout shows that having a beacon installed with crosswalk relocation increases drivers' attention both on the beacon and the pedestrian along the road. However, a portion of participants failed to see and react to the pedestrian treatments, causing concern about the visibility of these treatments at the roundabout exit leg.

INTRODUCTION

Several studies (1-4) have shown that roundabouts pose accessibility challenges for pedestrians who are blind or visually impaired. Although geometric elements of a roundabout are designed to promote speed reduction within the circle (5), drivers have higher speeds when they are exiting the roundabouts, compared to when entering (4, 6). As a consequence, studies have shown that driver yielding rates to pedestrians standing at the exit leg of roundabouts are lower compared to the entry (7). The purpose of this work is to test the effect of different treatments aimed at increasing driver yielding rates to pedestrians at

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the exit leg of roundabouts. The focus on the exit leg of two-lane roundabout is justified in an effort to focus study resources on the crosswalk location that is documented to pose the greatest accessibility challenges (4, 6).

The paper is organized as follows. We first present the background and literature on pedestrian accessibility to modern roundabouts, findings on drivers' yielding process to the pedestrians, and the effects of potential treatments on increasing driver yielding rate. The next section presents the objective of the research. The methodology section describes the process for designing the driver simulation experiment, sample size calculations, subject population attributes and challenges. Next, findings and results of driving simulator and eye tracker data are discussed. We conclude by providing conclusions and recommendations for future work.

BACKGROUND AND LITERATURE REVIEW

Title II of Americans with Disabilities Act (ADA) requires that "... new and altered facilities constructed by, on behalf of, or for the use of state and local government entities be designed to be readily accessible to and usable by people with disabilities (28 CFR 35.151)" (1). Various studies have shown that roundabouts (multi-lane) are not readily accessible to visually impaired and blind pedestrians (2, 3). While design speeds vary based on the geometric design, roundabouts are intended to promote speed reduction in the circulating lanes. However, when exiting a roundabout, drivers are accelerating, thus reducing their propensity to yield at the exit legs relative to entry (8). Geruschat and Hassan (6), among others, found drivers are more likely to yield to pedestrians at the entry than exit. The results from NCHRP report 674 also indicate the probability of a pedestrian encountering a yield is higher on the entry lane than on the exit lane, for one roundabout the yielding rate for entry verses exit is 90% to 58% respectively.(4).

Although roundabouts are proven to be operationally safe and efficient for motorists when operating below capacity (8), they do impose accessibility challenges for pedestrians with visual impairments. The TRB Roundabout Informational Guide (8) suggests roundabout signalization may be beneficial under three conditions, high vehicular volume, high pedestrian volume, and accessibility at more complex crossing situations. This FHWA recommendation is related to a recently released Notice of Proposed Rule-Making by the US Access Board that call for the use of accessible pedestrian signals at newly constructed roundabouts with multilane approaches (9). To avoid the cost and uncertain effectiveness of full signalization schemes, non-signalization treatments have been put forward to improve accessibility at complex roundabouts (4).

The Manual on Uniform Traffic Control Devices (MUTCD) has authorized the use of a new pedestrian crossing treatment, the Pedestrian Hybrid Beacon (PHB, also known as a HAWK) as a device intended to "warn and control traffic at signalized locations" and help pedestrians cross the street by having a red signal indication (10). Fitzpatrick et. al. (7,11,12) conducted research on the safety effects of PHB signals installed at uncontrolled pedestrian crossings and showed 86% decrease in pedestrian crashes. A separate study of PHB's indicated that the number of pedestrian crashes had decreased compared to reference sites with no PHB (13). They also reported high rates of driver compliance with PHBs, which resulted in higher driver yielding rate to pedestrians at the crossing location. NCHRP 674 tested a system of PHBs at a two lane roundabout in Golden, Colorado to increase accessibility for blind and visually impaired pedestrians (4). The report concluded that the average (blind) pedestrian delay while trying to cross the street dropped from 16.0 seconds to 5.9 seconds, and more importantly, reduced the occurrence of potential vehicle-pedestrian collisions from 2.8% to 0.0%. As with other previous studies, NCHRP 674 indicated that

driver compliance rate is not 100% with the installation of PHB at a two-lane roundabout and reports a 12.6% red light running rate (4). Regardless of the findings on PHB's, they are supported as an alternative to signalization by the US Access Board (9).

Another type of beacon sanctioned in the MUTCD is the Rectangular Rapid Flashing Beacon (RRFB). Shurbutt et. al. studied the effect of RRFB on yielding rate and found that installation of side-mounted RRFB's at multilane uncontrolled crosswalk locations increased driver yielding rate, on average from 18.2 to 87.8 *percent* (14, 15). Hunter et. al. evaluated the effect of a RRFB at a trail crossing in Florida and reported driver yielding to cyclists and pedestrians increased significantly compared to the no beacon condition. However the report mentions that "...the device is not fail safe, and communities employing the device, especially at trail crossings, should take note of this..." and suggests additional effort on educating the drivers and residents about the RRFB device (14). The RRFB system is being considered as a potential treatment for improving accessibility in upcoming research by FHWA, but at the present time, is not mentioned explicitly as an alternative to pedestrian signals by the US Access Board (9).

OBJECTIVE

This research aims at exploring driver yielding behavior to pedestrians at the exit-leg of roundabouts. Three different treatments are assessed in terms of their propensity for increasing driver yielding rate at the exit leg of roundabouts. These are stop bar and crosswalk relocation away from the roundabout, and two types of beacons: a Pedestrian Hybrid Beacon (PHB) and a Rectangular Rapid Flashing Beacon (RRFB). In particular, the research will address the following hypotheses:

- If the presence of either beacon improves driver yielding rates over a regular crosswalk base scenario;
- Which type of beacon produces a higher driver yielding rate;
- If the location of the crosswalk relative to the circulating lane affects driver yielding rate;
- If yielding behavior (or lack therefore) is related to drivers consciously ignoring the pedestrian at the crosswalk, or to a lack of awareness.

The last objective aims to distinguish between drivers that saw the pedestrian and/or the treatment, but decided (consciously) not to yield, and those that didn't notice the pedestrian and/or the treatment. It is important to note that relocating the crosswalk farther away from the roundabout has some disadvantages including adding walking distance for the pedestrians and potentials for higher speeds for the vehicles when exiting.

METHODOLOGY

The research team used a driving simulator equipped with an eye tracker device for this study. Using a driving simulator is cost effective compared to field studies. It also allowed the research team to conduct a controlled experiment in terms of the location of crosswalk, pedestrians, traffic volume, and type of treatment. The driving simulator software also simplifies the data collection process for the experiment in the sense that all participants are exposed to exactly the same stimulus conditions (although in a randomized order). It also enabled the team to collect different types of data related to driver behavior and driver attentiveness through the use of an eye tracker system. The eye tracker provided valuable information about drivers' eye movement and gaze pattern in the process of yielding (or not yielding) to the pedestrian while exiting the roundabout. The following sections discuss the

equipment used to conduct the study, the experimental design, and the measures used to test the effectiveness of the simulated treatments.

The Driving Simulator

A STISIM Drive™ M400 driving simulator (System Technology Inc.) located in the Ergonomics Lab of Industrial Engineering department was used for the study. The driving simulator is interactive and has a modular steering unit with full-sized steering wheel, semi-adjustable car seat, turn indicator, speedometer, modular accelerator and brake pedal unit, adjustable speed-sensitive steering force-feel system, horn and audio system. Three 37 inch HDTV monitors provide a 135 degree field of view for the driving environment. Drivers can see the rear view and side mirrors through the animation provided on the screens, as well as a button to do shoulder check for blind spots. STISIM Drive™ software allows the logging of various types of data for each trial such as speed of the drivers at any time and point, acceleration, deceleration, lane changing, etc. (16).

The Eye Tracker

An eye-tracker is mounted on the participants' head to track their pupil movement on the screen (17). An H6 Head Mounted Optics Eye Tracking System can accurately track the pupil diameter and eye position relative to the person's head. The eye tracker provided valuable information about the drivers' gaze pattern during driving as they enter and exit the roundabouts. Figure 1 shows a screen shot of the driving simulator and eye tracker while approaching the PHB.

Experimental Design

The research team designed an experiment with the driving simulator to test a side-mounted RRFB and overhead-mounted PHB compared to a standard crosswalk base scenario at the exit legs of multilane roundabouts. In addition, the team tested two offset distances from the circulating lane to the crosswalk, measured at 20 and 60 feet from the beginning of exit leg. The pedestrian crosswalk and beacons were installed with reference to the location of stop bar according to MUTCD guidelines (10).

The simulator experiment was designed as a full factorial experiment with two factors, the stop bar distance measured upstream of the exit leg and the type of beacon. The type of beacon factor has three levels PHB, RRFB, and control (no beacon) condition (CTRL). The full factorial combination generates 6 unique scenarios (CTRL20, PHB20, RRFB20, CTRL60, PHB60, and RRFB60). Each scenario simulates an urban corridor of eight roundabouts located at a constant spacing of 2000 feet. Four of the roundabouts have one pedestrian standing at the crosswalk with one foot on the crosswalk. This design thus allows for subject replication. The location of the roundabouts with a pedestrian is randomized across each of the scenarios. The use of buildings, trees, pedestrians walking along the sidewalk, and traffic assisted in creating a realistic urban environment. The roundabouts were modeled with an hourly flow rate of approximately 200 vehicles per hour for the subject approach, to assure operations well below capacity. Modeling of a congested roundabout and the associated gap acceptance rules for simulated vehicles (other than the subject driver) was not possible with the available simulator technology. The roundabouts have two entering and exiting lanes in each approach, each 12 feet wide, and two circulating lanes in the circle. The center islands have diameter of 100 feet and the speed limit is 35 mph.

Each participant was asked to drive all six scenarios. The team decided not to advise the participants about the true purpose of the study as to not bias their yielding behavior in the experiment. Instead drivers were told that the experiment was geared at studying roundabout

corridors, and to drive the scenarios as they would naturally drive while observing the traffic rules and regulations to the best of their knowledge. A Latin Square design for 6x6 experiments (18) is used to randomize the order of scenarios for each subject. In order to eliminate any learning effects, each driver was asked to drive one additional scenario at the end of the experiment, which is a repetition of the 1st scenario. This should allow the team to account for any learning effects during the experiment. Table 1 shows the 6 different patterns for the order of scenarios. For the purpose of this paper only, the results of orders 2 through 7 are presented, treating the first scenario as a pilot run.

Each participant is randomly assigned one of the six patterns, while assuring that overall an equal number of scenarios is achieved across all subjects. For example, a participant assigned to pattern 2 would start with the PHB20 case (treated as a practice run), followed by CTRL20, PHB60, RRFB20, RRFB60, CTRL60, and PHB20. The randomization of scenarios is intended to account for any learning effects or changes in driver behavior over time. With four pedestrians present in each scenario, a total of 24 usable data points for each participant was generated, with four within-subject replications of each of the six scenarios.

Sample Size Calculation

Since the goal is to report whether drivers yield to a pedestrian at the crosswalk exit leg, the experiments result in a success or failure. Therefore the binomial distribution is used to calculate the required sample size. There are not any published results on the prevailing yielding rates at roundabout exits for RRFB. However, NCHRP 674 reported a 22% yielding rate to pedestrians at a channelized turn lane with a flashing beacon installed (4). The same source also cites an approximately 87.4% yielding rate in both lanes of a two-lane roundabout, entry and exit, with PHB installed (4). NCHRP 572 reports an average yielding rate of 29% for roundabouts across the United States (19). These values were chosen to calculate the sample size for the base scenario and each beacon scenario. The significance value (alpha) is chosen to be 0.05 and the power at 0.8. By carrying out a two-sided test and with the approximate success rates discussed above, the resulting sample size was estimated at 70 (20). The data was collected from 45 subjects, with 4 pedestrian crossings in each scenario; the sample size adds up to 180 which allowed for multiple replications. The equation below is used for sample size calculations (20).

$$n = \frac{\left(z_{\alpha} \sqrt{2PQ} + z_{\beta} \sqrt{P_1Q_1 + P_2Q_2} \right)^2}{\delta^2}$$

where:

Z_{α} = Upper 100(1- α) is the percentile of the standard normal distribution,

Z_{β} = Upper 100(1- β) is the percentile of the standard normal distribution,

$\Delta = P_2 - P_1$: $P_2 > P_1$ is the sample size standard deviation,

$P = \frac{1}{2} (P_2 + P_1)$ is the success rate, and

$Q = \frac{1}{2} (Q_1 + Q_2)$, $Q = 1 - P$, is the failure rate.

Driver Population

The participants' population was limited to drivers with 20/20 vision without eyeglasses or contact lenses. The study was performed in Raleigh, NC on the campus of North Carolina State University, where a total of four roundabouts (three single-lane and one two-lane roundabout) are located within a quarter mile of the building housing the simulator. The

subjects were recruited by using fliers in the campus and the businesses around the campus and sending emails to a few of email lists such as previous participants of driver simulator.

Out of the 45 subjects, 60% are male and 40% female and the age distribution ranged from 19 to 60 years. A set of debriefing questions was developed to ascertain the subjects driving experience and for gauging their understanding of the elements of the study - including driving simulators, different beacons, stop bar distance, and how they felt about yielding to pedestrians when exiting the roundabouts. Table 2 depicts the results from the first portion of the questionnaire, which gives information about the sample driver population and driving habits. It is important to note that the debriefing questionnaire was asked from the participants after all scenarios were completed as to not bias their behavior.

Table 2 shows drivers' perception rate of their yielding to pedestrians at roundabouts. On average, participants reported they yield to pedestrians at the exit leg of roundabouts 70% of the time. This percentage is assumed to be for roundabouts without any special pedestrian treatment. The fraction yielding at other uncontrolled intersections with pedestrians is 80%.

Measures of Effectiveness

For the purpose of this study, the measure of effectiveness extracted from the driving simulator is the driver yield rate to pedestrians in each scenario. Later in the results section, the yielding rate was analyzed based on different subject attributes; for example, their driving experience, average weekly encounter with pedestrians, etc.

The performance measures extracted from the eye tracker are the pupil fixation duration, and the number of pupil fixations on each type of beacon and (or) pedestrians, as well as the percentage of fixations on different objects on the scene. Fixation is defined as "those eye movements that best indicate the locations of the viewer's (overt) visual attention" (21). The fixations are measured in milliseconds and thresholds are discussed later in the results section.

Challenges

Since the driving simulator software was not designed to simulate roundabout and circular vehicular movements or, for that matter, different types of signals, the research team faced significant challenges in designing an acceptable roundabout environment. In order to overcome such challenges the roundabouts - including center islands, splitter islands, and pavement markings - were designed as 3D objects and imported into the simulator. RRFB and PHB's were also designed as 3D objects and incorporated into the simulator software. The research team further simulated circular traffic movements in the roundabout. The team simulated the traffic by breaking down the vehicle movements into several straight and diagonal movements in order to create the appearance of circulating traffic, as well as, right and left turning movements in the roundabout.

RESULTS

Yielding Rates

Each of the 45 subjects was exposed to 4 pedestrian crossings in each scenario yielding a sample size of 180. Table 3 shows the yielding rate for each scenario. Taking the CTRL20 scenario as the base case, the table shows the increase in yielding percentage (% Increase), the results of a z-test (Z-Score) to test the significance of each scenario with the base scenario, along with the associated p-value to see if results were significant at the 95 percentile confidence level.

The results of the z-test shows statistically significant differences between the base case (CTRL20) and scenarios with beacon installments, ($\alpha=0.05$, $\beta=0.8$). Although not significant at the 95 percentile confidence level, it should also be noted that the CTRL60 scenario also showed positive signs of improvement over the base condition ($p=0.054$), with an estimated 27.3% improvement. While smaller than the beacon effects, this represents a potential low-cost modification to the roundabout that may help improve yielding propensity.

The pattern of improved yielding with re-locating the crosswalk was also observed for the PHB60 and RRFB60, which resulted in the two highest overall yielding rates. In fact, relocating the PHB from 20 to 60 feet increased yielding from 68.3% to 85.6% ($p\text{-value}=0.00010$), and relocating the RRFB from 20 to 60 feet resulted in an increase from 51.7% to 73.9% ($p\text{-value}=0.00001$). The combined effects of higher yielding at an increased off-set distance is an important finding, especially since higher off-set distances have previously been linked by research to improved operational performance for vehicles (22), resulting in lower pedestrian-induced impacts on vehicular delay over the standard crosswalk location.

In a comparison of the RRFB and PHB treatments, the PHB generally resulted in somewhat higher yielding rates. At the 20-foot distance the PHB yielding rate of 68.3% exceed the RRFB rate of 51.7% ($p=0.00125$). Similarly, the PHB and RRFB yielding rates at 60 feet were 85.6% and 73.9%, respectively, ($p\text{-value}=0.00591$). Therefore, the PHB generally resulted in improved yielding behavior and the differences to the RRFB were statistically significant at the 95 percentile confidence level.

Further analysis has been done to show the effect of different subject attributes on yielding rates. The team divided the subjects in to two groups (i.e. less than or more than 10 years of driving experience) based on their Duration of driving in US with driving license (Experience), Average hours of driving per week (Driving), Average count of passes through a roundabout per week (Roundabout), and Average count of passes through intersections with pedestrian crossings (Pedestrians). The z-test is used to study if there is a significant difference in yielding rates between the two groups for each of the above subject attributes. The results are summarized in Table 4 and discussed below. Effects with a p-value less than 0.05 are highlighted in bold.

• **Duration of Driving in United States with Driving License (Exposure)**—The sample population was divided into two groups, drivers with less than and more than 10 years of driving experience in the United States. Using a confidence level of 95%, the results of z-test shows there is no significant difference in yielding behavior between the two groups of drivers in the base scenario (CTRL20) and RRFB20. However, more driving experience resulted in significantly more yielding to pedestrians in the rest of the scenarios.

• **Average Hours of Driving per week (Driving)**—The yielding rate in each scenario appears to be higher for subjects who, on average, drive more than 7 hours a week. However, there is no significant difference between yielding rate in each scenario except for the PHB60 scenario. It appears that drivers with longer driving hours during the week are more responsive to the red indication of the PHB when the crosswalk and stop bar are re-located further away from the roundabout ($p=0.046$). The same behavior is observed for RRFB with a confidence level of 90%.

• **Average count of passes through a roundabout per week (Roundabout)**—Table 4 shows interesting results of yielding behavior for drivers based on their weekly count of passing through roundabouts. Drivers who pass through roundabouts more than once a week have higher yielding rates than drivers with fewer passes. However, the

difference is only significant in the base scenario. These results suggest that drivers with more exposure in navigating roundabout are more likely to yield to pedestrians. They may further suggest that the effects of the tested treatments are independent of driver experience with roundabouts, as both categories end up with comparable yielding rates, on average. These results imply that the tested treatments will have more significant relative effect on increasing yielding rate for drivers with less roundabout experience.

• **Average count of passes through intersections with pedestrian crossings (Pedestrians)**—Drivers who have higher number of encounters with pedestrians in intersections tend to have higher yielding rates in roundabouts, across all scenarios. However, the difference is significant only in the base scenario and in the scenarios with RRFB installation. However when a PHB is installed or the crosswalk is relocated, although the yielding rate increases for both categories of drivers, there is no significant difference between the two populations. Therefore, drivers with more weekly pedestrian encounters are likely more responsive to yield to pedestrians with the existence of an RRFB signal. However, these results of the questionnaire are self-reported and it doesn't take into account the possibility that some drivers don't know when they don't notice pedestrians.

Eye Tracker Results

The critical performance measures of the eye tracker data are the frequency and duration of *fixation*, measured in milliseconds. The research team defined a threshold fixation duration, which is used to infer that the driver's visual attention was in fact focused on the object in question (pedestrian or beacon). The proper threshold for fixation duration found in literature is 67 milliseconds (0.067 seconds) (23). For the purpose of this study the team used the same threshold. Therefore, any fixation duration less than 0.067 seconds was eliminated from the data.

The results of this experiment can assist in understanding whether the drivers were aware of the presence of the beacons and pedestrians along the road and whether or not they comprehended the implication of their presence. Drivers essentially must negotiate traffic from three different directions in the roundabout while their main focus is to drive out of the circulating lane toward the exit leg. Therefore, they will tend to pay less attention toward objects along the road or the sidewalk along the way.

Table 5 shows the results from the eye tracker experiments. For the scenarios with no beacon installations, fixations on pedestrians and for scenarios with PHB and RRFB the fixations on pedestrians and beacons were extracted and analyzed. Since the RRFB system was modeled in the form of side-mounted beacons, the eye tracker data is not able to do depth analysis and distinguish between the pedestrian and RRFB. Therefore, for RRFB the fixation is both on pedestrians and beacon. PHBs were overhead beacons and therefore fixations on pedestrian and beacon could be distinguished in the analysis.

The results show that the *number of fixations* is highest in the PHB60 scenario at an average of 7.8 fixations, relative to the base case of 3.1. The result of a t-test on the difference between the number of fixations on the pedestrian in each scenario compare to base scenario shows that installing any kind of beacon will significantly increase the number of fixations on the pedestrian, or in general the objects along the road. Therefore the presence of a beacon tended to increase drivers' attention to the presence of pedestrians on their path. It should be mentioned that for PHB20 scenario the increase in number of fixations is not significant at 95% confidence level. The authors hypothesize that in the 20 feet scenario; the PHB is located too close to the roundabout and makes it difficult for drivers to make eye contact. The comparative values of percent fixation on objects and fixation duration also support that hypothesis.

Relocating the crosswalk and stop bar to 60 feet does not have a significant increase in the number of fixations on the pedestrian for the base case. For the RRFB and PHB, the relocation of the crosswalk to 60 ft does suggest a slight increase in the number of fixations on the pedestrian over the equivalent 20 ft scenario, but these increases are not statistically significant. The p-values for 20 versus 60 feet for a RRFB and PHB are 0.306 and 0.101 respectively.

The t-test on the *percentage of fixations* on the pedestrian, and both pedestrian and RRFB in the scenarios show the same trend observed in the number of fixations. Table 5 shows no significant difference between base scenario and CTRL60, but more significant difference between the rest of the scenarios and base case. At a 95 confidence level, there is no significant difference between the base case and PHB20, which suggests against installing a PHB close to roundabouts.

A t-test on the values of *fixation durations* shows there is not a significant difference in the duration of drivers' fixations on pedestrians in the CTRL60 and base (CTRL20) scenarios. It also supports the results of number of fixations and percentage of fixation on pedestrians. Overall, the three measures of effectiveness discussed in Table 5 suggest that relocating the crosswalk does not have a significant increase on drivers' gaze pattern on the pedestrians by itself. Although having an overhead PHB beacon 20 feet from the stop bar increases the fixation time, it is not significant at the 95 confidence level.

Table 5 also shows the regression models developed for the eye tracker measures of effectiveness. X_1 , x_2 and x_3 are binary factors (0 or 1) and they define the crosswalk relocation to 60 ft., PHB and RRFB respectively (when equal to 1). The coefficients show how much the measures of effectiveness (*number of fixations*, *percentage of fixations* and *fixation duration*) will be changed with any of these conditions. Note that x_2 and x_3 cannot equal to 1 at the same time.

Debriefing Questionnaire on Treatment Effectiveness

A series of debriefing questions was asked pertaining to the drivers' experience with roundabouts and their perception of the different treatments installed in each of the scenarios. The results indicated that 91% of the subjects were aware of the presence of both types of beacons at the roundabout. This means that 9% (or 4 drivers) did not even notice the RRFB or PHB at the crosswalk. Nearly 80% of the drivers understood the purpose of both beacons at the roundabouts. However about 9% didn't associate the PHBs with pedestrian crossings and 11% of the drivers were seemingly unaware of the RRFB's purpose. Overall, 76% of the drivers felt safer with the stop bars located at 60 feet while 7% didn't notice the differences. The rest of the drivers (18%) felt the stop bar should be moved even further away from the roundabout.

Each driver was also asked to rank the perceived safety of each treatment scenario from 1 to 5, with 1 being the least safe and 5 being the safest condition that will promote nearly 100% yielding to the pedestrians. The results of the safety scores with each scenario and their 96 percentile confidence level are shown in Figure 2. The results show that participants felt the safest with the PHB or RRFB, having stop bars located 60 feet downstream, of the roundabout. The safety score of PHB60 is significantly higher than other scenarios; however, when it comes to stop bars located at 20 feet from the roundabouts they prefer to have RRFB compared to overhead PHB. One possible explanation is that with a stop bar at 20 feet drivers do not feel safe enough to yield to pedestrians. Therefore they prefer to have RRFB which implies caution and does not show a red indication to stop. The RRFB gives the option to drivers (with yellow flashing lights) of whether to yield or not, while the solid

red location at the RRFB requires a driver to stop. The safety score of the base scenario (CTRL20) and crosswalk relocation scenario (CTRL60) are not significantly different.

CONCLUSION

This paper aimed to test three different pedestrian crosswalk treatments at the exit leg of multilane roundabouts using a driving simulator and eye tracker. Six unique scenarios were developed based on the combination of crosswalk distance and type of beacon (or no beacon at all). The three treatments studied were the base scenario (CTRL), Pedestrian Hybrid Beacon (PHB), and Rectangular-rapid Flashing Beacon (RRFB). Each treatment was tested using two crosswalk locations (stop bar located at 20 and 60 feet). Drivers were asked to drive a simulated corridor of eight roundabouts, four of which had pedestrian crossings. The driver yielding rate to the pedestrians in each scenario showed that existence of any kind of beacon increases driver yielding rate significantly ($\alpha=0.05$). Among the treatment options, the use of PHB signal with a stop bar located at 60 feet, appeared to have the highest increase in the yielding rate.

Further analysis on the effect of subject population attributes show some effects on yielding rate. In general, longer driving experience has a significant effect on increasing yielding rate when it comes to installation of beacons as treatments. Other attributes, such as the average driving hours per week, average pedestrian encounters, or average weekly passes through roundabouts do not show conclusive effects on increasing the propensity to yield.

The eye tracker provided valuable information about the gaze patterns of drivers while exiting the roundabouts. Three performance measures including the number of fixations, the percentage of fixation on objects of interest, and mean fixation duration were investigated. Overall, the existence of any type of beacon at roundabout increased the drivers' attention to the pedestrians waiting to cross.

For future analysis, a more detailed study of the results of eye tracker data to analyze gaze pattern for each yielding or non-yielding event for drivers in different scenarios is planned. Future research will also explore the relationship between drivers' speed at exit and their yielding.

The findings in this research imply that the use of RRFB or PHB systems successfully increased the rate of driver yielding at the exit leg of multilane roundabouts. For both beacon treatments, the yield rate was further increased when relocating the treatment to a distance of 60 feet, instead of the 20-foot standard crosswalk location. This low-cost modification to the crosswalk therefore warrants additional consideration, especially since it has been linked in prior research to lower pedestrian-induced vehicular delay impacts of the installed signal.

Finally, the yielding rate resulting from the PHB (with solid red indication) was significantly higher than that of the RRFB, which only has a flashing yellow beacon. While care should be taken to draw broad conclusions from this simulator to engineering practice, the yielding rate of only 85.6% is disconcerting. Even the highest yield percentage of 90.7% is well below the full compliance that one might expect from a solid red indication. This is comparable to findings at a field installation of a PHB at a two-lane roundabout, where red-light running occurred 12.6% of the time (4), which is actually quite similar to the 14.4% observed, and within the lower bound of the 95 percent confidence interval of 80.4% (19.6% non-compliance). The 85.6% average compliance rate is furthermore for the PHB60 location, while the rate for the more standard 20-foot crosswalk is only 68.3%. While not statistically significant, the yielding rate at a 60-foot distance RRFB was higher than for a 20-foot distance PHB. These results call for a careful exploration of any future installations

of PHB or other beaconing systems at multilane roundabout exits, as some compliance issues are expected.

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Figure 1.
Driving Simulator Screen Shot and Eye Tracker used in the Study, Source for Figure 1b:
Ergolab at NCSU

Figure 2.
Drivers Safety Score Rate

Table 1

Latin Square Design for Randomizing the Order of Trials

	Randomized Order of scenarios						
Pattern	1st	2nd	3rd	4th	5th	6th	7th
1	CTRL20	CTRL60	RRFB20	PHB60	PHB20	RRFB60	CTRL20
2	PHB20	CTRL20	PHB60	RRFB20	RRFB60	CTRL60	PHB20
3	RRFB20	PHB60	CTRL60	RRFB60	CTRL20	PHB20	RRFB20
4	CTRL60	RRFB20	RRFB60	PHB20	PHB60	CTRL20	CTRL60
5	RRFB60	PHB20	CTRL20	CTRL60	RRFB20	PHB60	RRFB60
6	PHB60	RRFB60	PHB20	CTRL20	CTRL60	RRFB20	PHB60

Table 2

Participants' Driving Profile from Debriefing Questionnaire

Questions Regarding Driving Profile	Ave.	St. Dev.	Min	Max
Duration of driving in US with a driving license (years)	14.0	8.3	2.5	39.0
Average driving hours, per week (hours of a typical week day)	8.3	6.4	1.5	36
Average count of passing through roundabouts, per week	2.0	2.0	0	8
Average count of passing through intersections with pedestrian crossings, per week	6.2	5.2	0.3	24
Average reported yielding rate to pedestrians at uncontrolled intersections *, %	80%	22%	20%	100%
Average reported yielding rate to pedestrians when exiting roundabouts *, %	70%	39%	0%	100%

* These two questions were asked directly from drivers to gauge their own perception of their yielding rate to pedestrians at intersections and roundabouts.

Table 3

Yielding Rate Results for Each Scenario Compared to the Base (CTRL20) scenario

	CTRL20	CTRL60	PHB20	PHB60	RRFb20	RRFB60
Yielding Rate	36.7%	46.7%	68.3%	85.6%	51.7%	73.9%
% Increase	Base	27.3%	86.4%	133.3%	40.9%	101.5%
Z-Score	Base	1.92	6.02	9.51	2.87	7.10
P-value	Base	0.054	<0.0001	<0.0001	0.0042	<0.0001

Table 4

Subject Attributes Effect on Drivers Yielding Behavior

	CTRL20	CTRL60	PHB20	PHB60	RRFb20	RRFB60
Experience 10 Yrs (n=68)	30.9%	30.9%	52.9%	73.5%	45.6%	63.2%
Experience>10 Yrs (n=112)	40.2%	56.3%	77.7%	92.9%	55.4%	80.4%
Z-Score	1.25	3.31	3.46	3.58	1.27	2.54
P-value	0.2095	0.0009	0.0005	0.0003	0.2035	0.0112
Driving 7 hr/wk (n=92)	31.5%	47.8%	65.2%	80.4%	46.7%	68.5%
Driving>7 hr/wk (n=88)	42.0%	45.5%	71.6%	90.9%	56.8%	79.5%
Z-Score	1.46	0.32	0.92	2.00	1.35	1.69
P-value	0.143	0.750	0.358	0.046	0.176	0.091
Roundabout 1 per wk (n=72)	28.7%	42.6%	67.6%	85.2%	48.1%	68.5%
Roundabout>1 per wk (n=108)	47.2%	52.8%	68.1%	86.1%	56.9%	80.6%
Z-Score	2.65	1.37	0.06	0.13	1.17	1.62
P-value	0.0080	0.1697	0.9511	0.8930	0.2430	0.1046
Pedestrian 5 per wk (n=100)	26.0%	43.0%	63.0%	84.0%	44.0%	68.0%
Pedestrian>5 per wk (n=80)	50.0%	51.3%	75.0%	87.5%	61.3%	81.3%
Z-Score	3.32	1.10	1.72	0.66	2.30	2.01
P-value	0.0009	0.2703	0.0855	0.5069	0.0214	0.0443

Table 5

Eye Tracker Results

	Object	Number of Fixations		t-test	% Fixation on Object		t-test	Fixation Duration(sec.)			t-test
		Average	St. dev.		Average	St. dev.		Average	St. dev.	Max	
CTRL20	Ped.	3.1	1.6	Base	8%	6.40%	$\alpha=0.05$	0.201	0.105	0.683	$\alpha=0.05$
CTRL60	Ped.	3.8	1.9	p=0.76	10%	6.30%		0.222	0.144	0.842	p=0.13
RRFB20	Ped&Beacon	5.9	2.6	$p=0.009$	32%	5.80%	$p=0.030$	0.301	0.292	2.758	$p=0.031$
RRFB60	Ped&Beacon	6.1	2.6	$P<0.001$	65%	7.20%	$P<0.001$	0.329	0.248	2.075	$P<0.001$
PHB20	Ped.	5.4	2.4	p=0.057	20%	8.20%	p=0.060	0.242	0.276	2.518	p=0.051
	Beacon	6.2	2.3	-	32%	6.50%	-	0.272	0.304	2.700	-
PHB60	Ped.	7.3	2.5	$P<0.001$	26%	6.10%	$p=0.022$	0.275	0.315	3.814	$P<0.001$
	Beacon	7.8	2.3	-	51%	7.30%	-	0.385	0.345	5.375	-

Regression Models				
Models	Intercept	Coefficient for x_1 (=1 if Crosswalk at 60 ft.)	Coefficient for x_2 (=1 if beacon is PHB)	Coefficient for x_3 (=1 if beacon is RRFB)
Number of Fixations	3.1	0.89	2.73	1.61
% Fixation on Object	0.09	0.02	0.68	0.49
Fixation Duration	0.198	0.011	0.083	0.072
		Regression Model		
		$3.1+0.89x_1+2.73x_2+1.61x_3$		
		$0.09+0.02x_1+0.68x_2+0.49x_3$		
		$0.198+0.011x_1+0.083x_2+0.072x_3$		