Evaluating Countermeasures to Improve Pedestrian and Bicycle Safety

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SAFETY RESEARCH USING SIMULATION

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Abstract

Pedestrian crashes have reached an alarming level in the U.S. Different factors could contribute to the occurrence of these crashes at an intersection, including driver errors, the type of maneuver, and pedestrian behaviors. All these factors highlight the need to develop a traffic warning signal to protect pedestrians and bicyclists at intersections. Therefore, a supplemental traffic signal has been proposed to warn the left-turning driver about crossing pedestrians and bicyclists at intersections. This signal will be activated when the pedestrian pushes a call button or when a bicyclist has been detected by a detection loop. The aim of this supplemental traffic signal is to enhance pedestrian and bicyclist detection by warning drivers who are focusing their attention on finding a gap in the oncoming traffic.

A number of different supplemental warning traffic signal designs were proposed, and the evaluation of their designs was split into two stages. Stage 1 involved a screening tool to eliminate weak designs that are confusing or have poor legibility by asking drivers how well each design conveys the message. After collecting and analyzing 259 responses, results showed that two designs, identified throughout the report as Design 1 and Design 3, were ranked the highest. Design 1 is a supplemental yellow pedestrian warning indication. Design 3 is a modified version of an R10-15 MUTCD sign. Stage 2 involved an open-ended question survey that asked subjects to interpret the meaning of Design 1 and Design 3. A total of 145 responses were collected in Stage 2. An analysis of Stage 2 responses found Design 3 to be the most promising design for communicating the presence of conflicting pedestrians to left-turning drivers. Findings from the survey process will facilitate the evaluation of the scenarios on a driving-simulator platform by narrowing the conditions and factors tested during the experiment.

1 Introduction

Although the number of total crashes decreased annually in the U.S. up until 2015, the percentage of pedestrian and bicyclist fatalities has increased. The percentage of pedestrian fatalities increased from 11% of total roadway fatalities in 2004 to 15% in 2015 while the percentage of bicyclist fatalities increased from 1.7% of total roadway fatalities in 2004 to 2.3% in 2015 [1, 2]. Also, between 2005 and 2009, there were more than 311,000 traffic crashes that involved pedestrians hit by light vehicles [3]. In 2015, according to the National Highway Traffic Safety Administration (NHTSA) 76% of pedestrian fatalities occurred in urban areas, 82% occurred at non-intersection locations, and 74% took place in dark conditions [2]. Accordingly, in 2015 NHTSA reports that 72% of bicyclist fatalities occurred at non-intersection locations, 70% occurred in urban areas, and 47% took place in dark conditions. Percentages described for non-intersection include actual non-intersection values reported by NHTSA as well as other percentages not categorized as intersection.

The 21st century has seen many technological innovations from the automotive industry. These innovations promise to improve traffic safety and enrich the driving experience. One such innovation is autonomous vehicles. In theory, autonomous vehicles could operate without the need for traditional traffic control devices (TCD), suggesting the possibility of a future without post-mounted traffic signs. However, the high cost of these new technologies may delay their mass adoption into our road networks.

Pedestrians and bicyclists are key users in the traffic network. To reduce pedestrian and bicyclist crashes, the causes of these crashes must be understood. As described extensively later in this report, a number of factors could contribute to the occurrence of pedestrian and bicyclist crashes. However, driver factors are considered the main contributor. One of the main driver factors is a failure to yield to either pedestrians or bicyclists, which may increase the likelihood of a crash. Alerting drivers to crossing pedestrians or bicyclists could enhance the detection of pedestrians. There have been efforts to enhance the detection of pedestrians by providing a supplemental signal warning, but to date these devices have been intended for right-turning drivers only.

These factors demonstrate the need to develop a supplemental traffic signal device to warn the left-turning drivers about crossing pedestrians and bicyclists at intersections. This signal will be activated when the pedestrian pushes a call button or when a bicyclist is detected by a detection device. The aim of this supplemental traffic signal is to enhance detection of pedestrians and bicyclists by warning drivers who are either focusing their attention on finding a gap in the oncoming traffic (high workload) or not focusing on the environment (low workload).

To develop this supplemental traffic signal device, the research team utilized American National Standards Institute (ANSI) standard Z535.3. The first step was to review the existing traffic signal devices. Then, the research team identified and evaluated four possible supplemental traffic signal devices and evaluated them in two stages. Stage 1 involved a screening tool to eliminate weak designs that were confusing. After being introduced to the four traffic signal devices and their context and intended meaning, drivers were asked to rank them based on how well each design conveyed the message. Design 1 and Design 3, shown in **Error! Reference source not found.** and Figure 1-2, were ranked highest. The two designs were then tested in Stage 2, which was the traffic signal device evaluation stage. In this stage, the comprehension of these traffic signals was tested by asking respondents an open-ended question. Respondents were asked, “If you want to turn left and you see the signal indication that is shown, what will you do?” The answers were classified into correct and not correct. The results showed that the Design 3, shown in Figure 1-2, was the most the understandable design.

Figure 1-1 - The layout of Design 1

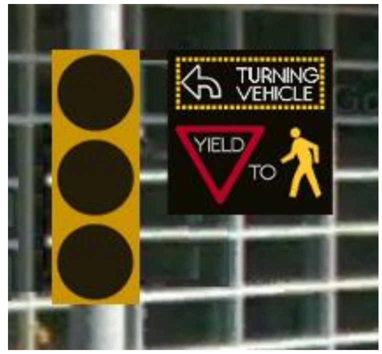

Figure 1-2 - The layout of Design 3

2 Supporting Literature and Existing Practices

Various factors could contribute to the occurrence of pedestrian and bicyclist crashes at an intersection, including driver errors, the type of maneuver, and pedestrian behaviors. These factors can be categorized into different causes: driver, bicyclist, pedestrian, and road factors. Each of the factors is described in the following sections.

2.1 Driver Factors

Driver error is one of the main contributors to crashes involving pedestrians and bicycles. Driver errors could be the result of drivers who “looked but failed to see,” drivers who failed to look, lack of information, or a late response to avoid the crash [4]. In Wisconsin, researchers found that 28% of fatal crashes involve drivers who failed to yield to pedestrians in the crosswalk [5]. “Looked-but-failed-to-see" crashes are defined as crashes in which the drivers reported they correctly looked, but they did not detect the bicyclists or pedestrians in time to prevent the crash. Researchers found that the third most occurring crashes were looked-but-failed-to-see crashes and that 83.3% of looked-but-failed-to-see crashes occurred in intersections [6]. The most common explanations for the looked-but-failed-to-see crashes are shortcoming in attention or recognition failure [7] [6] and expectancy failure where the drivers were looking only for cars. Attention failure could occur when:

- hazard detection fails,
- there is low conspicuity of pedestrians and bicyclists that limit detection, or

- there is a high attention demand that limits hazards processing.

Hazard perception is considered one of the major factors in driver errors, and it is defined as the process of detecting, processing, and responding to critical events on the road. Studies have shown that inexperienced drivers may have a higher response time to hazard perception that may increase the likelihood of being involved in a crash [8]. The complexity of the driving task could also affect peripheral detection. Peripheral detection rates have been found to decrease as the degree of complexity increases [9]. Many crashes could be attributed to a failure of detecting hazards. Researchers found that the drivers and cyclists who were neither able to detect the danger nor had time to react caused about 37% of accidents in Finland [10].

Improper scanning detection could be another cause of failure in hazard perception. However, improper scanning detection could be attributed to learned practices by drivers, which may result in traffic crashes if driver behavior is misinterpreted [10]. Based on various driving experiences, a study evaluated the hazard detection for two critical stimulus events, precursor and hazard [11]. The study found that learner drivers focused less on critical stimuli than experienced drivers did. Also, researchers found that the hazards were fixated sooner than the precursors. Regarding hazard detection, learners were found to be slower than experienced drivers. The failure in detecting an object or subject can be attributed to the fact that the detection of an object or subject in motion could be challenging [12] [13]. Researchers have also found that drivers have difficulties predicting the path of a pedestrian in motion [14].

Driver age could be another contributor to improper scanning detection. Due to the declining physiological ability to turn their heads, older drivers are less likely to scan [15]. A study examined the visual scanning of old, middle-aged, and young drivers by using an instrumented vehicle [16]. The study found that old drivers scanned the left and right sides of the intersection less than other drivers. Also, the study found that the middle-aged drivers checked the rear mirror more than the other drivers. Older drivers also have some deficiencies that limit their detection and perception including a narrow field view, slower eye movements, issues with depth perception, and higher time required to change their focus [17] [18]. These limitations could explain why 24% of older drivers responded that “turning maneuvers gave them a hard time” [19]. Therefore, it is not surprising that a higher number of drivers involved in looked-but-failed-to-see crashes are older drivers [6].

Another contributor to crashes between drivers and other road users (pedestrians, bikes, and drivers) is that each of the road users interpolates road situation awareness differently. Situation awareness is defined as “activated knowledge regarding road users' tasks at a specific point in time” [20]. Researchers found that road users do not interpret the same road situation equally [21, 22]. Also, each road user observes and uses different information when exposed to the same road conditions [20]. Different experiences, expectations, or views are the causes of these differences. Misunderstanding among road users who do not know how to share the road or are not expecting other road users' moves could lead to increased conflicts among road users. These conflicts could lead to differences in situation awareness, which may increase traffic crashes [23]. Another study found that one of the main explanations for car-bicycle crashes is improper expectations about the behavior of other road users [10]. Users' attitudes are one of the factors that impact driver behavior around bicyclists and pedestrians.

Attitude is defined as a “relatively enduring tendency to respond to someone or something in a way that reflects a positive or negative evaluation of that person or thing” [24]. A study found that drivers made a closer overtake to a bicyclist wearing a helmet, while drivers took a wider overtake when a bicyclist appeared to be female [25]. Also, drivers consider bicyclists to be a source of danger and to be annoying [23]. These negative attitudes towards bicyclists have a negative correlation with driving behavior and road-rule knowledge [24, 26].

2.2 Bicyclist Factors

Bicyclists are considered valuable road users nowadays. Although drivers have lower crash rates than bicyclists, the exposure rate of crashes for bicyclists is higher than the exposure rate of drivers [27]. An Australian study surveyed 838 bicyclists and found that 48.2% of these bicyclists had been involved in crashes or near misses with drivers [28]. Two different studies examined the near-collision events and found similar rates of near collisions; about 0.8 per hour [29, 30]. Also, bicyclists reported feeling at higher risk and experiencing more aggression than other road users [31].

Head injuries were the most common type of bicycle-related injuries [32]. In England, the groups most involved in bicycle injuries were the elderly and children [33]. This high number of crashes among old and young bicyclists could be attributed to the lack of knowledge and an inability to apply this knowledge [10]. Also, it has been found that males are overrepresented in bicycle injuries at all ages [34]. Previous studies have shown that experienced drivers detect and respond to hazards faster than novice drivers. A study found similar results when video from a camera installed on the handlebar of a bicycle were shown to two groups of bicyclists (frequent and infrequent bicyclists) [35]. Then, they were asked to indicate how cautious they would be in the situation by using a slider. The results showed that frequent bicyclists had higher detection and response rates than infrequent bikers.

Multiple studies have examined and analyzed factors associated with bicyclist-driver collisions. A study found that most serious and fatal injuries in bicycle accidents are associated with a higher speed limit and failure to yield the right of way [33, 36]. In Australia, a naturalistic study was conducted on the behavior of bicyclists during near collisions with other road users. There were three major factors in near-collision events: bicyclists approaching or hesitating in an intersection (pre-incident maneuver), drivers overtaking the bicyclists (precipitating factor), and drivers avoiding collision (evasive maneuver). It was found that the rate was 1.2 near collisions per hour. The study found that turning at an intersection and approaching an intersection is risky for bicyclists. The study concludes that the difference in speed limits at intersections and bicyclist's capabilities encouraged drivers to overtake bicyclists, although it is not allowed in Australia.

Alcohol affects both driving and bicycling behaviors. It has been found that bicyclists under the influence of alcohol are at a higher risk of head or face injuries [37]. Falling off a bicycle because of alcohol influence is associated with a higher risk of injuries than vehicle accidents [38]. Each road user perceives risk differently. In interactions between bikes, bicyclists felt safer because they believed that other bicyclists would have mutual experience in bike maneuvers [23]. On the other hand, interactions between vehicles and bikes increase the perceived risks. Also, the objective and perceived risks do not match for a variety of reasons, such as differences in operating speed, size, level of protection, and visual scanning [23].

2.3 Pedestrian Factors

As they represent a large percentage of road users, pedestrian behaviors are a fundamental factor to understand. At intersections, pedestrian behaviors are unpredictable [39]. Based on an analysis of 9,808 pedestrian crossings at four-leg intersections in Vancouver, B.C., the previous study found that 13% of pedestrians entered the crossing illegally. In a study of 2,157 pedestrian collisions in 13 U.S. cities, police records indicated that 34% of the collisions were the result of pedestrians abruptly entering the roadway (darting out) at midblock locations [40]. In addition, it found that only 7% of the collisions were the result of a vehicle attending to oncoming traffic and not noticing the pedestrian. A naturalistic driving study in Japan found that major patterns of accidents at non-intersection locations occurred because pedestrians behaved in unexpected manners [41]. Different studies examined the vehicular speed in the presentence of pedestrians at crosswalks in Israel and Nottingham, England [42, 43]. These studies reached different conclusions. The study from Israel concluded that the presence of pedestrians in crosswalks reduced vehicular speed, while the England study found that the presence of pedestrians had no effect on vehicle speed.

2.4 Road Factors

Road segment factors can influence the severity and number of bike and pedestrian crashes. A study found that wider streets have more pedestrian crashes than two-lane streets because of the higher speed [44]. In terms of injury severity, a study found that roadway lighting reduced the severity of injury [45]. A different study on the effect of infrastructure on bicycling injuries and crashes concluded that major roads have a higher risk than minor roads, and that a bicycle facility has the lowest risk of crashes while sidewalks and “multi-use trails” (paved or unpaved paths) increased the risk. Due to road sharing between drivers and bicyclists, studies have shown that drivers feel more in danger as a result of annoyance and frustration. [24]. A naturalistic driving study conducted in Indiana for over a year analyzed conflicts between pedestrians and vehicles. The study found that crosswalks and junctions have higher potential conflicts between cars and pedestrians when compared with other road infrastructure [46]. Also, it found that the conflict rate is higher when pedestrians cross the road, compared to when they are just walking along or against traffic.

Intersections are known to be unsafe for bicyclists when compared with other road sections [10]. A study developed an accident prediction model for cross intersections and T-intersections and found that T-intersections were more dangerous for pedestrians [47]. In a study that analyzed the effect of the intersection characteristics and the density of traffic on attention allocation by using driving simulation, it was found that the behavior of Gaza drivers differed between the two sides of a T-intersection [4]. In the analysis of Gaza drivers at the left side of the intersection, the study found that only the traffic density influenced their behavior. The analysis of the drivers on the right side of an intersection showed that existence of pedestrian crossing increases the gaze mean. One issue with a signalized intersection is that the green phase should be long enough to accommodate the pedestrian volume, but it has been argued that the design does not accommodate the walking speed of the whole population.

Perceived risk is as important as objective risk. Based on the location of the intersection, low-density areas have a relatively higher perceived risk than mixed-use areas [48]. As expected, neighborhoods that promote walkable streets have a lower perceived crash risk [49].

The type of intersection maneuver can increase the complexity of a driving task and increase the mental load. The mental load has been found to be the highest for the left turning maneuvers [50, 51]. A survey conducted in California found that the protected signal phases were understood better by drivers [50]. Higher comprehension rates could be a reason for left-turn movements being four times more dangerous to pedestrians than through movements [52].

Another contributing factor is visibility at night. Researchers found that detection of bicyclists by drivers is low at night; however, wearing appropriate clothes and using mandatory lighting can increase the detection rate [53]. The previous study found that bicyclists wearing fluorescent clothing have a lower accident rate. Another study found that bicyclists who reported wearing high-visibility clothing experienced fewer crashes [54].

2.5 Previous Traffic Signals

Different countermeasures have been implemented to enhance the detection of pedestrians by providing a supplemental signal warning; however, these devices are intended for right-turning drivers only. One of these signals is the flashing pedestrian indicator (FPI) shown in Figure 2-1 [55]. This indicator is activated when the pedestrian button is pressed for the conflicting crosswalk; the "Walk" pedestrian signal comes up and alternates with the yellow arrow. It was found that while the drivers were able to understand the meaning of the FPI, there was some confusion for drivers going through as the drivers thought that they should expect pedestrians crossing in front of them.

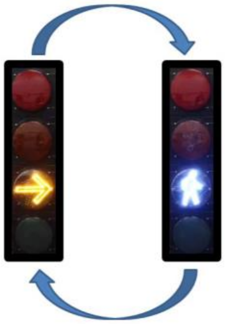

Figure 2-1 - Supplemental signal warning for right-turning motorists [55]

Another signal is the yellow pedestrian border (YPB) shown in Figure 2-2 [56]. This signal was implemented in California, and it modifies the pedestrian traffic signal box by adding yellow lights around the border. It is activated when the pedestrian pushes the call button; the yellow lights remain lit through the walk phase until the flashing red hand and countdown appear in the signal box. This alerts the driver that someone is approaching from behind and is preparing to cross. The yellow border will then go dark until the button is pushed again.

Figure 2-2 - The yellow pedestrian border (YPB) [56]

Another type of LED traffic signal was designed and installed in Portland in 2011 [57]. It is a warning for drivers turning left about coming bicyclists. It warns drivers by flashing “turning vehicle yield to bikes” (Figure 2-3). This traffic signal is connected to two different loop detections for vehicles and bicycles. According to the designer of this traffic signal, it was developed based on a similar MUTCD sign that has the same function, warning drivers about the need to yield to bikes. Researchers stated that the sign “seems to have reduced right-turn conflicts by more than 60 percent since its 2011 installation.” The study found that the number of crashes after implementation fell to 11.7 crashes per million entering vehicles, compared to 23.6 before implementation.

Figure 2-3 - Flashing turning vehicle yield to bikes

2.6 Summary of Literature Findings

Pedestrian and bicycle crashes have reached an alarming level. The aim of the supplemental traffic signal is to enhance pedestrian and bicyclist detection by warning drivers who are focused on finding a gap in the oncoming traffic (high workload) or who are not focusing on the environment (low workload). Different factors contribute to pedestrian and bicycle crashes at intersections. including driver errors, the type of maneuver, and pedestrian behavior. Driver error is the main contributor to pedestrian and bike crashes. These driver errors could be the result of drivers who looked but failed to see, drivers who failed to look, lack of information, or a driver who had a lower response to avoid the crash [4]. In Wisconsin, it was found that 28% of fatal crashes involved drivers who did not yield to pedestrians in the crosswalk [5]. Most serious and fatal injuries in bicycle accidents are associated with a higher speed limit and failure to yield the right of way [33, 36]. Road factors can have a significant impact on the causes of pedestrian and bicycle crashes; these include the type of maneuver, configuration of the intersection, presence of lighting, and traffic volume [47, 50, 51, 53]. These factors highlight the need to develop a supplemental traffic signal device to warn left-turning drivers about crossing pedestrians and bicyclists at intersections. This supplemental signal should be activated when the pedestrian pushes a call button or when a bicyclist is detected.

3 Driver Comprehension Survey

3.1 Survey Methodology

This chapter describes the survey evaluation of supplemental traffic signal devices. The objective of the methodology was to evaluate comprehension of potential supplemental traffic signal devices. In this driver comprehension survey, the American National Standards Institute (ANSI) standard Z535.3 methodology was used, and it was conducted in two stages. The Z535.3 methodology provides guidelines for evaluating safety symbols that alert drivers about the hazard and provide general safety messages. The first step in the Z535.3 methodology is to review the existing symbols and develop an initial set of potential designs. So, the research team identified four possible supplemental traffic signal devices. Some of these designs are modified versions of traffic signal devices that have been described previously. A detailed description of the four designs is presented in the next section, and details of the methodology and results are presented in the sections that follow. The University of Wisconsin-Madison Review Board (IRB) approved this research.

As described previously, the first step in the Z535.3 methodology is to review the existing symbols and develop an initial set of potential designs. Once a potential set of designs is established, the process proceeds as follows:

- Stage 1: Screening tool. Stage 1 is a screening tool to eliminate weak designs that are confusing. In this stage, subjects were told the context and the intended meaning of the traffic signal devices and were asked to rank how well each design conveyed the message. Then, two highest-rated designs are carried to the next stage.

- Stage 2: Evaluation tool. The traffic signal device evaluation consists of testing using an open-ended question format where a new set of subjects was asked to explain the meaning of the traffic signal device and then describe what they would do as a result of the signal indication.

Stage 1 and Stage 2 were conducted at Department of Motor Vehicles offices in Madison, Wisconsin, and the Student Union at the University of Wisconsin-Madison. Both stages were carried out using a tablet computer. Due to the need to present a dynamic demonstration of the traffic signals, the tablets used Qualtrics, which is a web-based survey tool, to conduct and evaluate the research surveys.

3.2 Proposed Designs

The research team identified four alternative traffic signal devices for Stage 1. These traffic signal devices are activated when the pedestrian pushes a call button or when a bicyclist is detected. The aim of this supplemental traffic signal is to enhance pedestrian and bicyclist detection by warning drivers who are focusing their attention on finding a gap in the oncoming traffic (high workload) or who are not focusing on the environment (low workload). As shown in Figure 3-1 and Figure 3-3, Design 1 would flash and be an alternative between the yellow arrow and yellow walking pedestrian warning indication. The new supplemental device would be installed within the existing traffic signal head, which would reduce the cost. Design 2 is shown in Figure 3-2 and Figure 3-4; it also flashes a yellow walking pedestrian indication. The difference between Design 1 and Design 2 is that the flashing walking pedestrian is located in a supplemental traffic signal head in Design 1, as shown in Figure 3-1 through Figure 3-4.

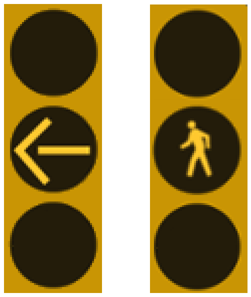

Figure 3-1 - The layout of Design 1

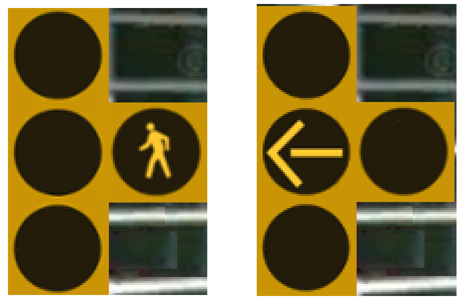

Figure 3-2 - The layout of Design 2

Figure 3-3 - The layout of Design 1 at an intersection

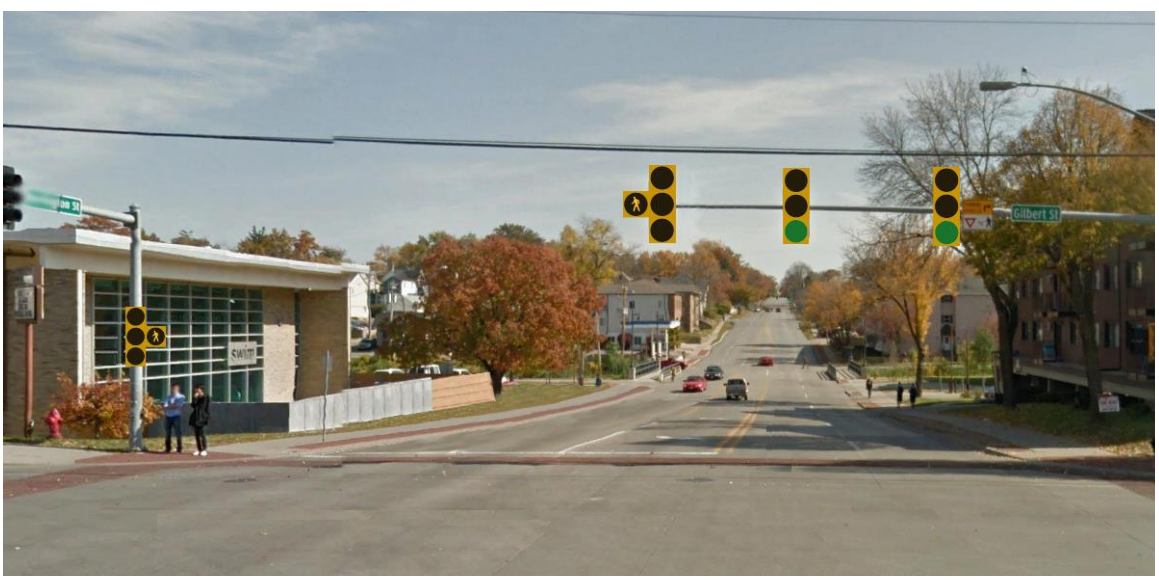

Figure 3-4 - The layout of Design 2 at an intersection

Design 3 is a supplemental traffic signal that relies on a modified flashing version of the MUTCD sign (R10-15) as shown in Figure 3-5 and Figure 3-6. Design 3 flashes a yield triangle symbol, the word “TO,” a pedestrian symbol, the words “TURNING VEHICLE,” and a left arrow symbol. Design 3 is used only on the left side of the intersection. This supplemental signal is expected to be heavy and may introduce a high momentum on the end of the overhead pole. Therefore, it may require special mounting procedures. Design 4 is a supplemental traffic signal device that flashes a text warning signal (PED XING) as shown in

Figure 3-9. Design 4 is located on the left side of the intersection for the same reasons as Design 3.

Figure 3-5 - R10-15 MUTCD sign

Figure 3-6 - The layout of Design 3

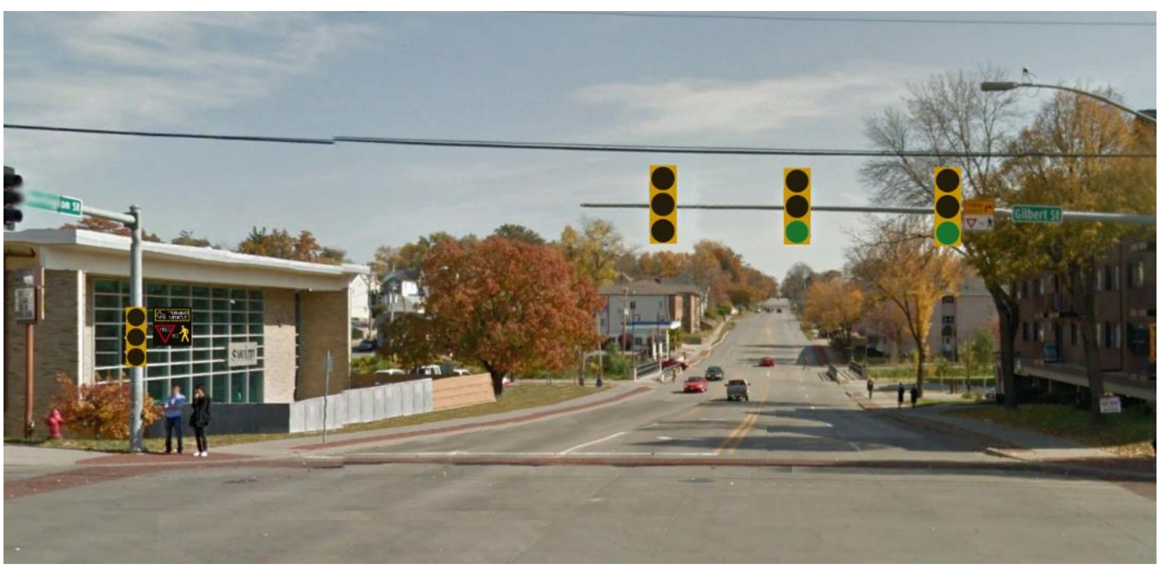

Figure 3-7 - The layout of Design 3 at an intersection

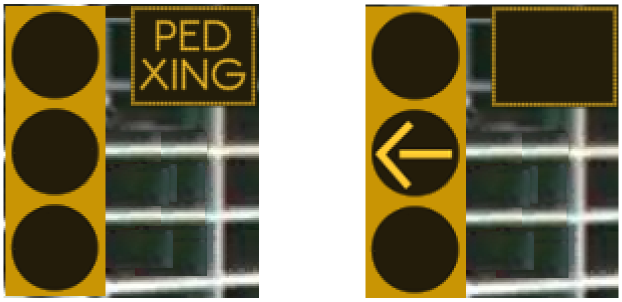

Figure 3-8 - The layout of Design 4

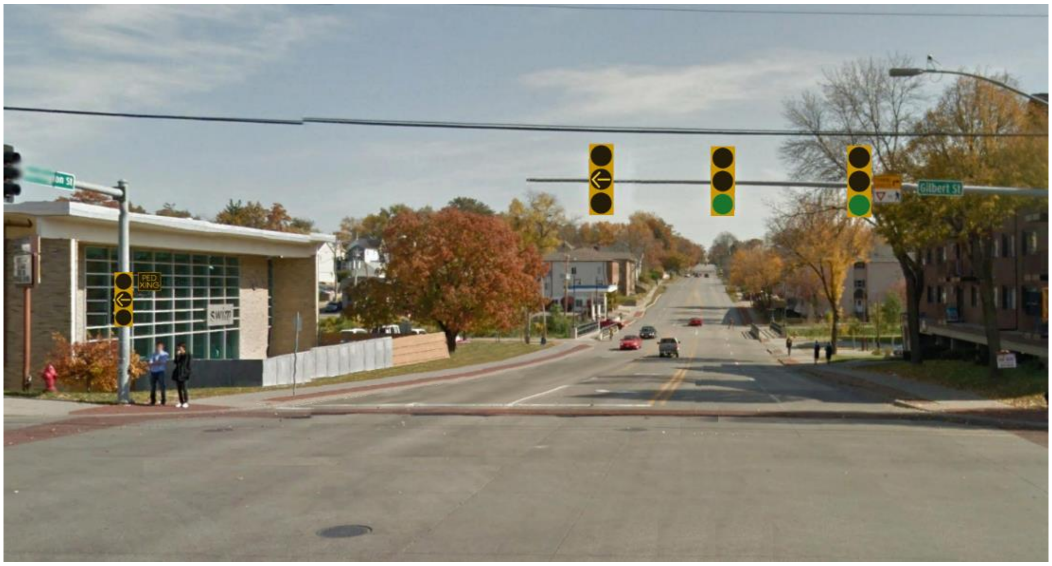

Figure 3-9 - The layout of Design 4 at an intersection

4 Results

This section describes results from the surveys conducted in Stage 1 and Stage 2. Results presented include the demographic characteristics, ranking of designs by subjects, and feedback received from subjects in the form of open questions.

1.1 Stage 1 Results

The objective of this stage is to serve as a screening tool to eliminate weak designs that are confusing. A total of 259 survey responses was collected. The questionnaire and Stage 1 results are presented in the sections ahead.

1.1.1 Stage 1 Questionnaire Characteristics

The first section of the questionnaire focused on demographics questions such as age, gender, level of education, and number of hours driven weekly. As seen in

Figure 4-1, subjects were told the context and the intended meaning of the traffic signal devices and were asked to rank how well each design conveyed the message. The full details of the Stage 1 questionnaire are available in Appendix A.

1.1.2 Stage 1 Subject Demographics

The research team collected 259 survey responses. The demographics of the survey respondents are shown in Table 4-1. Demographic highlights include:

- Sixty-one (23.55%) of respondents were female, while 197 (76.06%) of respondents were male; only one respondent (0.39%) indicated other.
- Middle-aged drivers were well represented, while older drivers were underrepresented; 10 (3.86%) of the respondents were older than 65.
- One hundred and forty-two (54.52%) of the respondents drove 10 hours or less each week, while 106 (40.9%) of the respondents drove more than 10 hours and less than 35 hours each week. Only 11 (4.25) of the respondents drove 35 or more hours each week.
- One hundred and two (39.38%) of the respondents had a two-year degree or lower as the highest level of education, while 157 (60.62%) of respondents had a 4-year degree or higher as the highest level of education.

1.1.3 Stage 1 Ranking Results

As previously mentioned, respondents were asked to rank how well each design conveyed the intended message. In the ranking system, a low score indicates that survey subjects thought a traffic signal would be relatively easy to understand (most preferred), while a high score suggests the design was difficult to understand. Table 4-2 shows the descriptive statistics of the ranking procedure. The average and standard deviations of the rankings are presented for each of the four traffic signal designs and are broken down by gender and age.

Figure 4-2 and Figure 4-3 show a graphical representation of the results.

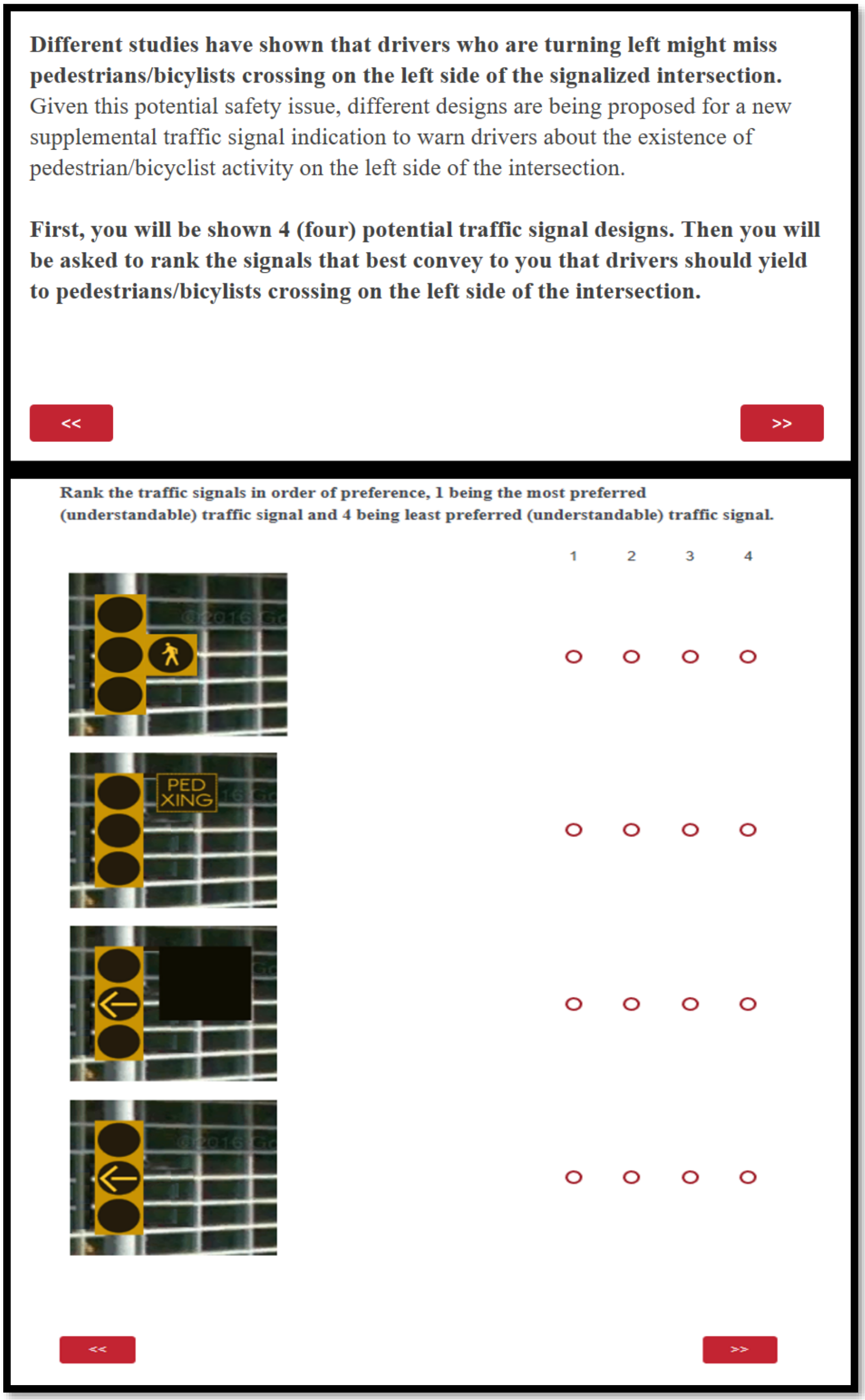

Figure 4-1 - Sample of the Stage 1 questionnaire

As shown in Table 4-2 and Figure 4-2, Design 1 had the highest ranking among the designs, as well as among the different genders and drivers older than 18 years. Design 3 was the second highest ranked design. Although the only difference between Design 1 and Design 4 is the location of the supplemental traffic signal device, the ranking of Design 1 is higher than the ranking of Design 4 (third place). Design 2 is a text-based traffic signal device and received the lowest ranking, although it had been expected to be one of the highest ranked. (Its text-based design had been expected to make it easier to understand the intended message.) Design 3 is a text-based traffic signal device with a yield icon. As expected, this design was one of highest ranked because of its text-based design and its similarity to the R10-15 MUTCD sign (Figure 3-5). Figure 4-3 shows the ranking results of each design in Stage 1 and the number and percentage of responses for each design. Figure 4-3 shows Design 3 had the most Rank 1 responses, with 91 (35.1%). Also, it shows that Design 3 had the most Rank 4 responses, with 86 (33.2%).

Table 4-1 - The demographics of the survey respondents of Stage 1

Distribution of Responses by Gender			
Gender	Female	Male	Other
Responses	61	197	1
Percentage	23.55	76.06	0.39

Distribution of Responses by Age Group							
Age Group	18 – 24	25 – 34	35 – 44	45 – 54	55 – 64	65 – 74	75 – 84
Responses	72	88	29	41	19	8	2
Percentage	27.8	33.98	11.20	15.83	7.34	3.09	0.77

Distribution of Responses by Hours Driven Weekly								
Hours	≤ 5	6 – 10	11 - 15	16 - 20	21 - 25	26 - 30	31 - 35	> 35
Responses	74	68	42	36	12	9	7	11
Percentage	28.57	26.25	16.22	13.90	4.63	3.47	2.70	4.25

Distribution of Responses by Highest Level of Education

Education Level	Less than High School	High School	Some College	2-year Degree	4-year Degree	Professional Degree	Doctorate
Responses	1	34	54	13	82	60	15
Percentage	0.39	13.13	20.85	5.02	31.66	23.17	5.79

Table 4-2 - Results of comparing different traffic signal designs in Stage 1

Design 1	Design 2	Design 3	Design 4
			
Overall: 2.1815± 1.0086 Women: 2.000 ± 0.121 Men: 2.2386± 0.073 Age ≤ 18: 2.1727 ± 0.0638 Age ≥ 65: 2.4 ± 0.34	Overall: 2.749 ± 0.9659 Women: 2.443 ± 0.118 Men: 2.843 ± 0.069 Age ≤ 18: 2.7631 ± 0.0617 Age ≥ 65: 2.4 ± 0.221	Overall: 2.5058 ± 1.274 Women: 2.738 ± 0.168 Men: 2.426 ± 0.089 Age ≤ 18: 2.5141 ± 0.0805 Age ≥ 65: 2.3 ± 0.448	Overall: 2.5637 ± 1.1304 Women: 2.820 ± 0.139 Men: 2.492 ± 0.081 Age ≤ 18: 2.5502 ± 0.0713 Age ≥ 65: 2.9 ± 0.407

In summary, these results showed that Design 3 had the most Rank 1 and Rank 4 responses, which indicates that respondents preferred Design 3 the most and the least. These conflicting results could be the result of the simplicity and clarity of the conveyed message and the high volume of information presented. Because the two highest-ranked designs were Design 1 and Design 3, they have been selected for the second stage.

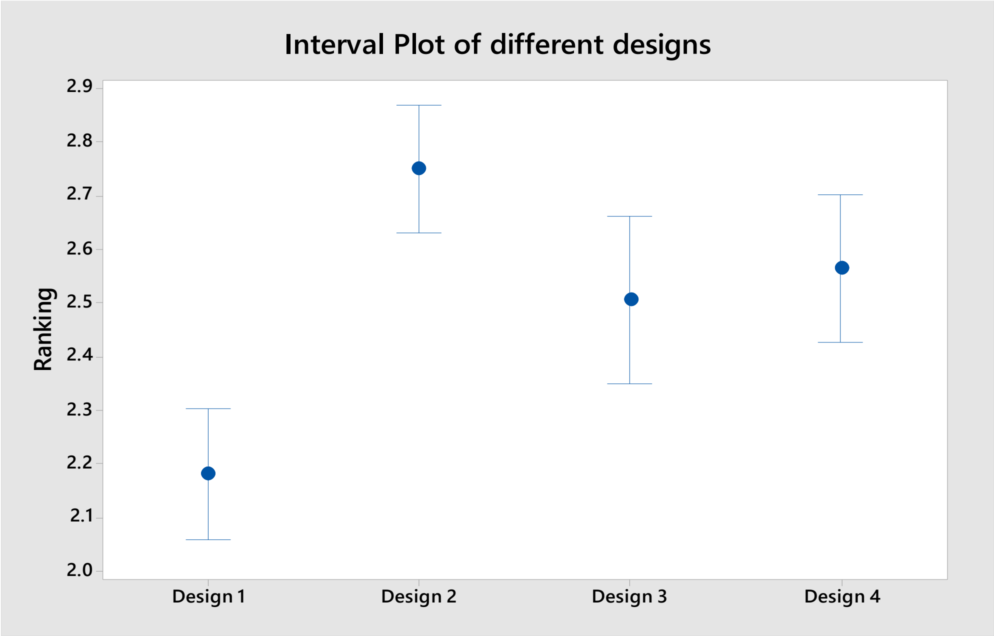

Figure 4-2 - The overall results of the sample of ranking question in Stage 1

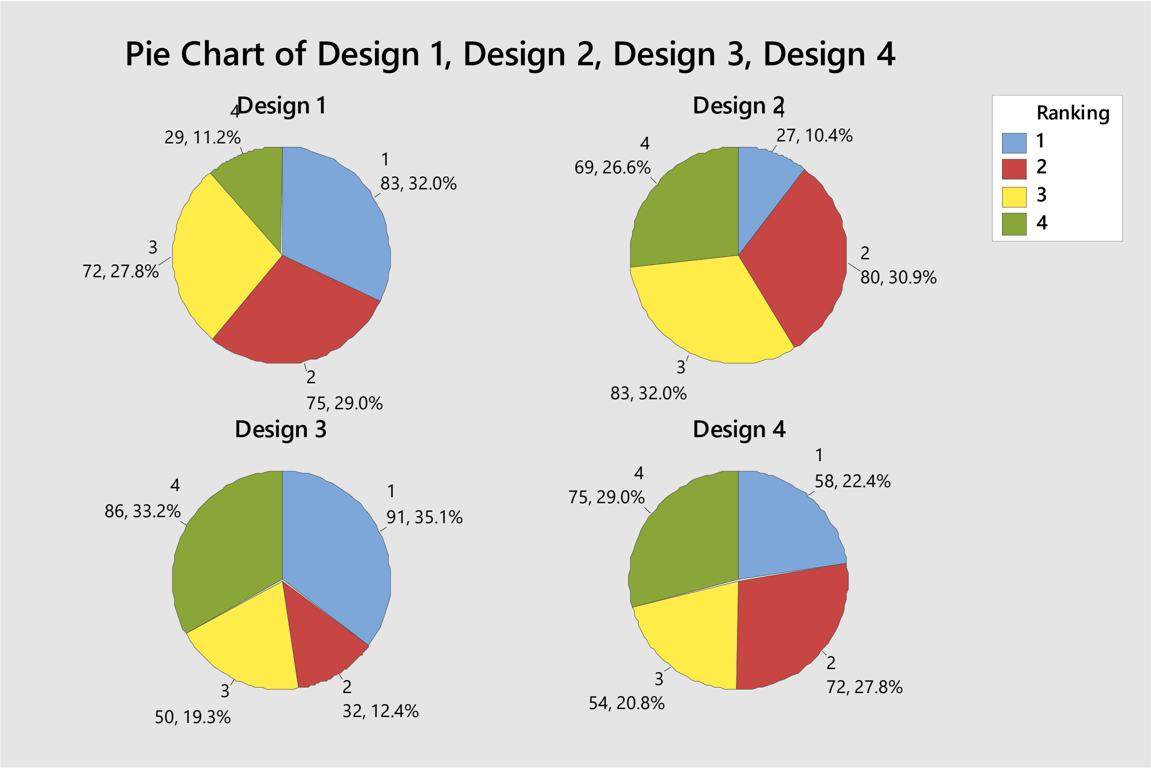

Figure 4-3 - The pie chart of ranking results for each design in Stage 1

1.2 Stage 2 Results

The objective of Stage 2 was to assess the comprehension of the two selected designs (Design 1 and Design 3, shown in Figure 4-4 and Figure 4-5). The research team collected 145 survey responses. The questionnaire and the results of Stage 2 are presented in the sections ahead. Since the objective of Stage 2 was to assess subjects' comprehension of the traffic signal devices, open-ended questions were used to meet this objective. Respondents were asked, "If you want to turn left and you see the signal indication that is shown, what will you do?" Figure 4-6 shows a sample of an open-ended question used in the survey. The second section of the questionnaire focused on demographics questions such as age, gender, level of education, and the number of hours driven weekly. The full details of the questionnaire are shown in Appendix B.

Figure 4-4 - The layout of Design 1

Figure 4-5 - The layout of Design 3

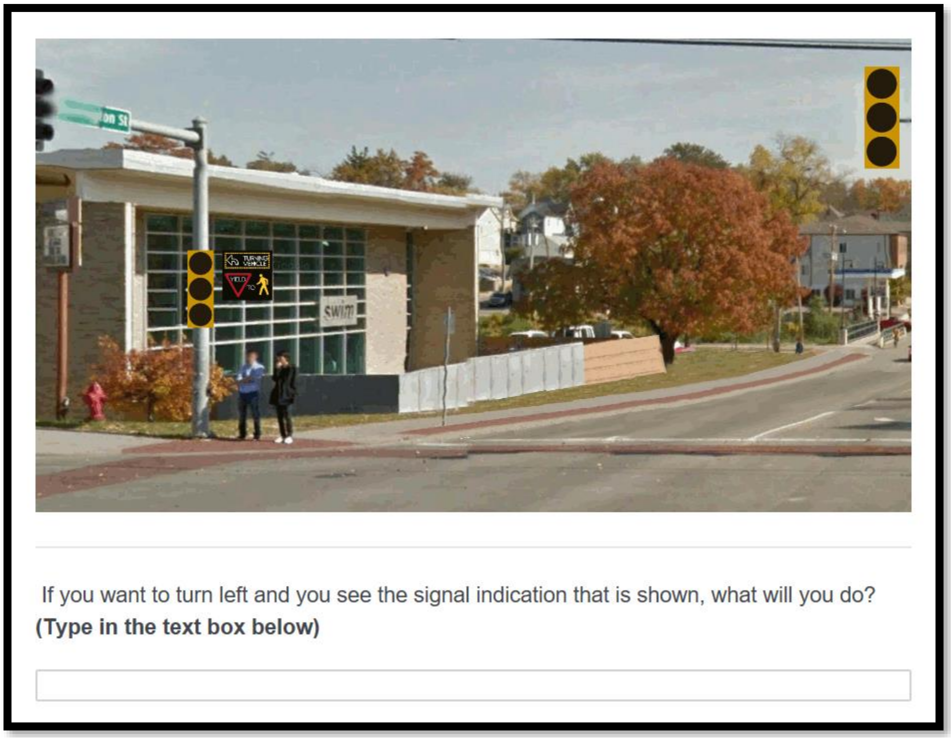

Figure 4-6 - Sample of open-ended question in Stage 2

1.2.1 Stage 2 Subject Demographics

The research team collected 145 survey responses. The demographics of the survey respondents are shown in Table 4-3. Demographic highlights include:

- Seventy-three (50.34%) of respondents were female, while 72 (49.66%) of respondents were male.
- Middle-aged drivers were well represented, while older drivers were underrepresented; 10 (6.90%) of respondents were older than 65.
- Eighty-nine (61.39%) of the respondents drove 10 hours or less each week, while 44 (30.64%) of respondents drove more than 10 hours and less than 35 hours each week. Only 12 (8.28%) of the respondents drove 35 hours or more each week.
- Fifty-eight (40%) of respondents had a two-year degree or lower as the highest level of education, while 87 (60%) of respondents had a four-year degree or higher as the highest level of education.

Table 4-3 - The demographics of the survey respondents for Stage 2

Distribution of Responses by Gender

Gender	Female	Male
Responses	73	72
Percentage	50.34	49.66

Distribution of Responses by Age Group

Age Group	19 – 24	25 – 34	35 – 44	45 – 54	55 – 64	65 – 74	75 – 84
Responses	28	33	31	33	10	8	2
Percentage	19.31	22.76	21.38	22.76	6.90	5.52	1.38

Distribution of Responses by Hours Driven Weekly

Hours	≤ 5	6 – 10	11 - 15	16 -20	21 - 25	26 - 30	31 - 35	> 35
Responses	44	45	16	15	4	8	1	12
Percentage	30.34	31.03	11.03	10.34	2.76	5.52	0.69	8.28

Distribution of Responses by Highest Level of Education

Education Level	High School	Some College	2-year Degree	4-year Degree	Professional Degree	Doctorate
Responses	19	22	17	36	33	18
Percentage	13.10	15.17	11.72	24.83	22.76	12.41

1.2.2 Stage 2 Open-ended Question Results

Responses to the open-ended questions were evaluated and classified into two categories:

- **Correct:** The respondent fully understood the intended message.
- **Incorrect:** The respondent misunderstood the traffic signal or indicated that its meaning was unknown or unclear.

The results of the Stage 3 survey are summarized in Table 4-4, Figure 4-7, and Figure 4-8. Table 4-4 shows examples and the percentage of each response (correct and incorrect) to the open-ended questions by age and gender. The percentage of correct responses to Design 1 was 59.3%, while the percentage of correct responses to Design 3 was 73.8%. The results show clearly that Design 3 is more comprehensible than Design 1. According to Figure 4-7 and Figure 4-8, drivers 65 years and older understood Design 3 more than Design 1. Also, the results showed that both males and females understood Design 3 more than Design 1.

Table 4-4 - Summary of responses to Stage 2 open-ended questions

Traffic signal design	Response	Response Example	Percent of Responses
Design 1 	Correct	Yield for pedestrians and traffic while looking for an opening to turn left.	59.3%
	Incorrect	Proceed if there is no oncoming vehicle.	40.7%
Design 3 	Correct	Turn left yielding to pedestrians.	73.8%
	Incorrect	Stop before turning.	26.2%

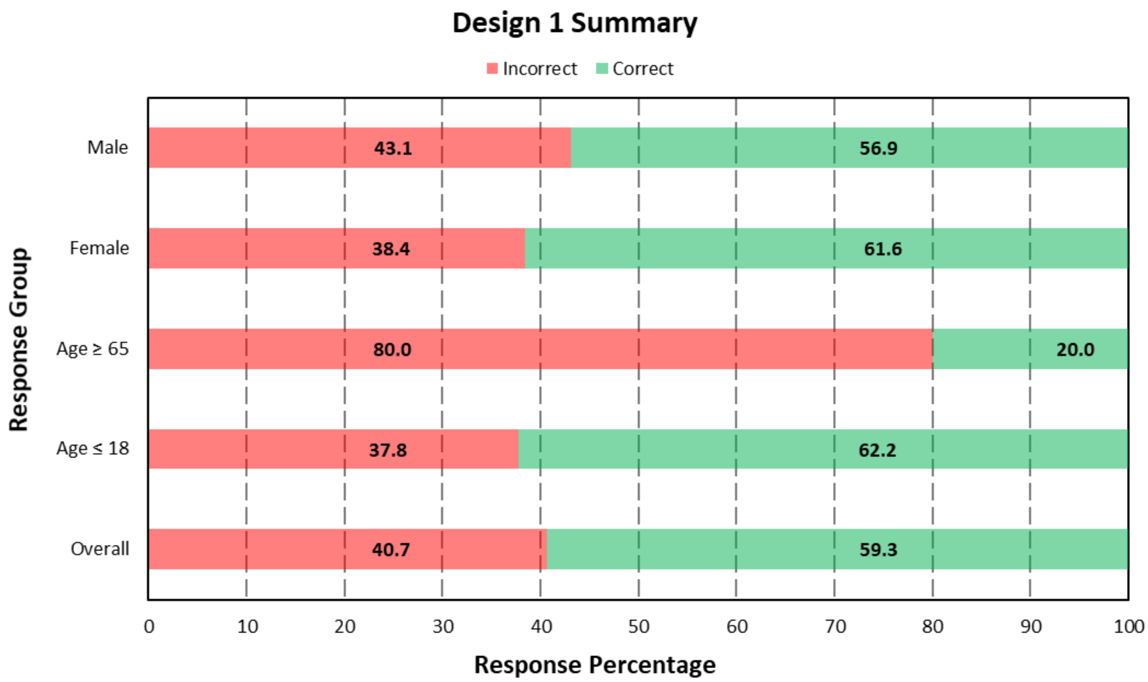

Figure 4-7 - The summary results of Design 1 for Stage 2

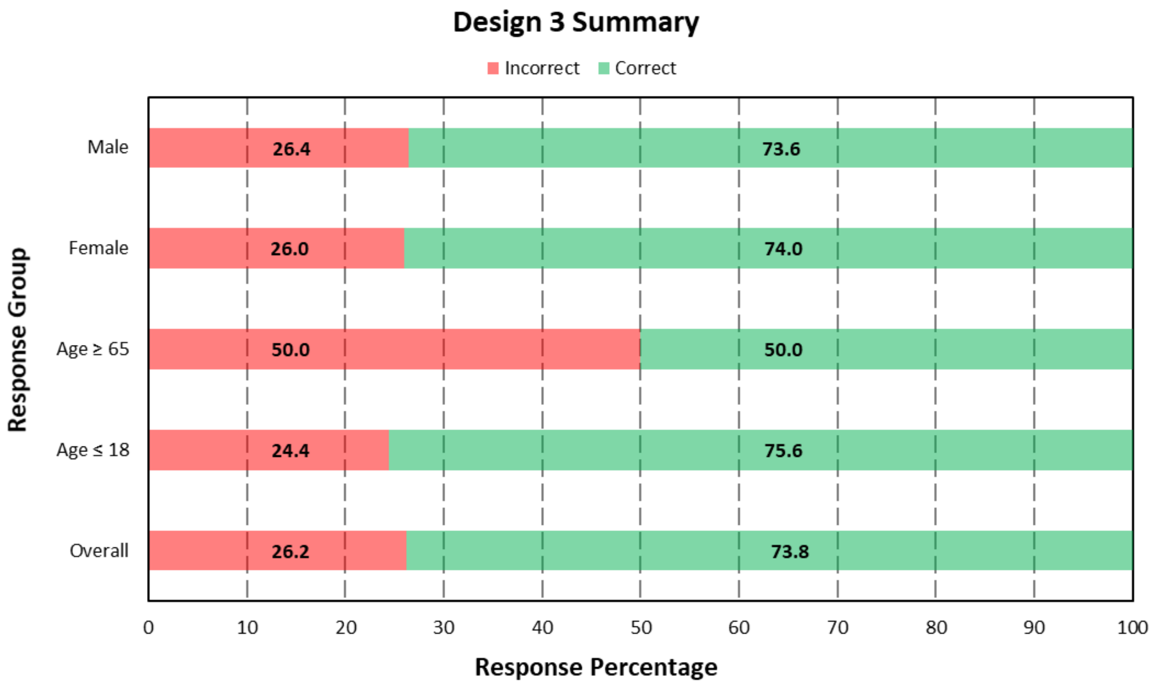

Figure 4-8 - The summary results of Design 3 for Stage 2

5 Conclusions

Pedestrians and bicyclists are key users of the traffic network. To reduce pedestrian and bicyclist crashes, the causes of these crashes should be understood. As described in this report, a variety of factors could contribute to the occurrence of pedestrian and bicyclist crashes, but driver factors are considered the main factor. One of the main driver factors is the failure to yield to either pedestrians or bicyclists, which may increase the likelihood of a crash. Alerting drivers to crossing pedestrians or bicyclists could enhance the detection of pedestrians by providing a supplemental signal warning. A variety of efforts have been implemented to enhance the detection of pedestrians by providing a supplemental signal warning, but these devices have been intended for right-turning drivers only.

Therefore, there a need to develop a supplemental traffic signal device to protect left-turning drivers was identified. The proposed signal could be activated when the pedestrian pushes a call button, or when a bicyclist is detected. The aim of this supplemental traffic signal is to enhance pedestrian and cyclist detection by warning drivers who are focusing their attention on finding a gap in the oncoming traffic (high workload) or who are not focusing on the environment (low workload). To develop this supplemental traffic signal device, the research team utilized the American National Standards Institute (ANSI) standard Z535.3 methodology. Four possible supplemental traffic signal designs were identified. An evaluation of the designs was was conducted in two stages.

Stage 1 involed a screening tool to eliminate weak/confusing designs by asking subjects to rank designs based on how well they believe a message is conveyed after the context and intended meaning was described. The two highest ranked designs (Design 1 and 3) involve a supplemental pedestrian indication on the right of an existing signal. These two designs were then tested in Stage 2 which involved testing using an open-ended question format. Respondents were asked, “If you want to turn left and you see the signal indication that is shown, what will you do?” The answers were classified into correct and not correct. The percentage of correct responses to Design 1 was 59.3%, while the percentage of correct responses to Design 3 was 73.8%. The results suggest that Design 3 is better at conveying the intended message than Design 1. Correct response rates were similar across different age and gender groups. Based on the results, this study concludes that the most promising design for field evaluations is Design 3, a supplemental traffic signal used only on the left side of the intersection that relies on a modified flashing version of the R10-15 MUTCD sign.

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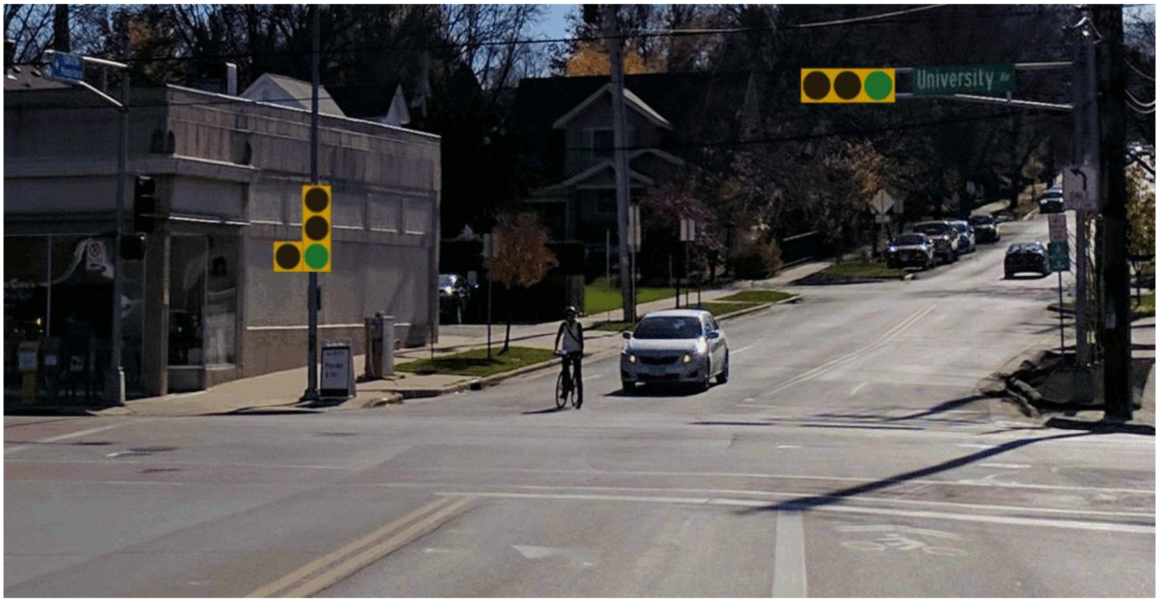
Appendix A: State 1 Survey Details

The following survey is part of a research project conducted by the University of Wisconsin-Madison. The purpose of this study is to understand driver behavior and comprehension of pedestrian and bikes infrastructure. You may ask any questions about the research at any time. If you have questions about the research, you should contact the Principal Investigator David A. Noyce at (608) 265-1882. If you are not satisfied with the response of the research team, have more questions, or want to talk to someone about your rights as a research participant, you should contact the Education and Social/Behavioral Science IRB Office at 608-263-2320. Your participation is completely voluntary. If you decide not to participate or to withdraw from the study, it will have no effect on any services or treatment you are currently receiving. If you decide to participate in this research, you will be asked to Fill out a 5-10 minute survey that asks questions about Pedestrian/Bike Safety. Due to the nature of the online survey, we don't anticipate any risks to you from participation in this study. We also don't expect any direct benefits to you from participation in this study. This study is anonymous. Neither your name or any other identifiable information will be recorded. Next Steps: If you agree to proceed by selecting "I Agree to Proceed" you can proceed to the next page by clicking/tapping the ">>" button.

Q48 If you want to turn left and you see the signal indication that is shown, what will you do?



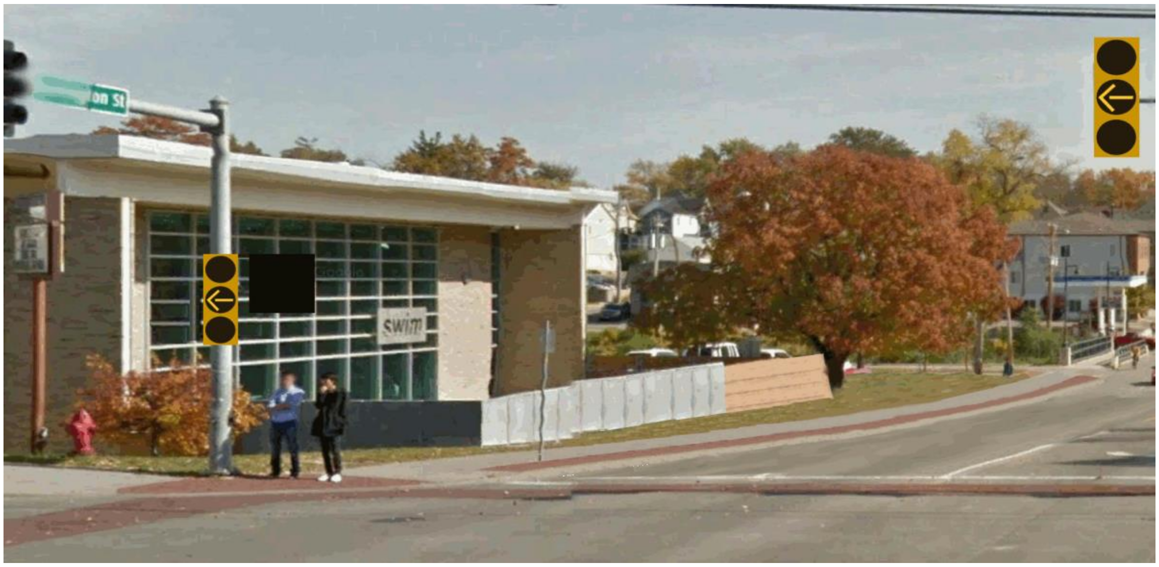
- Go (1)
- Yield to oncoming traffic and yield to pedestrians/bicyclists in the crosswalk AHEAD of you (4)
- Yield to oncoming traffic and yield to pedestrians/bicyclists in the crosswalk to the LEFT of you (3)
- Yield to oncoming traffic and yield to pedestrians/bicyclists in ALL the crosswalks (6)
- Fully Stop (2)

Q55 Different studies have shown that drivers who are turning left might miss pedestrians/bicyclists crossing on the left side of the signalized intersection. Given this potential safety issue, different designs are being proposed for a new supplemental traffic signal indication to warn drivers about the existence of pedestrian/bicyclist activity on the left side of the intersection. First, you will be shown 4 (four) potential traffic signal designs. Then you will be asked to rank the signals that best convey to you that drivers should yield to pedestrians/bicyclists crossing on the left side of the intersection.

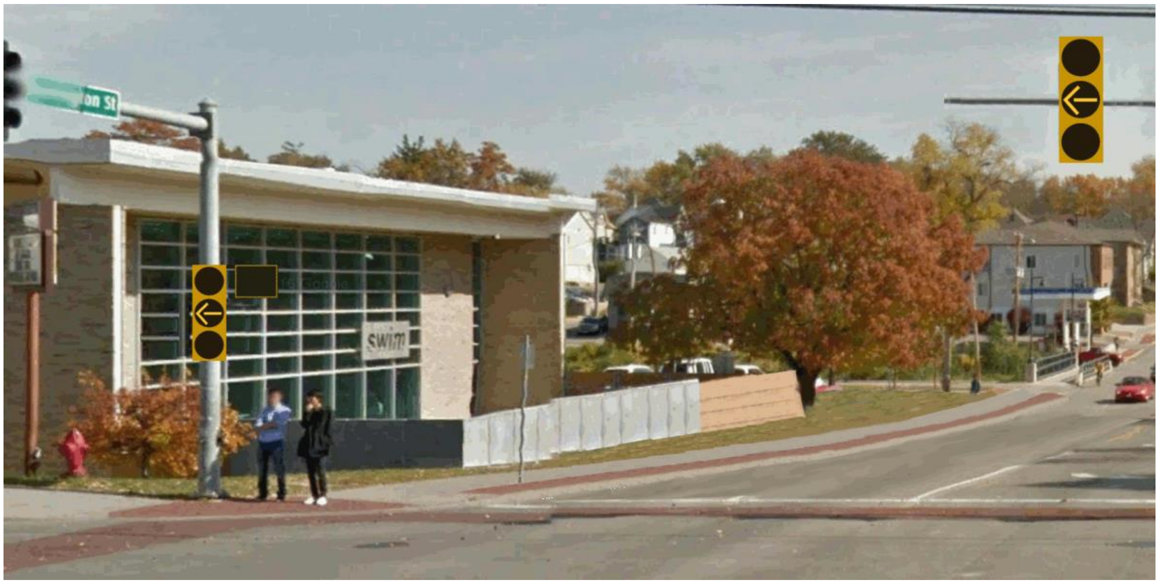
Q57 This is Design 1.   Click Next to move to Design 2.

Q60 This is Design 2.   Click Next to move to Design 3.

Q61 This is Design 3. Click Next to move to Design 4.



Q64 This is Design 4. Click Next to move to ranking question



Q56 Rank the traffic signals in order of preference, 1 being the most preferred (understandable) traffic signal and 4 being least preferred (understandable) traffic signal.

Design	1	2	3	4
				
				
				
				

Do you have a driver license or permit?

- O Yes
- O No

Age

- O 13 or Younger
- O 14-16
- O 17-18
- O 19-24
- O 25-34
- O 35-44
- O 45-54
- O 55-64
- O 65-74
- O 75-84
- O 85 or Older

What is your primary language?

- ○ English
- ○ Spanish
- ○ Other (please specify)

____

Please indicate your gender in the box below or choose from the list:

- ○ Man
- ○ Woman

What is the highest level of education you have completed?

- ○ Less than High School
- ○ High school graduate
- ○ Some college
- ○ 2-year degree
- ○ 4-year degree
- ○ Professional degree
- ○ Doctorate

Approximately how many hours do you drive each week?

○ Less than 5	○ 21 to 25
○ 6 to 10	○ 26 to 30
○ 11 to 15	○ 31 to 39
○ 16 to 20	○ 40 or more

Thank you for your participation!

Appendix B: Stage 2 Survey Details

College of Engineering
UNIVERSITY OF WISCONSIN–MADISON

Traffic Sign Survey

The following survey is part of a research project conducted by the **University of Wisconsin-Madison**. The purpose of this study is to understand driver behavior and comprehension of pedestrian and bikes infrastructure.

You may ask any questions about the research at any time. If you have questions about the research, you should contact the Principal Investigator David A. Noyce at (608) 265-1882. If you are not satisfied with the response of the research team, have more questions, or want to talk to someone about your rights as a research participant, you should contact the Education and Social/Behavioral Science IRB Office at 608-263-2320.

Your participation is completely voluntary. Due to the nature of the online survey, we don't anticipate any risks to you from participation in this study. This study is anonymous. Neither your name or any other identifiable information will be recorded.

If you want to turn left and you see the signal indication that is shown, what will you do?	**Please, look at the screen for the full-screen of the indication** 

If you want to turn left and you see the signal indication that is shown, what will you do?	**Please, look at the screen for the full-screen of the indication**