Smartphone-Based Mid-Block Pedestrian Crossing In-Vehicle Warning – Phase 2

Final Project Report

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Final Report – April 30, 2020

U.S. Department of Transportation
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16. Abstract

Recent data show that the greatest proportion of pedestrian fatalities occurs at non-intersection locations, where physical and electronic infrastructure required to support dynamic safety treatments are less common. To address this gap, the Federal Highway Administration (FHWA) and Intelligent Transportation Systems Joint Program Office (ITS JPO) developed a vehicle-to-pedestrian (V2P) smartphone application that allows pedestrians to signal their intent to cross midblock, which triggers an in-vehicle warning to nearby drivers. Previous testing at a closed track with participant drivers indicated that the in-vehicle warning, communicated via dashboard-mounted smartphone, encouraged drivers to yield at marked midblock crossings. The current research expanded on previous work by evaluating pedestrians' perceptions and use of the FHWA smartphone application to signal their intent to cross at a marked midblock crossing. First, feedback from focus group interviews was used to improve the application interface to support proper use. Subsequent field tests conducted at three live crossing locations indicated that participants used the application as intended without significant changes in crossing behavior relative to a non-connected smartphone-based alternative. Future work may explore interactions between drivers and pedestrians using the application in relatively controlled, urban-like settings, such as a university campus.

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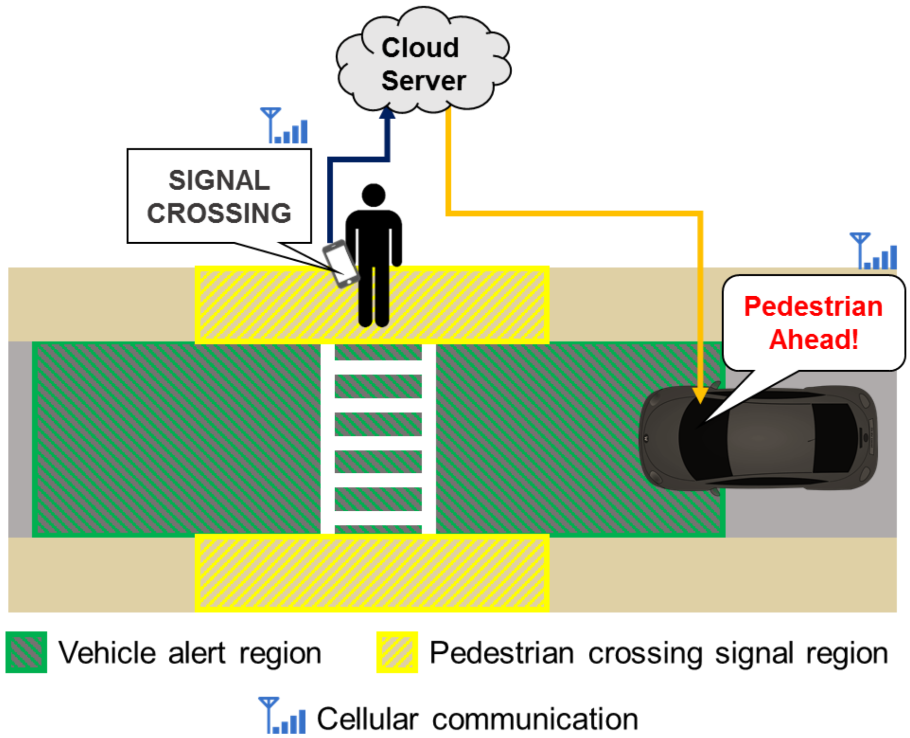
Executive Summary

Despite an overall reduction in traffic fatalities in the past decade, the number of pedestrian and bicyclist fatalities has continued to increase. In 2018, 6,482 pedestrians were killed in traffic incidents, representing a 3.4 percent increase from the previous year (National Highway Traffic Safety Administration [NHTSA], 2019b). Fatality data from 2017 show that the greatest proportion of pedestrian fatalities occurs at non-intersection locations (73 percent), in urban settings (80 percent), and at nighttime (75 percent; NHTSA, 2019a). Compared to signalized intersections, non-intersection locations, such as marked midblock crossings, may have less frequent and predictable patterns of use and are less likely to be equipped with the physical and electronic infrastructure required to support other dynamic safety treatments, such as rectangular rapid-flashing beacons. To address this gap, the Federal Highway Administration (FHWA) and Intelligent Transportation Systems Joint Program Office (ITS JPO) are exploring safety systems that use connected wireless vehicle and pedestrian technology to provide midblock crossing safety treatments that are accessible, cost effective, and available on-demand. One area of research is the use of communications among pedestrian devices, infrastructure, and vehicles to improve safety as part of the Vehicle-to-Pedestrian (V2P) research program.

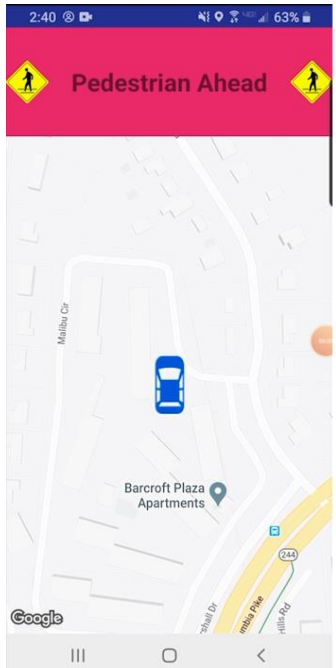
Due to their increasing availability and continuous technological improvements, cellular smartphones are a promising candidate for rapid deployment of connected pedestrian safety applications. However, smartphone-based systems face several critical challenges related to pedestrian and driver safety, comprehension, usability, and consistency of use. In an effort to develop a smartphone-based safety system to improve pedestrian safety at midblock crossings, the FHWA developed the Smartphone-based Mid-block Pedestrian Crossing In-vehicle Warning system. This smartphone application (app) allows pedestrians to signal their intent to cross at a marked midblock crossing when they are within a predefined region surrounding an enabled crosswalk (figure 1). The pedestrian crossing signal triggers a warning message that is sent to drivers using the same app within a geofenced region around the crosswalk. The warning notifies drivers that a pedestrian is ahead to improve driver awareness and prepare drivers to yield (figure 2). This alert was intended to increase the driver’s awareness of the potential need to stop and allow the pedestrian to cross. The effectiveness of the Smartphone-based Mid-block Pedestrian Crossing In-vehicle Warning app, referred to here as the Mid-block app, was tested in a multiphase study to evaluate driver response and pedestrian usability.



Note: Regions are not to scale.

Source: FHWA, 2020

Figure 1. Illustration. Overview of the Mid-block app.

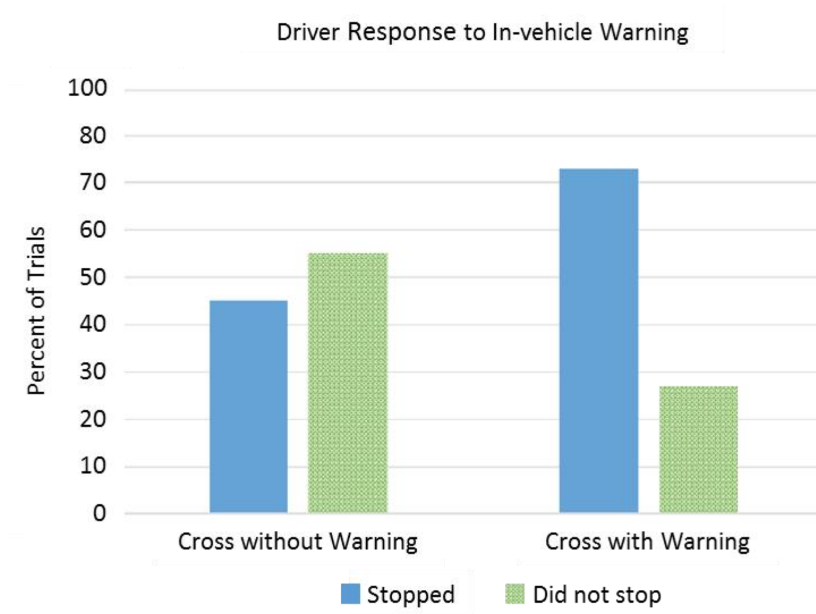


Source: FHWA, 2019

Figure 2. Screenshot. In-vehicle warning provided by the Mid-block app. The display was accompanied by alert tones and the audio message: "pedestrian ahead."

Previous Research

The U.S. Department of Transportation (USDOT) recently completed Phase 1 of the Federal Highway Administration (FHWA) Smartphone-based Mid-block Pedestrian Crossing In-vehicle Warning project. Phase 1 focused on the scenario of a driver reacting to an in-vehicle alert as a pedestrian crosses at a marked midblock crossing without active traffic control devices (e.g., traffic signal, pedestrian beacon). In this study, the Mid-block app was tested with participant drivers on a closed track at Turner-Fairbank Research Center (TFHRC) in McLean, Virginia (Federal Highway Administration, 2018). Eighty participants drove a route in which they approached a midblock crossing four times. In one of the approaches, a researcher acting as a pedestrian was present at the crosswalk and activated a crossing alert. The crossing alert triggered an in-vehicle warning consisting of the audio-visual message "pedestrian ahead" delivered via smartphone mounted on the participant vehicle's dashboard. In another approach to the crosswalk, the confederate pedestrian was again present but did not activate the crossing signal. The order in which participant drivers either did or did not receive a crossing signal was counterbalanced across the sample. Drivers who received the in-vehicle alert were more likely to stop to allow the pedestrian to cross (figure 3). In addition, although no alert was provided on the second encounter with a pedestrian, drivers who received an in-vehicle alert on their first encounter approached the crosswalk more slowly than drivers who never received a warning. These results suggested that the in-vehicle warning may reduce conflicts at marked midblock crosswalks and motivated further investigation of the app's effectiveness.



Source: FHWA, 2018

Figure 3. Graph. Percent of trials with and without a warning in which drivers stopped or did not stop ahead of the crosswalk.

Current Research

Although testing indicated favorable driver response to the Mid-block app's pedestrian safety alert, the Phase 1 study did not gather information about pedestrian interactions with the app. Considering that the Mid-block app system relies on pedestrians voluntarily triggering the in-vehicle warning, Phase 2 of the research effort employed a two-part assessment of pedestrians' attitudes toward and interactions with the app.

The first part of Phase 2 brought participants of varying ages together for focus group interviews to collect feedback on the app's interface and clarity from the perspective of a pedestrian. Interviewees were asked about their willingness to accept and use a variety of potential smartphone-based interfaces aimed at improving pedestrian safety. Points of confusion or dissatisfaction related to app interfaces were discussed, as well as the features that participants considered to be most valuable. This feedback was used to modify the pedestrian component of the Mid-block app interface to improve clarity and support proper use. Specifically, messages were added to emphasize that the crossing alert was active and to remind users that activating the alert did not guarantee safety.

Following the focus group interviews, the modified Mid-block app was field tested with participant pedestrians at three live midblock crossing locations. The pedestrian field study explored participants' comprehension of the app's role in supporting safe crossings and influence on crossing behavior in different roadway settings when an approaching vehicle was or was not present. Participants also completed a questionnaire to provide feedback on their satisfaction with and acceptance of the Mid-block app.

In the Phase 2 field study, crossing locations with various features were selected to explore the influence of roadway setting (rural, suburban, or urban), crossing configuration, and surrounding infrastructure on pedestrians' use of and attitudes toward the Mid-block app. During the experiment, 60 participants were instructed to activate the pedestrian warning before entering the crosswalk 20 times. On half of these crossings, a vehicle driven by a researcher simulating a driver who had received the in-vehicle pedestrian alert approached the crosswalk and yielded to allow the pedestrian to cross. Participant crossing behavior was measured, including the time it took to enter the crosswalk after activating the warning, the time it took to exit the crosswalk, and looking behavior toward the approaching vehicle before and during crossing. In general, any smartphone app designed to assist pedestrians with crossing a road may influence crossing behavior, so pedestrian behavior while using the Mid-block app was compared with behavior while using a simple, non-connected app designed to increase pedestrian conspicuity. This alternative app, referred to as the Flashing app, consisted of a high-contrast flashing pattern and was deployed in half of the trials in a controlled randomized order. At the end of the experiment, participants rated both apps on preference, effectiveness, and acceptance.

The results of the pedestrian field experiment indicated that pedestrian crossing behavior was similar when using the Mid-block or the Flashing app. Safety-related behaviors, such as waiting to enter the crosswalk after activating the signal and looking toward the approaching vehicle before and during crossing, were observed during use of either app. However, in later trials, participants entered the crosswalk more quickly after activating the app and completed their crossing more quickly. Roadway setting also influenced the delay between activating the app and entering the crosswalk, with the shortest delay observed at the urban location, followed by the suburban and rural locations. At the urban location, participants aged 46 or older waited significantly longer to enter the crosswalk than participants younger than 46. Finally, the post-experiment questionnaire indicated that the Mid-block and Flashing apps were rated similarly on preference, satisfaction, and acceptance. However, participants were significantly more likely to agree that the Mid-block app was helpful for detecting hazards compared to the Flashing app.

Overall, the outcomes of the pedestrian field test provide preliminary evidence that the Mid-block app neither promoted nor discouraged safe crossing behaviors relative to a non-connected smartphone-based alternative. However, users appeared to remain aware of the need to maintain their own safety and perceived the Mid-block app as having an added benefit over the flashing alternative. Although crossing behavior while using the Mid-block app was not compared to unassisted crossing behavior, the field observations and survey responses collected during the experiment suggest that pedestrians reliably comprehended and deployed the Mid-block app without introducing significantly more risk than a non-connected alternative.

Finally, the information collected from all experiments conducted in Phases 1 and 2 are used to provide recommendations and near-term needs for larger-scale field testing. Larger-scale testing could explore interactions between drivers and pedestrians using the app in a real-world, urban-like setting. A wider-scale deployment would allow the evaluation of the conditions under which the app is most often used and perceived to be most valuable. In addition, use of and response to the app over time can be explored. However, natural variations in crossing conditions, such as weather, traffic volume, and crossing geometry, as well as the proportion of the population with access to the app, may have important implications for consistency of use and, therefore, effectiveness.

Chapter 1. Human Factors Study

Introduction

Prior to conducting field testing with participant pedestrians, the pedestrian interface of the Mid-block app required assessment and improvement to ensure usability and comprehension for unfamiliar users. To collect feedback and identify potential improvements to the app interface, the first part of the Phase 2 research effort consisted of a human factors study, which took the form of a focus group interview. Two groups of volunteers provided insights on typical walking experiences, attitudes toward physical and smartphone-based pedestrian safety treatments and suggestions for effective smartphone app interfaces. These perspectives were descriptively evaluated for major themes regarding pedestrian crossing behavior and effective safety treatments. Participant feedback was also used to identify modifications to the app interface that would improve the clarity and effectiveness of operations and user messaging.

Method

Participants

Eleven participants were invited to participate in focus group interviews. Participants were divided into two groups: Group 1 was comprised of four males and two females aged 18–36, with a median age of 26. Group 2 was comprised of three males and two females aged 54–76, with a median age of 61. The two groups were interviewed on separate days. Participants provided written informed consent and received compensation for their time.

Procedure

Focus group interviews were conducted at TFHRC in McLean, Virginia. Participants were seated in front of a large monitor, which was used to display images depicting crossing infrastructure, smartphone app user interfaces, and potential user messages. Two researchers presented stimuli to participants and led the group discussion using scripted questions about their typical walking experiences and their perspectives on physical and software treatments designed to improve pedestrian safety. The script used by the researchers is provided in Appendix A. The researchers probed participants to elaborate on their perspectives, as needed. Two additional researchers were present and recorded notes on the discussion. Each interview session lasted approximately 2 hours. Two video cameras recorded the discussion and any interactions with the stimuli.

First, each focus group was asked questions about walking, both generally and considering participants' specific personal experiences. Participants were then presented with four photographs depicting real-life examples of midblock crossings. The four examples are illustrated in figure 4, figure 5, figure 6, and figure 7 and varied in their infrastructure designed to improve pedestrian safety:

- Signs and markings only.
- Rectangular rapid flashing beacon.
- Pedestrian hybrid beacon.
- Signalized crossing.

Source: Google Maps®, 2018

Figure 4. Photograph. Example Crossing 1.

Source: Google Maps®, 2018

Figure 5. Photograph. Example Crossing 2.

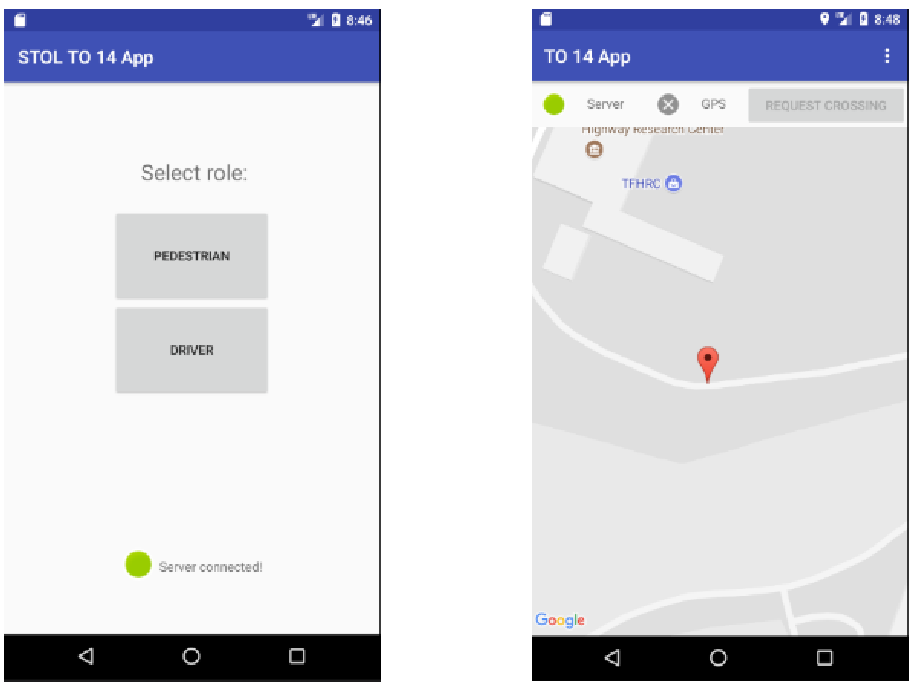
Source: Google Maps®, 2018

Figure 6. Photograph. Example Crossing 3.

Source: Google Maps®, 2018

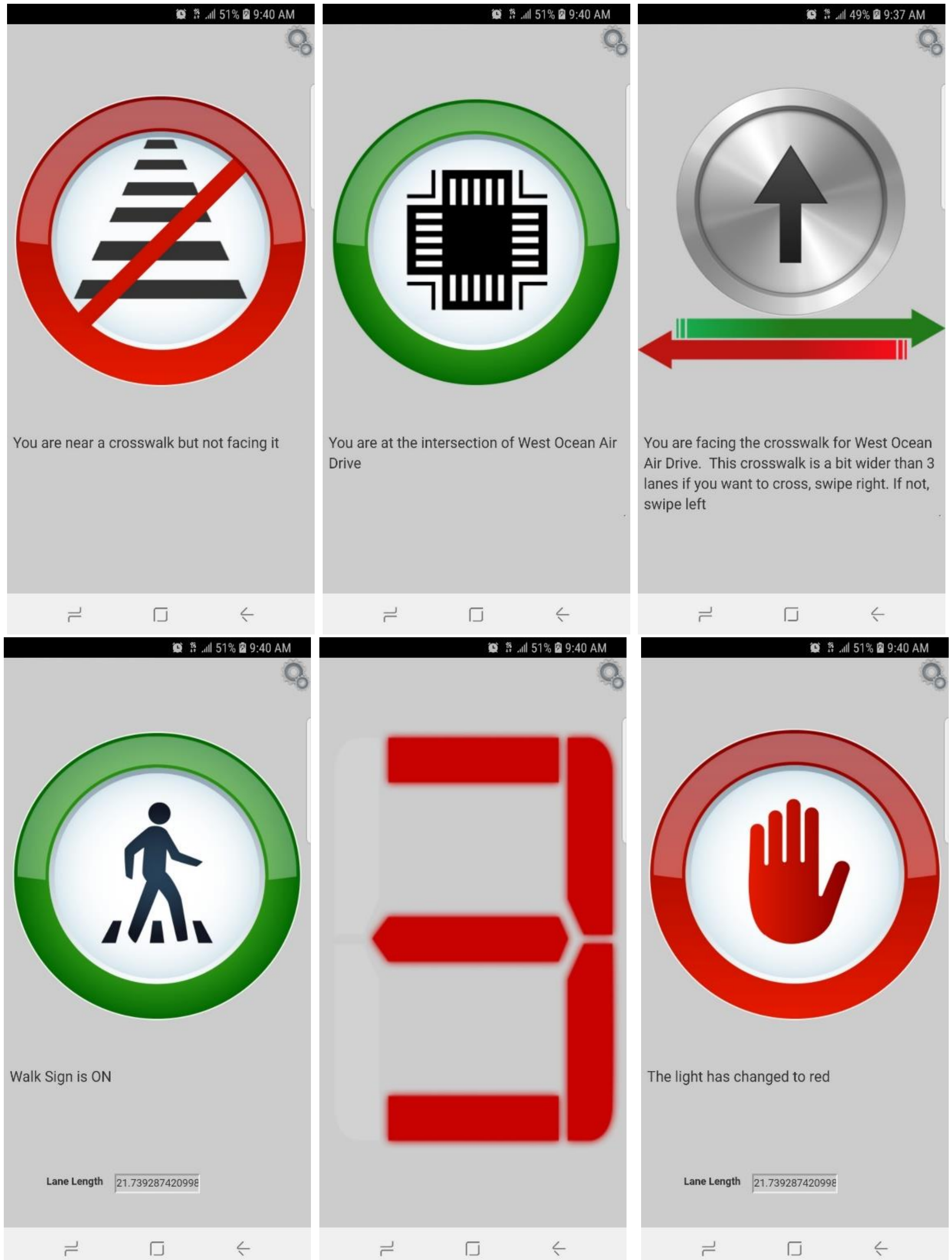
Figure 7. Photograph. Example Crossing 4.

Next, the researchers presented four distinct examples of smartphone app interfaces designed to support pedestrian safety. App interfaces appear in figure 8, figure 9, figure 10, and figure 11. Participants provided their perspectives on the clarity and usability of each app interface as well as their general thoughts on its features and appearance.



Source: FHWA, 2018

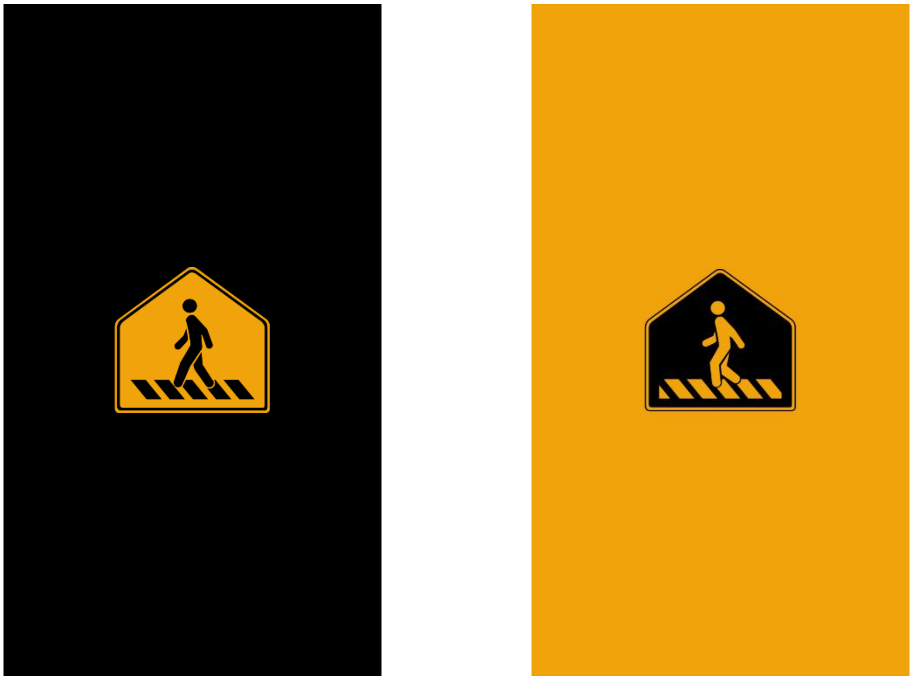
Figure 8. Screenshots. Interface design A.



Note: Images progress from left to right in each row. The symbol in the final screen was also shown with the message "Do not walk."

Source: FHWA, 2018

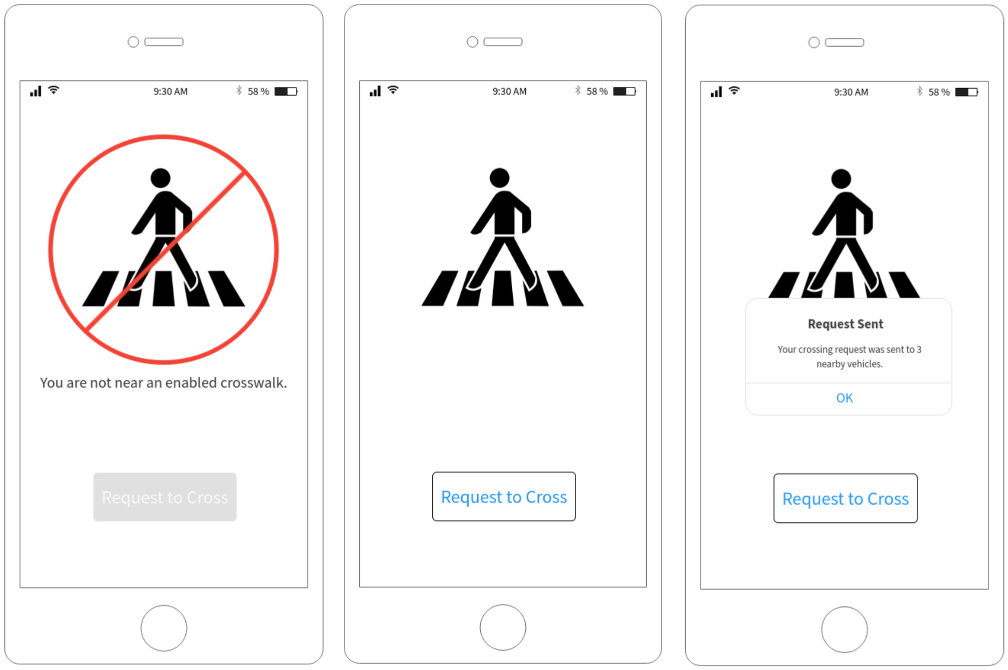
Figure 9. Screenshots. Interface design B.



Note: Simulated flashing between the two images was briefly shown to participants.

Source: FHWA, 2018

Figure 10. Illustrations. Interface design C.



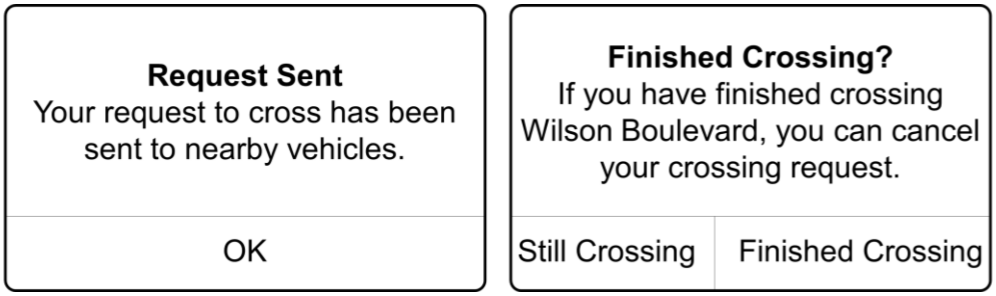
Source: FHWA, 2018

Figure 11. Illustrations. Interface design D.

Finally, participants were asked to provide feedback on the clarity and effectiveness of several app messages designed to support safe and proper use. The content of each message is provided in table 1 and an example of the each message's appearance shown to participants is provided in figure 12.

Table 1. Application messages and response options

Message	Message Content	Response Button Options
1	Request Sent. Your request to cross has been sent to nearby vehicles.	OK
2	Request Transmitted. Your crossing request has been received by 4 nearby vehicles.	OK
3	Cross the Street. It is now safe to cross Wisconsin Avenue.	OK
4	Finished Crossing? If you have finished crossing Wilson Boulevard, you can cancel your crossing request.	Still Crossing; Finished Crossing
5	Cross with Care. Look both ways and make sure vehicles are yielding to you before you cross.	OK
6	Warning. Drivers may not have the crossing app. Use caution when crossing the street.	OK



Source: FHWA, 2018

Figure 12. Illustrations. Application Messages 1 and 4, illustrating the template in which messages were shown to participants.

Data Reduction

Following the focus group interviews, two researchers reviewed the recordings, noted major discussion themes, and conducted a partial transcription of discussion points relevant to the scripted questions. The two sessions were reviewed and transcribed separately. Once data reduction was completed, the recordings were destroyed to maintain participant privacy.

Results

General Experiences

When asked to describe positive experiences while walking, both groups of interviewees highlighted infrastructure elements that support pedestrian travel, such as signalized intersections, signalized pedestrian crosswalks, and marked crosswalks. Group 1 also noted that the presence of other pedestrians was associated with positive walking experiences.

When asked for negative walking experiences, both groups cited conflicts with other road users. Participants commented that ambiguity in right-of-way causes stress for crossing pedestrians. Participants in Group 1 cited a location in nearby Washington, DC as an example of a location at which pedestrians often conflict with right-turning vehicles. Similarly, Group 2 cited the intersection of a walking trail and a suburban road in Virginia for its ambiguity in right-of-way caused by a midblock crossing occurring in close proximity to a signalized intersection.

The two groups differed on their general reaction to the concept of a smartphone-based midblock crossing app, with Group 1 being generally receptive to the idea and Group 2 expressing more skepticism. While these initial thoughts differed, both groups indicated that such a treatment would need to demonstrate effectiveness and ease of use before it would be accepted by road users.

Infrastructure Treatments

As previously mentioned, physical infrastructure to support walking was frequently associated with positive walking experiences for both groups. More specific feedback on the types of infrastructure that participants founds to be most beneficial for pedestrian safety was collected during review of the four real-life examples presented to the groups. Table 2 summarizes general feedback provided on real-life crossing examples, aggregated over both groups.

Table 2. Summary of common feedback received for four crossings

Example Crossing	Desirable Elements	Undesirable Elements	Suggested Improvements
1	• Median refuge island.	• No lights (neither traffic control devices nor streetlights).	• Improve pedestrian visibility.
2	• Flashing yellow lights.	• Unclear right-of-way implications of rectangular rapid flashing beacon. • Poor maintenance, including signs and lane markings. • Location of waiting area pins pedestrians between cars and guardrail.	• Restripe pavement. • Update signs. • Relocate waiting area. • Change traffic control devices.
3	• Clear signing. • Staggered crosswalks.*	• Staggered crosswalks.* • Narrow crossing.	• Increase size of signing.
4	• Clear traffic control operations. • Wide crosswalk. • Good visibility.	• Good visibility and straight crossing may encourage pedestrians to violate the signal.	• None noted.

* = mixed positive and negative comments.

General comments from both groups indicate that participants appreciated well-maintained infrastructure that provides clear guidance about right-of-way. For example, rectangular rapid flashing beacons were appreciated as an infrastructure improvement, but participants in both groups were confused about whether the device was intended to provide permissive right-of-way for the pedestrian or merely serve as a cautionary warning for drivers. Less ambiguous traffic control devices (i.e., the signalized crossing illustrated in Crossing Example 4) were described as being easier to understand and were perceived favorably by both groups. Regarding the combination of physical infrastructure and a smartphone-based app, participants in Group 1 indicated that an app should not be presented as a compensatory measure to improve safety at an otherwise poorly maintained crossing, but rather as a measure to complement existing infrastructure treatments.

Application Interfaces

Table 3 summarizes feedback and suggestions collected from both groups.

Table 3. Summary of common feedback received for four smartphone interfaces

Interface Design	Desirable Elements	Undesirable Elements	Suggested Improvements
A	• Simple design. • “Server connected” reassures user and aids in troubleshooting.	• Lack of explanation/unclear function. • Apparent discontinuity across screens. • Lack of context in map image.	• Include symbols/icons to improve comprehension. • Relocate “Request” button to easier-to-access location.
B	• Clear graphic design supplemented by colors and symbols. • Some explanation provided by text description of current status.	• Unclear/confusing pairing of colors and symbols with messages. • Unclear required actions. • Apparent discontinuity across screens. • Unclear how holding phone affects app functionality.	• Remove swiping interface and replace with button press. • Remove lane length measurement.
C	• Clear overall design. • Easy to use and understand.	• Requires free hand throughout the crossing. • Flashing could be misinterpreted by drivers or mistaken as a vehicle.	• Activate camera flash to further increase visibility.
D	• Simple, symbol-based design. • Easy to understand.	• Plain; design lacks detail.	• Include crossing direction and street name.

Participants generally preferred design elements that informed the user of the app’s connectivity status to the system server, afforded easy access to action buttons, increased pedestrian conspicuity to drivers, and provided clear direction for proper use and sequence of actions. Participants also provided positive feedback for app interfaces that included unambiguous and directly relevant map images. Interface design C was described as easier to comprehend and trust due to its simple design and straightforward purpose for facilitating increased visibility to drivers. Given that participants viewed static screen examples and were provided with minimal context or explanation for each app concept, participants tended to prefer simple graphic designs that focused on essential information that reflected the app’s current state, operating status, and appropriate sequence of actions. Without these components, participants indicated reduced willingness to use or trust the app.

Groups 1 and 2 provided several distinct observations regarding the example app interface designs. Group 1 participants voiced concerns regarding the implied role of the phone's orientation in design B when the user was standing near a crosswalk, but not facing the crosswalk. Specifically, participants in Group 1 were concerned that the phone orientation required to be categorized as facing the crosswalk may be unnatural or difficult to achieve. Because the app design suggested that pedestrians should be facing a crosswalk before they signaled a crossing, this could lead to difficulties in using the app. One participant in Group 1 recommended that, due to the complexity and number of steps involved in design B, a tutorial be provided during the app's first use to improve user comprehension.

Group 1 participants also noted that adding a camera flash to the flashing screen feature illustrated in design C could further increase visibility. Conversely, Group 2 participants were skeptical that design C would be sufficient to meaningfully improve pedestrian visibility and were concerned that the flashing pattern could be misinterpreted as the flashing lights of an emergency vehicle. In addition, Group 2 participants noted that design C would require a pedestrian to use a free hand to display the phone screen toward traffic while crossing, which could be challenging for pedestrians holding shopping bags or children's hands. Finally, Group 2 participants expressed concerns with the efficacy and usability of the app in adverse weather conditions.

Overall, responses to the smartphone app interfaces emphasized well-defined usability and functionality, with a preference for functions that offered clear benefits for crossing safety. Participants also tended to consider a wide range of user abilities, such as visual or mobility impairments, when evaluating the effectiveness of an app interface. Elements such as bold colors, simple and uncluttered graphic designs, and symbols that clearly represented appropriate user actions were considered favorable for the general population as well as users with specialized needs.

Application Messages

The messages shown to participants varied in their phrasing and content to identify elements that improve user comprehension and trust and support proper use. Participant responses to message content and phrasing were considerably fine-grained. Message 2, which alluded to the number of cars receiving the crossing signal, was deemed unfavorable by both groups due to the ambiguity in the number of total cars in the area compared to the number of cars receiving the signal. Some participants also cited difficulty trusting an app that was only able to communicate with a small subset of enabled cars, as indicated in Message 6. Importantly, participants in both groups noted that the term "request," as used in Messages 1, 2, and 4, implied a permissive or confirmatory response from drivers who received the request. As an alternative, Group 1 participants proposed that the term "signal" replace the term "request."

Both groups favored including a warning message, similar to Message 5, to remind participants to use their own judgment when crossing the street, thus engaging pedestrians and reinforcing accountability for their own safety. A participant in Group 1 suggested that Message 5 appear directly following a crossing signal sent by the user. Several participants in Group 2 thought it would be helpful for Message 5 to recur periodically while using the app to prevent users from becoming complacent over time. In keeping with this mindset, Group 2 participants thought Message 3, which told the user it was safe to cross, was inappropriate because it emphasized the app's determination of safety rather than the user's. Group 2 participants were less concerned with the implications of Message 3, but were confused about when and why this message would appear in the app.

Message 6, which gave participants the option to cancel the crossing request after finishing their crossing, was poorly received. Participants asserted that the option would largely be unused, as users would be unlikely to return to the app once their crossing was completed. In addition, participants noted that monitoring the phone to select the “still crossing” option instead of scanning the surrounding area could put pedestrians at further risk. To solve these issues, Group 2 participants recommended the app automatically terminate the crossing function by detecting when the pedestrian had reached the end of the crosswalk.

Discussion

The goal of this study was to gain insights on pedestrians’ perceptions of safety and obtain feedback on smartphone apps designed to support safe pedestrian crossings. Responses from participants will be used to inform modifications of the existing pedestrian interface of the FHWA Smartphone-Based Mid-Block Pedestrian Crossing In-Vehicle Warning system to make it more appropriate for use by participant pedestrians in upcoming field tests. Two groups of volunteers provided their opinions on safety while traveling as a pedestrian and shared their ideas on potential smartphone-based treatments to aid pedestrians during street crossings in focus group interviews.

The results of this study provide direction for updating the app interface previously used in the Phase 1 experiment. Focus group participants’ feedback suggests infrastructure that is desirable for improving pedestrian safety should support pedestrian visibility, provide clear expectations for right-of-way, and encourage vehicles to stop early. Ideally, a smartphone-based safety system should attempt to accomplish these goals as well.

To support driver and pedestrian visibility, focus group participants indicated that smartphone-based safety systems should focus on simple, clear, and easy-to-use interfaces that require minimal instruction. Focus group participants suggested that a straightforward, single-button interface would support both accessibility and desirability of use. Given the greater sense of trust and reliability associated with physical infrastructure treatments, smartphone-based safety systems could benefit from integration with existing infrastructure by identifying enabled crosswalks in the app, posting advisories at the crosswalk, or a combination thereof. In doing so, the app may become more reliable and trustworthy by allowing pedestrians to clearly identify which crosswalks are compatible.

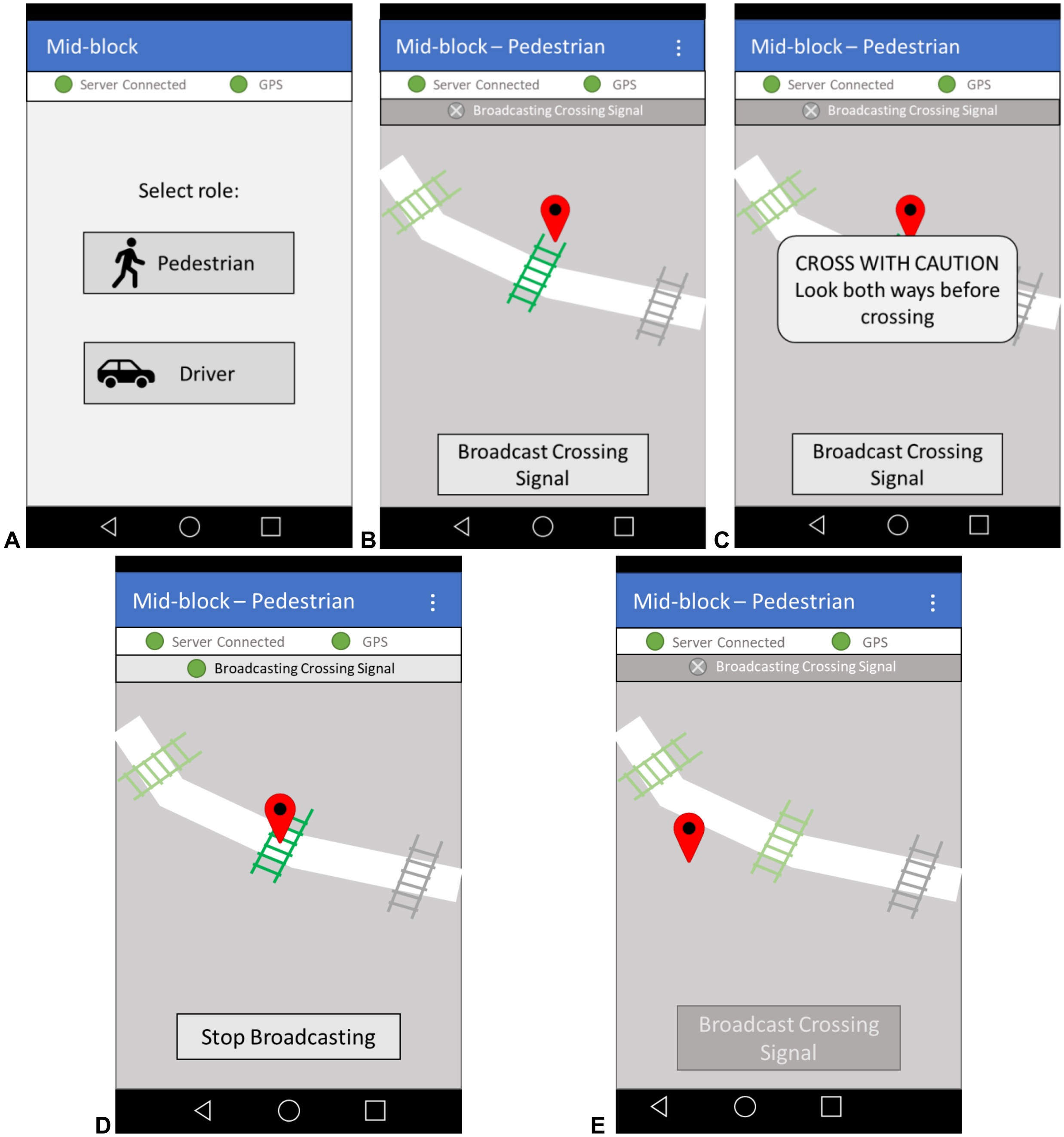
The focus group outcomes also suggested an app interface should reassure users that the app is functioning properly and has access to necessary wireless and/or data servers. However, the app should not give a false sense of security that drivers are guaranteed to yield in response to the app’s signal. As a result, the interface should provide consistent and clear indicators of its operating status (e.g., server connection, GPS location, whether the crosswalk is enabled for the app) as well as instruct pedestrians to remain vigilant and responsible for their own safety when crossing.

Focus group participants displayed a strong preference for app messages that further reinforce pedestrian responsibility at crossings. Unless the system can ensure that vehicles will stop for the crossing pedestrian, pedestrians should be reminded to look both ways and cross with care. Messages that were presented in the affirmative (e.g., “Look both ways and cross when it is safe”) rather than in the negative (e.g., “Drivers may not have the application and may not stop”) were preferred for supporting the app as a useful crossing aid. Participant feedback indicated language related to broadcasting a crossing signal was preferred over requesting a crossing, as a request suggested the need for acknowledgement from recipient drivers. However, if vehicles become capable of sending an automatic confirmation of the successful transmission of the crossing signal via connected systems, this feature could be feasible for future exploration.

Additional human factors issues noted by the focus groups included the reliability of drivers using the same app, the risk of users over-relying on the app to ensure safety, and the potential for the pedestrian to become distracted by the app or smartphone in general. Focus group participants also noted potential challenges for pedestrians carrying other items, traveling with children, or using the smartphone for other activities. These concerns were recorded for additional consideration but could not be addressed in the current research effort.

Next Steps

Based on results collected during focus group interviews, a modified interface incorporating four major themes from the focus groups was proposed: (1) clear, uncluttered design; (2) elements that communicate essential information to support comprehension and use; (3) direct relationship to the user’s physical location and intended actions, and (4) messages that remind the user to be accountable for their own safety by monitoring the road. The proposed modified interface provided in figure 13 illustrates the progression of screens as a user opens the app at a desired midblock crossing location and completes the crossing.



Source: FHWA, 2019

Figure 13. Illustrations. Proposed modifications to the Mid-block app interface based on focus group feedback.

While information gained from the focus groups provides formative guidance about the design of smartphone apps to aid pedestrian crossings, it also revealed strong opinions about the role and effectiveness of physical infrastructure in supporting pedestrian safety. Throughout the interviews, participants expressed concerns about the state of maintenance and upkeep of real-life examples of pedestrian infrastructure. While it is beyond the scope of the current research project, future implementations of smartphone-based pedestrian systems may explore the feasibility and effectiveness of apps that cooperate with signs or other infrastructure devices. Based on feedback from this study, pedestrians will be more receptive to smartphone-based interventions if they are perceived as complementary to existing infrastructure rather than compensatory.

Chapter 2. Pedestrian Field Test

Introduction

The following experiment builds on previous research evaluating pedestrians' use of and attitudes toward the modified version of the Mid-block app interface. Although changes were made to the app's pedestrian interface following the human factors study, the app's architecture and function remained the same as it was in Phase 1 (figure 1).

Testing was conducted at three live locations with marked midblock crosswalks to assess potential hazards and safety benefits associated with the app, as well as the likelihood that pedestrians would be willing to use the app as intended. In the absence of collision data, the safety benefits of the app could not be directly measured. However, the following expectations were used as a proxy for pedestrian safety during crossing:

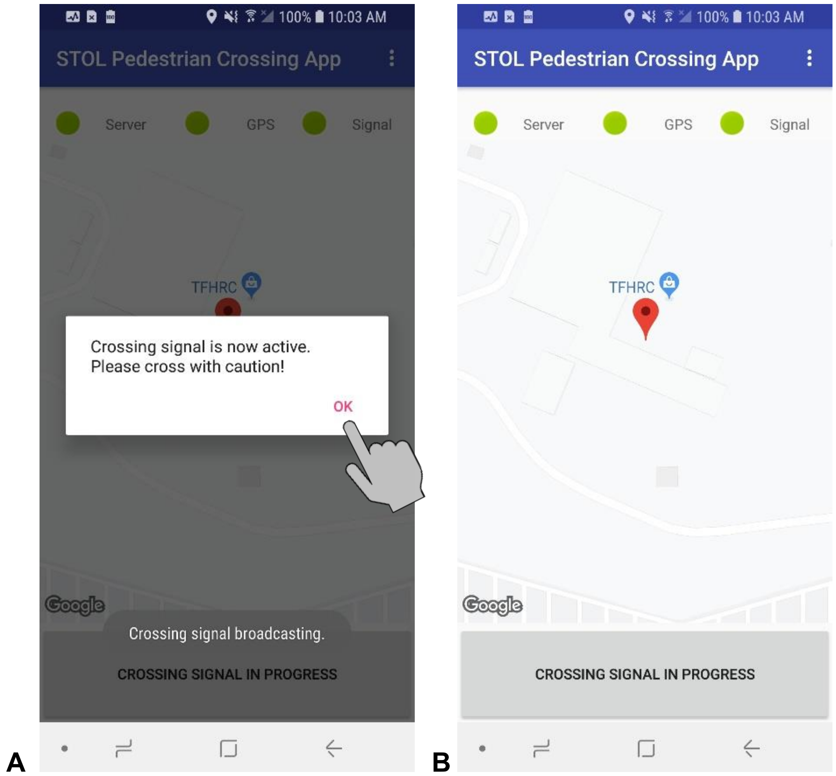
- When using the app, pedestrians should engage in safe behaviors before and during crossing, such as negotiating nonverbally with the driver, confirming the vehicle is yielding, and monitoring vehicle traffic.
- The Mid-block app should not distract users from monitoring traffic or the roadway more so than a comparable smartphone-based alternative.
- Users should find the Mid-block app beneficial during crossing, or at least not worse than crossing while using a comparable smartphone-based alternative.
- Users should trust the Mid-block app enough to want to use it, but should not become overconfident to the point where they reduce safety behaviors such as traffic monitoring.

Methodology

Smartphone Apps and User Interfaces

As previously mentioned, Phase 1 of the research effort exclusively investigated drivers' reactions to the in-vehicle pedestrian warning provided by the Mid-block app (figure 2). The current experiment explored the pedestrian component of the Mid-block app. Therefore, the driver interface was not used.

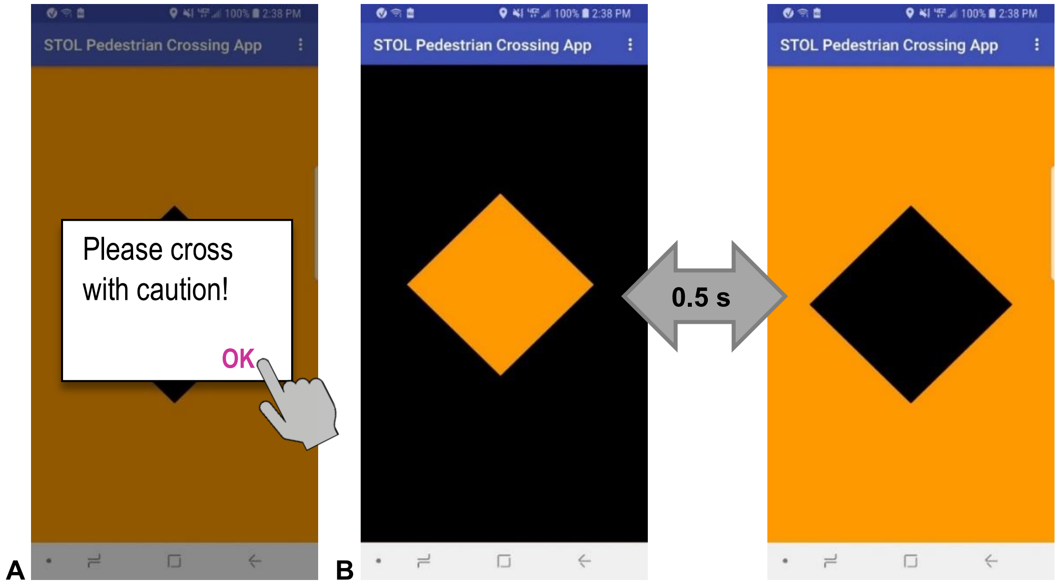
The pedestrian component of the Mid-block app provided users with a map of their general location and allowed them to activate a signal communicating their intent to cross the street. Activating the signal transmitted a message to nearby vehicles with devices running the app that a pedestrian was ahead. The user interfaces displayed during signal activation are presented in figure 14.



Source: FHWA, 2020

Figure 14. Screenshot. Progression of user interfaces when a signal was activated in the Mid-block app.

Because using a smartphone, in general, could influence crossing behavior, the Mid-block app was compared to a simple alternative app designed to increase pedestrian visibility during crossing. The alternative app increased the pedestrian's smartphone screen brightness and displayed two high-contrast images that alternated approximately every 0.5 seconds to increase the pedestrian's visibility when displayed to an approaching vehicle (figure 15). This high-contrast flashing app is referred to as the Flashing app in this report.



Source: FHWA, 2020

Figure 15. Screenshot. Progression of user interfaces when a signal was activated in the Flashing app.

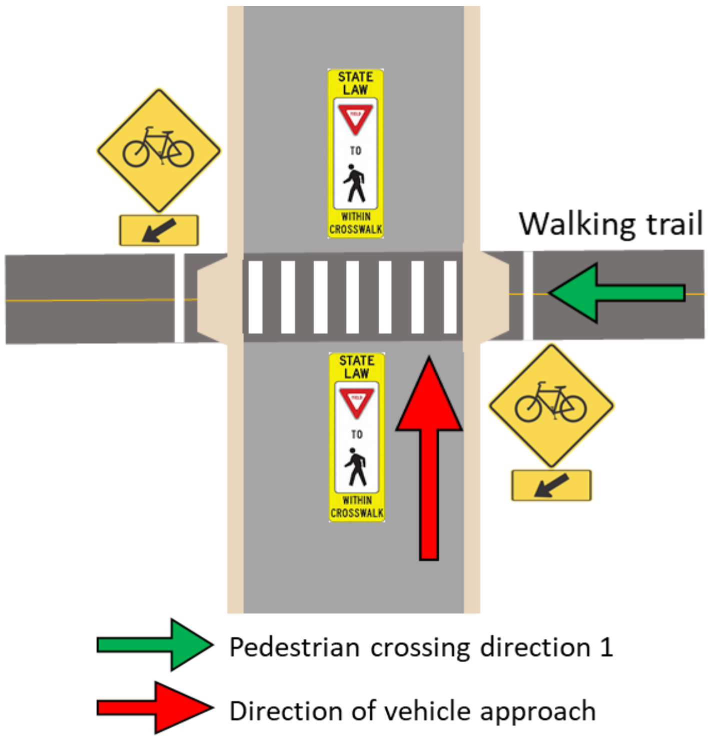
Test Sites

Testing was conducted at three live road locations in northern Virginia to evaluate the effect of the Mid-block app on pedestrian crossing behavior in real-world environments. The selected sites were distinguished by development density and categorized as suburban, urban, and rural based on the surrounding roadway, business, and residential infrastructure density. Each site had a maximum speed limit of 35 miles per hour (mph) and an estimated average of fewer than 8,000 vehicles per day, as rated by local departments of transportation and traffic-tracking navigation services. The specifications and speed limits for each site are provided in table 4.

Table 4. Test sites

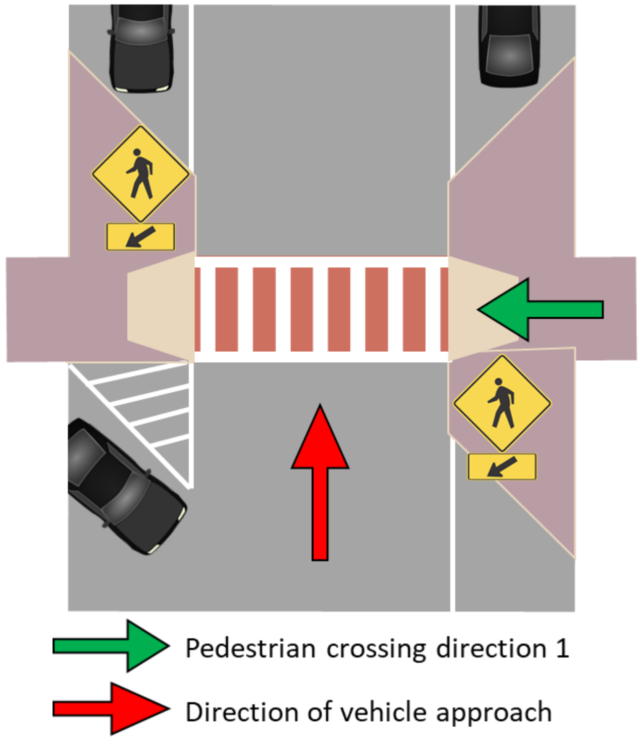
Site Number	Category	Speed Limit (miles per hour)	Approximate Length of Crosswalk (feet)
1	Suburban	25	27
2	Urban	25	25
3	Rural	35	23

The three sites were chosen for their variation in surrounding roadway geometry and infrastructure density to investigate if site features influenced the use and effectiveness of each app. Each location had a marked crosswalk and accompanying signage specifying bike or pedestrian use. Site 1 had one lane in each direction, whereas the crosswalks at Sites 2 and 3 spanned a single lane shared between two directions. The crosswalks at Sites 1 and 3 connected multi-use recreational nature trails, whereas Site 2 connected two open-air social spaces in an urban business center. The variations in geometry, signing, and appearance of Site 1, Site 2, and Site 3 are depicted in figure 16, figure 17, and figure 18, respectively. The green arrow in each figure indicates the direction in which participants crossed the road on Trial 1 at each site. On Trial 2, the participant crossed back toward the initial starting point. The red arrow indicates the direction from which a vehicle driven by a researcher approached the crosswalk in trials involving a confederate vehicle. Further details are provided in the Procedure section.



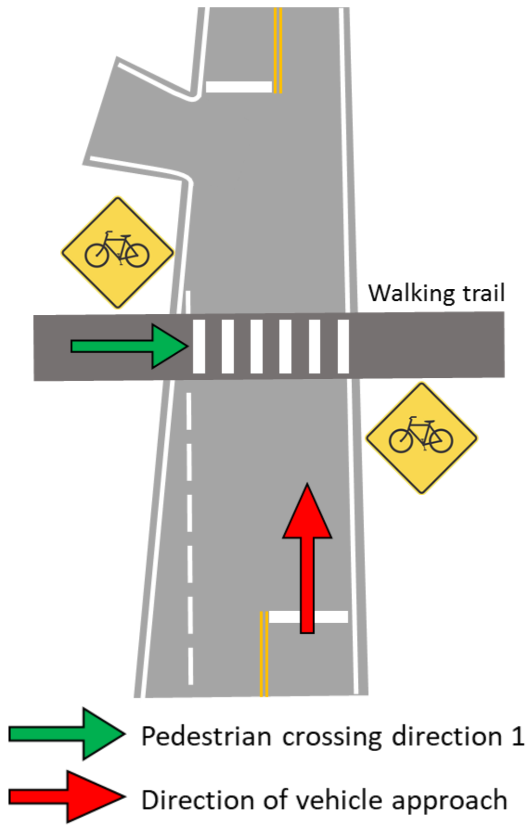
Source: FHWA, 2020

Figure 16. Illustration. Suburban test site (Site 1).



Source: FHWA, 2020

Figure 17. Illustration. Urban test site (Site 2).



Source: FHWA, 2020

Figure 18. Illustration. Rural test site (Site 3).

Participants

Sixty-one participants aged 21 to 79 and a mean age of 48 were recruited from the local community. However, one participant's data were excluded from analysis due to experimental error, resulting in a sample with an equal number of males and females (mean age did not change). This sample also represented an equal number of participants aged 18 to 45 and 46 or older. All participants reported normal vision and mobility, provided written informed consent, and received compensation at a rate of $40 per hour.

Procedure

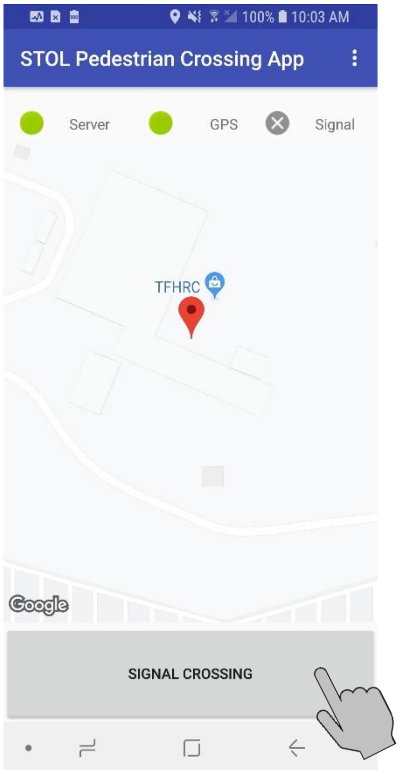
Participants met the researcher at a designated location near the midblock crosswalk. The researcher greeted participants and provided consent documents to sign and return that explained the purpose of the study, benefits, and risks. Next, participants were given an Android™ phone with the Mid-block and

Flashing apps installed. The researcher then provided participants with a wearable headset that recorded participants' interactions with the app and movement through the crosswalk.

The researcher provided brief instructions on the appearance and use of both apps and how to activate the crossing signal. For the Mid-block app, participants were given general instructions that any nearby vehicles using the same app would receive a notification that a pedestrian is at the crosswalk. Participants were also reminded that not all vehicles have this system. For the Flashing app, participants were instructed to orient the phone toward traffic to increase their visibility for nearby drivers. The researcher also made it clear that participants remain responsible for their own safety and should decide to cross only when they felt it was safe.

During experimental trials, participants were instructed to activate the smartphone crossing signal prior to each of 20 crossings (10 crossings from either side of the crosswalk). For each trial, participants stood at the designated starting position, faced the crosswalk, and closed their eyes. Closing their eyes in between trials prevented participants from monitoring their surroundings and planning their crossings prior to the start of the trial. The experimenter indicated the start of a trial by telling participants to open their eyes and cross when they felt it was safe. The researcher attempted to start trials when minimal vehicular and non-motorist traffic was present. However, other road users (including pedestrians and bicyclists and, less frequently, vehicles) were present during some trials, but additional traffic could not be recorded due to insufficient resources.

At the start of each trial, participants were presented with the screen shown in figure 19. Participants could choose when to activate the app by tapping the Signal Crossing button before entering the crosswalk. After tapping the Signal Crossing button, either the Mid-block or Flashing app was activated according to one of two randomized patterns equally distributed across participants: ABBA or BAAB, where A represents the Mid-block app and B represents the Flashing app. This pattern resulted in 10 trials with each app across the 20 crossings for each participant.



Source: FHWA, 2020

Figure 19. Screenshot. App screen used to initiate the Mid-block or Flashing app at the start of each trial.

Vehicle Approach

On half of the 20 crossing trials, a sedan driven by a confederate experimenter playing the role of an average driver approached the crosswalk at the start of the trial. Participants were not made explicitly aware that this driver was part of the experiment. Vehicle trials occurred in one of two predetermined orders for each participant. The researcher at the crosswalk announced the start of trials when the confederate vehicle would be clearly visible to participants. On each approach trial, the confederate driver approached the crosswalk at the posted speed limit, from the directions listed in figures 3–5, and always stopped ahead of the crosswalk to allow participants to cross. A camera mounted on the dashboard of the confederate vehicle recorded participant crossing behavior during vehicle approach trials. A breakdown of trial conditions is provided in table 5 and additional detail on the order of conditions is shown in Appendix B.

Table 5. Number of crossing trials by app and confederate vehicle approach

Smartphone App	Confederate Vehicle Present	Number of Trials
Mid-block app	Yes	5
	No	5
Flashing app	Yes	5
	No	5
Total		20

After completing all 20 crossing trials, participants completed a questionnaire about their perceptions of the ease of use and potential safety effectiveness of each app and their willingness to use and trust each one. The questions about trust and acceptance assessed the degree to which participants understood each app, believed it benefited their safety, and were willing to use it. The survey also asked participants to indicate if they would prefer to use the Mid-block or Flashing app in their regular lives. Responses were provided on a 1–5 Likert scale adapted from Van Der Laan, Heino, and De Waard (1997) and Gold, Körber, Hohenberger, Lechner, and Bengler (2015). Questionnaire items are shown in Appendix C.

Analysis

Dependent Measures

The head-mounted camera worn by the participant recorded smartphone interactions and crossing behavior for all 20 trials. The camera mounted inside the confederate vehicle captured a wider view of crossing behavior in trials with the approaching confederate vehicle. Video recordings from the head-mounted camera were used to calculate the elapsed time from when participants activated the crossing signal and first entered the crosswalk. The time elapsed from when participants entered and exited the crosswalk was also measured. In trials with an approaching confederate vehicle, the dash-mounted camera recorded participants glancing toward either side of the road before entering the crosswalk and while crossing the road. Major head movements toward the approaching vehicle were coded as looking behavior. The key dependent measures coded and explored in the analyses are described in table 6.

Table 6. Dependent measures and performance metrics.

Dependent Variable	Data Source	Units
Signal activation	Head-mounted video	Time (seconds)
First step into crosswalk	Head-mounted video	Time (seconds)
First step out of crosswalk	Head-mounted video	Time (seconds)
Looking toward approaching vehicle	Vehicle dashboard-mounted video	Yes/no prior to crossing and during crossing
Stated preference/ willingness to use	Questionnaire	Mean rating (5-point Likert scale)
Stated trust	Questionnaire	Mean rating (5-point Likert scale)

Design

As shown in table 7, this study included three within-subjects variables of interest: app, crossing direction, and vehicle approach. Behavioral measures for each participant were compared across these three factors to identify effects on individual behavior. Trial number was included as a covariate in each analysis to assess changes in crossing behavior over time. Age group (younger than 46 and 46 or older) and gender (male or female) were analyzed as between-subjects group variables to better understand demographic differences in pedestrian crossing behavior.

Table 7. Independent variables used for analyses

Independent Variable	Levels
App	Mid-block app Flashing app
Crossing direction	Initial direction Return direction
Vehicle approach	Yes No

The elapsed time between signal activation via button tap and the first step into the crosswalk was defined as the crossing delay. These data were analyzed using a generalized linear model (GLM) with a Gaussian distribution. Gender, age group, app, vehicle approach, crossing direction, site, and trial, and their interactions, were explored for their relationships to crossing behavior. Looking behavior in trials involving an approaching confederate vehicle was analyzed with the same variables, and their interactions, using a GLM with a logit link function and binomial distribution.

Responses to each post-experiment questionnaire item were coded based on agreement with positive, neutral, or negative statements. Responses to each item were compared within-subjects to identify significant associations with user behavior during crossing. Responses to each item were also compared between-subjects to assess differences by age group and gender. Survey responses were analyzed using a logistic regression to explore relationships between gender, age group, site, and app, and their interactions.

One participant (an older female at Site 3) unintentionally duplicated a previously completed testing condition and was excluded from the analysis. Additional data were lost for some trials due to the limited lateral range and resolution of the cameras, which prevented participant behaviors from being sufficiently captured (table 8). An examination of missing data indicated that the distribution of missing trials was not heavily biased toward any group. Therefore, partial participant data were retained for analysis.

Table 8. Summary of missing video data

Site	Percent Missing Head-Mounted Video Data	Percent Missing Car-Mounted Video Data	Percent Missing All Video Data
1	5	10	15
2	5	0	5
3	15	0	10

Results

The aim of this study was to compare crossing behavior of participants using the Mid-block app to cross a roadway with their crossing behavior when using the Flashing app. Attitudes toward and acceptance of each app were also evaluated. Accordingly, the main effect of app and two-way interactions between app and other factors in the model were the primary effects of interest and are described below. Other statistically significant main effects and interactions are reported but not discussed in detail.

Crossing Time

Differences in crossing time may provide insight into how pedestrians monitor the safety of a crossing situation. In this study, pedestrians were asked to cross while using the Mid-block or Flashing app when there was minimal or no vehicular traffic and when a confederate vehicle was approaching. Crossing time was not significantly different when participants used the Mid-block app compared to when they used the Flashing app, $\chi^2(1) = 0.73$, $p = .3937$. However, the interaction between app and gender was statistically significant at $\chi^2(1) = 5.67$, $p = .0173$. On average, men took 0.12 seconds longer to cross the road when using the Mid-block app compared to when using the Flashing app. In contrast, women took 0.1 seconds longer to cross the roadway when using the Flashing app compared to when using the Mid-block app. The difference in crossing time between apps for women was not significant. The App x Age Group, App x Vehicle Approach, App x Crossing Direction, and App x Site two-way interaction terms were not statistically significant.

The main effects of vehicle approach, $\chi^2(1) = 15.87$, $p < .0001$, site, $\chi^2(2) = 8.82$, $p = .0122$, and trial, $\chi^2(1) = 3.92$, $p = .0476$, on crossing time were statistically significant. Crossing time was significantly faster in the presence of an approaching confederate vehicle (5.21 seconds) compared to when there was minimal to no vehicular traffic (5.41 seconds). Differences in crossing time across sites reflected differences in crosswalk length and the surrounding environment. Average crossing time was shortest at suburban Site

1 (4.78 seconds), which had a 25-foot crossing distance, followed by rural Site 3 (5.44 seconds), which had a 23-foot crossing distance, and urban Site 2 (5.72 seconds), which had a 25-foot crossing distance. Finally, on average, participant crossing times decreased during the session as more trials were completed.

Crossing Delay

Pedestrians should pause to observe the road and traffic before crossing midblock. Crossing delay, or the time from when participants activated the signal to when they entered the street, was examined to determine if notifying an approaching vehicle of the intention to cross encouraged participants to cross the road sooner. However, crossing delay when participants used the Mid-block app was not significantly different from when participants used the Flashing app, $\chi^2(1) = 0.03$, $p = .87$.

On average, participants waited significantly longer ($M = 4.15$ seconds) to cross the roadway from the initial starting position compared to when they returned to the starting point at each site ($M = 3.83$ seconds), $\chi^2(1) = 5.13$, $p = .0235$. The effect of crossing direction on crossing delay appeared to be moderated by app, but the interaction was not significant, $\chi^2(1) = 3.36$, $p = .07$. The App x Gender, App x Age Group, App x Vehicle Approach, and App x Site two-way interactions also failed to reach statistical significance.

A significant main effect of trial on crossing delay was found, $\chi^2(1) = 14.27$, $p = .0002$. On average, crossing delay significantly decreased as participants completed more trials. The main effect of site on crossing delay was also statistically significant, $\chi^2(2) = 24.34$, $p < .0001$. Participants waited significantly longer to begin crossing the 23-foot crosswalk at rural Site 3 (5.07 seconds) compared with the 27-foot crossing at suburban Site 1 (3.18 seconds) and the 25-foot crossing at urban Site 2 (3.72 seconds). The two-way interaction between site and gender, $\chi^2(2) = 12.01$, $p = .0025$, and two-way interaction between site and age group, $\chi^2(2) = 6.18$, $p = .0454$, were also statistically significant. At rural Site 3, women had a significantly longer crossing delay compared to men. Participants who were 46 years or older also took significantly longer to begin crossing the roadway at urban Site 2 compared to participants younger than 46. No other effects were statistically significant.

Looking Behavior

The likelihood of looking toward the approaching confederate vehicle was analyzed to examine participant awareness and responsibility for one's own safety. The likelihood of looking toward the confederate vehicle prior to entering the crosswalk was analyzed separately from the likelihood of looking toward the confederate vehicle after entering the crosswalk. This analysis only included data from trials with an approaching confederate vehicle.

Prior to entering the crosswalk, participants were no more likely to look toward the approaching confederate vehicle when using the Mid-block app than when using the Flashing app, $\chi^2(1) = 0.32$, $p = .5726$. However, the likelihood of looking toward the approaching confederate vehicle prior to crossing the roadway was significantly different between men and women across the two smartphone apps, $\chi^2(1) = 6.99$, $p = .0082$. The odds of men looking at the approaching confederate vehicle prior to entering the crosswalk were 3.2 times more than the odds of women when using the Flashing app, but only 1.2 times the odds of women when using the Mid-block app. None of the other two-way interactions that included the app factor were statistically significant.

The analysis also indicated that, in general, men were significantly more likely to look toward the approaching confederate vehicle prior to entering the crosswalk than women, $\chi^2(1) = 4.43$, $p = .0353$. This gender difference varied significantly by site, $\chi^2(2) = 12.27$, $p = .0022$, and was most pronounced at suburban Site 1.

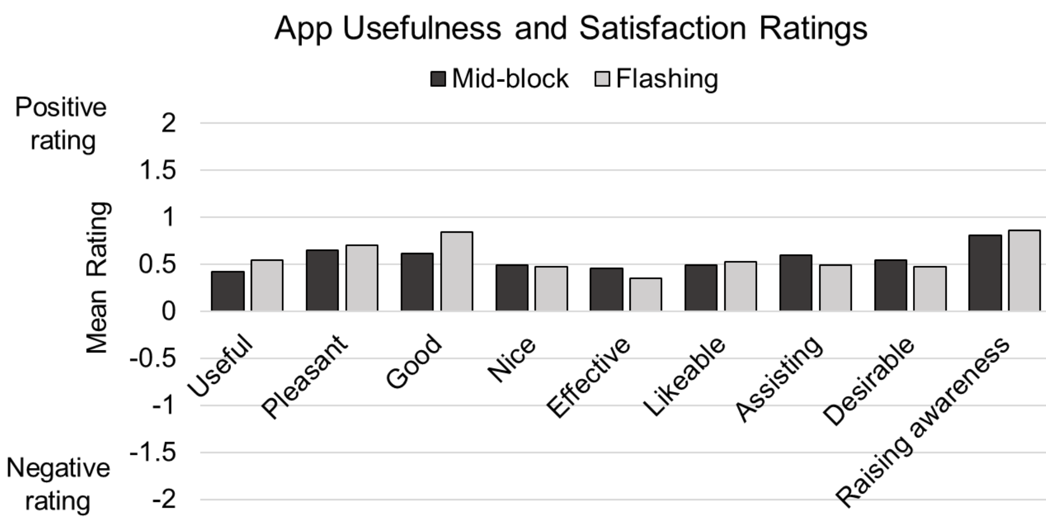
The likelihood of looking toward the approaching vehicle after entering the crosswalk was examined. Participants were slightly less likely to look at the approaching confederate vehicle when in the crosswalk while using the Flashing app compared to when using the Mid-block app. However, the effect failed to reach statistical significance, $\chi^2(1) = 3.39$, $p = .07$. None of the two-way interactions that included the app factor were statistically significant.

The two-way interaction between site and crossing direction was the only other effect in the model that had a significant influence on the likelihood of looking toward the approaching confederate vehicle when in the crosswalk, $\chi^2(2) = 19.71$, $p < .0001$. Participants were significantly more likely to look toward the approaching vehicle when traversing the crosswalk in the initial crossing direction at rural Site 3 compared to when returning back to the starting position. In contrast, participants were less likely to look toward the approaching vehicle when crossing in the initial direction at suburban Site 1 and urban Site 2 compared to when returning to the initial starting position.

Questionnaire Results

After completing the 20 crossing tasks, participants were asked to complete a questionnaire about their attitudes toward and acceptance of each app. Overall, survey responses were internally correlated, which indicated that reactions to the apps were generally positive or generally negative. Responses were analyzed using a logistic regression.

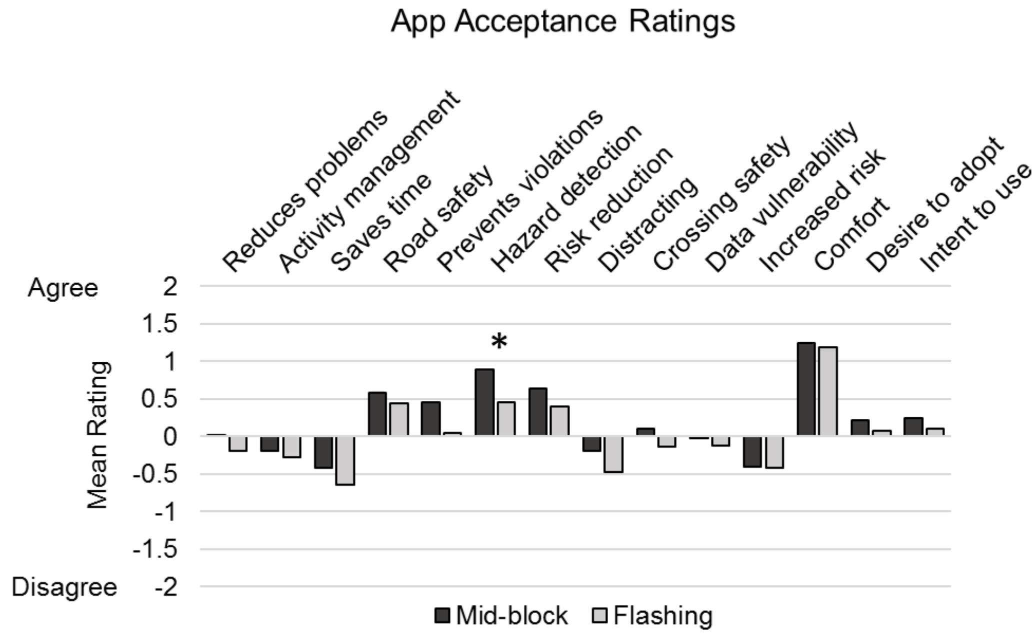
Responses to the first nine items of the questionnaire were used to examine the perceived usefulness of and satisfaction with the Mid-block app and the Flashing app. Responses to each of these nine items for the Mid-block app were not statistically different from responses for the Flashing app (figure 20).



Source: FHWA, 2020

Figure 20. Graph. Mean satisfaction and usefulness ratings for the Mid-block and Flashing apps.

The remaining 14 survey questions evaluated acceptance (figure 21). The likelihood that participants agreed the Mid-block app supported detecting hazards in time was significantly higher than the likelihood that they agreed the Flashing app did the same, $\chi^2(1) = 3.96$, $p = .0467$. In general, participants were more likely to agree that the Mid-block app prevents traffic violations compared to the Flashing app, but this effect was not statistically significant, $\chi^2(1) = 3.03$, $p = .08$. The likelihood of agreeing with the remaining statements about acceptance was not significantly different between the Mid-block app and the Flashing app.



Source: FHWA, 2020

Figure 21. Graph. Mean acceptance ratings for the Mid-block and Flashing apps.

Discussion

This research effort was designed to explore the potential for wireless connected applications to reduce the rate of fatalities for pedestrians at vulnerable midblock crossing locations. In order for V2P systems to be safe and effective, both pedestrians and drivers should be able and willing to use the system as intended. In particular, the use of a smartphone app should not distract pedestrians who use it or encourage unsafe crossing behaviors.

The purpose of this experiment was to evaluate how the FHWA Smartphone-based Mid-block Crossing app influenced pedestrian crossing behavior. The results from this study indicated that the Mid-block app had a negligible effect on pedestrian crossing behavior compared with a high-contrast flashing app designed to increase pedestrian conspicuity. Compared with the Flashing app, the use of the Mid-block app was not associated with significant changes in the time it took participants to enter the crosswalk, cross the road, or the likelihood that they looked toward an approaching confederate vehicle. Although the Mid-block app did not influence crossing behavior compared to the Flashing app, participants appeared to recognize the potential safety benefits of the Mid-block app based on their responses to one item in the post-experiment questionnaire. Specifically, participants were significantly more likely to agree that the Mid-block app helped drivers detect hazards compared to the Flashing app. This sentiment was consistent with results from the previous Phase 1 study that indicated drivers were more likely to stop for pedestrians when drivers received an in-vehicle pedestrian alert (Federal Highway Administration, 2018).

The results of the field study showed some evidence that the two apps influenced the behavior of men and women differently. Compared to the Flashing app, men took significantly longer than women to cross the road when using the Mid-block app and were less likely to look toward the approaching confederate vehicle prior to entering the crosswalk. Slower crossing behavior and fewer glances toward an approaching vehicle suggest that, relative to women, men may have been more confident that the driver of the confederate vehicle was going to respond appropriately to the in-vehicle message.

The results also suggested that continued use of the Flashing and Mid-block apps affected crossing behavior over time. Specifically, participants began crossing sooner and crossed the roadway quicker over the duration of the experiment. It is likely that participants became more comfortable with the experimental procedure over time and began to expect the approaching confederate vehicle to reliably stop for them in the crosswalk. Crossing behavior also varied as a function of test site. Participants waited significantly longer to begin crossing the road at the rural location (Site 3), which had a unique configuration in which vehicles approaching from either direction wait at stop bars and alternate driving through the crosswalk.

There were several limitations to the study. First, because of insufficient video recordings, up to 30 percent of available trial data from a given recording source could not be analyzed, which resulted in a limited sample of valid data from which to draw conclusions. However, missing data were fairly evenly distributed. Second, each of the three crossing sites varied in their characteristics, roadway design, and use. While this variation is important to investigate pedestrian use of the Mid-block app in various conditions, it is unclear which site characteristics influenced pedestrian crossing behavior. Third, crossing behavior while using the Mid-block app was not compared to situations in which pedestrians crossed without any smartphone treatment so the general effect of using a smartphone app on crossing behavior was not examined. Fourth, the same confederate vehicle was used throughout the experiment, which likely led participants to expect the driver to stop over time and influenced crossing behavior. Driver responses in a real-world scenario would likely be more varied. Finally, although the experiment administrator attempted to begin trials when minimal vehicular or foot traffic was present, this could not always be achieved. Unfortunately, the current study did not have sufficient resources to account for the presence of other road users and the corresponding influence on pedestrian crossing behavior. Future work may build on these findings and begin to address these knowledge gaps by conducting testing in a more controlled setting with specific and measurable differences across sites. In addition, data on naturalistic pedestrian crossing behavior could be collected and compared to crossing behavior when the Mid-block app is used.

Next Steps

Looking ahead toward further study and potentially larger deployment of the Mid-block app, the behavioral and survey results do not provide evidence that the Mid-block app promotes or hinders safe crossing behavior. However, responses to the use and acceptance survey suggest that most pedestrians noted the value of the Mid-block app in its potential to prevent conflicts with approaching drivers who receive the crossing signal. There is some evidence that the Mid-block app influenced behavior differently as a function of gender, age, and location. Further research with a larger sample is needed to more fully understand the relationship between demographic characteristics, roadway characteristics, and crossing behavior during use of the Mid-block app. A larger-scale deployment in a more controlled setting, such as a university, could begin to address some of the remaining questions regarding pedestrian and driver interactions in a variety of ecologically valid scenarios.

Chapter 3. Recommendations for Larger-scale Field Testing

Introduction

The results of the previous field tests and focus group interviews provide preliminary evidence that drivers and pedestrians can use the FHWA Mid-block app safely, effectively, and appropriately. Further testing of the Mid-block app can build on previous work by exploring the interactions between participant drivers and pedestrians using the app in real-world scenarios. Such larger-scale deployment would allow for the observation of natural interactions between road users and provide insight on the app's safety and effectiveness over time and in varying conditions. Deploying the Mid-block app in an enclosed, defined environment with predictable vehicular and non-vehicular travel patterns, such as a university campus or local agency, is recommended to facilitate reliable data collection and minimize added risk for users. The following discussion draws on the findings and limitations of the current research effort to outline near-term needs and provide recommendations to support the safety, success, and value of larger-scale testing.

In its current state, the Mid-block app is a voluntary opt-in system that relies on pedestrians taking intentional action to reduce their risk while traveling. Comparatively, the role of drivers is relatively straightforward: they either use the app or they do not, and they respond to the warning by yielding to the pedestrian or they do not. Furthermore, as connected vehicle technology progresses, warnings triggered by pedestrian smartphones could be communicated directly to the driver via integrated vehicle notification systems. This type of communication would likely relieve some of the concerns reported during the focus group interview regarding doubt as to whether a driver is capable of receiving the in-vehicle warning. Nonetheless, it may be useful to explore driver behaviors such as speed and attention in response to the in-vehicle warning, particularly with continued exposure. However, with its current design, the Mid-block app cannot function without pedestrians who are able and willing to consistently deploy the crossing signal that triggers the in-vehicle warning. Supporting this new and voluntary behavior in a large and varied population of pedestrians poses several unique challenges. Therefore, the following recommendations focus primarily on supporting the safe and effective use of the Mid-block app by pedestrians.

Near-term Research Needs

The outcomes of the current research effort suggest that larger-scale field testing would be valuable for addressing knowledge gaps regarding two main factors shown to influence pedestrian app use and crossing behavior: site characteristics and pedestrian demographics, particularly age and gender. In addition to these variables, the major benefits of larger-scale field testing would include the ability to observe direct interactions between drivers and pedestrians using the app over time and potentially compare these interactions with unassisted crossings. In addition, market penetration or availability of the app and its effects on app use or disuse over time can be explored. Users' perceived value of the app as it varies with market penetration can have important implications for ensuring the future success of connected safety systems.

The results of the Phase 2 field study indicate that the characteristics of the crossing site, including roadway geometry, speed limit, number of lanes, urbanity, infrastructure density, and density of vehicular and non-vehicular traffic, should be investigated for potential effects on pedestrian crossing behavior and app use. Although testing at a variety of crossing locations in a larger-scale test may aid in identifying situations in which the Mid-block app is more effective or less effective, an effort should also be made to include similar crossings with minimal variations to allow for direct comparisons between site features. A balanced selection of varied and similar crossings should provide further insight on specific roadway features with the strongest influence on app use and crossing behavior.

Another benefit of large-scale deployment would be the opportunity to investigate more complex crossing scenarios and interactions between pedestrians and drivers, including pedestrians' decisions about when and where they use the Mid-block app. In the previous experiments, drivers and pedestrians were required to use the app while approaching the crosswalk. However, in real-world scenarios, users may forget to activate the app or decide that its benefits are not worth the preparation and effort needed to use it. This is a particular concern for pedestrians who are already responsible for monitoring their surroundings. A wide variety of factors may affect a pedestrian's decision to use the app in a real-world scenario. For example, a pedestrian who is rushing or distracted by talking with a friend may be less likely to use the app appropriately. Additional potential variables include:

- Number of other pedestrians present at the crosswalk.
- Speed at which the pedestrian approaches the crosswalk.
- Pedestrian's destination and desired time of arrival.
- Driver use and response to the app.
- Ease of access and use of the pedestrian's smartphone during a given crossing scenario.
- Use of the pedestrian's smartphone for other activities, such as talking or texting.
- Status of the pedestrian's smartphone, including battery life and data connection.

Exploring the influence of these and other variables on pedestrian crossing behavior and the decision to use the Mid-block app are key to ensuring the system's effectiveness in situations where it is most beneficial.

Finally, attention should be paid to the use of the Mid-block app by individuals with varied age and gender demographics. For example, pedestrians aged 50–59 represented the largest proportion of pedestrian traffic fatalities in 2017, with pedestrians aged 50–54 and 55–59 each representing 21 percent of fatalities (NHTSA, 2019a). Other research suggests that older pedestrians walk significantly slower and judge vehicle gaps differently than younger pedestrians (Forde & Daniel, 2017; Lobjois & Cavallo, 2007). During the focus group interview, participants aged 46 and older expressed more hesitancy and concern with using the Mid-block app compared to participants younger than 46. Although some settings, such as universities, may be more likely to be composed of younger individuals, it will be important to include participants of all ages in larger-scale testing to identify avenues for improving accessibility and usability for all users.

Additional Considerations

Previous testing of the Mid-block app was limited to daytime settings, off-peak travel, and single users. As previously mentioned, the majority of pedestrian fatalities in 2017 occurred outside of intersections, in urban settings, and at night (NHTSA, 2019a). Considering these factors, the Mid-block app's greatest benefit may be seen at night and in urban settings. In addition, the results of the Phase 2 field test supported the possibility that age and gender may influence differences in app use, particularly in urban settings. However, since nighttime urban environments also represent the conditions in which pedestrians are most vulnerable, careful planning would be required to ensure that the Mid-block app could be safely evaluated without increasing the risk for users. A university campus may approximate an urban setting with some degree of control over vehicular and non-vehicular traffic. However, large-scale testing in this type of setting will introduce other variables that have not been investigated and may influence safety, crossing behavior, and app usage, such as weather and interactions between multiple drivers and pedestrians.

Larger-scale testing also introduces the opportunity for interactions between multiple pedestrians and drivers, some of whom may not be using the Mid-block app in a given crossing situation. For example, how is the crossing behavior of a group of three pedestrians affected if only one is using the Mid-block app? Likewise, how would pedestrians and drivers respond to a situation in which two vehicles are approaching a crossing from opposing directions but only one is using the app? Because the previous testing was limited to interactions between single pedestrians and drivers, the interactions between multiple actors are unknown and should be carefully explored to identify and design mitigation strategies for any conflicts that arise between multiple users.

Other real-world factors that may affect app use and crossing interaction but were not explored in previous research are weather and peak travel times. It is reasonable to expect that use of the Mid-block app among both drivers and pedestrians may be affected by weather such as rain or snow. Pedestrians in these situations are likely to face the added difficulty of interacting with the smartphone while holding an umbrella or otherwise avoiding exposure to the elements. Similarly, the Mid-block app may be particularly effective during peak travel times by reducing risk for pedestrians at non-intersection locations. However, whether high traffic volumes increase or decrease pedestrians' comfort with and likelihood of using the app when preparing to cross midblock remains to be evaluated. Observing changes in pedestrian app use and attitudes in these conditions would contribute to a more accurate understanding of the potential safety benefits offered by the Mid-block app.

Feedback from participants in Phase 2 suggests that the interface and messaging of the app are important for communicating its appropriate role and value for users. An important characteristic of the app is that it relies on proper and consistent use by bother drivers and pedestrians. However, pedestrians in Phase 2 voiced concerns regarding the lack of information about the number of nearby vehicles capable of receiving the in-vehicle warning. In order to address this concern, future changes to the app's capabilities and interface may include adding a graphic indicator of vehicles within the geofenced area that are actively using the system or notifying the pedestrian that their communication was received by a vehicle. Information regarding other app users should adhere to guidelines regarding the security of personal data, and additional messaging should clearly remind the pedestrian that the presence of equipped vehicles does not guarantee a safe crossing.

Finally, modifications to the Mid-block app's system architecture will likely be required to support larger-scale deployment. Currently, the pedestrian warning signal remains active for a default duration of 30 seconds. However, this duration may not be appropriate for all crossing locations. Continuous signals triggered by large groups of pedestrians moving through a crosswalk may also lead to confusion or conflicts for drivers and pedestrians. Although the app is currently capable of notifying drivers who enter a geofenced region in which a crossing alert has already been activated, there is no comparable function for pedestrians. Multiple pedestrians using the app at the same time at a given crosswalk may need to be informed when another user has already triggered a crossing signal at that location. A countdown of the remaining signal duration available to all pedestrians using the app in a given location may also prevent users from relying on an existing signal or extending the signal beyond a reasonable limit.

Potential Research Approach

To improve the feasibility of larger-scale testing, it is recommended that a group of volunteers from the selected testing environment be invited to download the Mid-block app and instructed on the use and purpose of its driver and pedestrian components. Several crosswalks at non-intersection midblock crossings may be designated for observation. Ideally, these locations would be outfitted with video equipment to record pedestrian and vehicle behavior with and without the Mid-block app. To encourage pedestrians to use the app at enabled crosswalks, signs posted at either end of the crosswalk may be used to notify pedestrians that the crosswalk is compatible with the Mid-block app. Usage and location data can be collected through the app itself for later comparison with recorded behavior. With adequate metrics, time-based conflict indicators based on the vehicle's distance from the crosswalk and the pedestrian's crossing time may be used as indicators of pedestrian safety (Vedagiri & Kadali, 2016; Zhuang & Wu, 2012). Likewise, the Mid-block app can collect data on drivers, including when and where drivers activate the app, the duration of activation, approximate travel speed, and the number of in-vehicle warnings received. Periodic surveys administered through the app could obtain feedback from users on general use as well as specific crossing experiences.

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Appendix A. Human Factors Study - Interview Script and Stimuli

Introduction

Now that everyone has read and signed the informed consent documents, we have turned on the video cameras and can begin. Welcome to this focus group. Today we will be looking at applications that people can use when they want to cross the street. We're going to ask you some questions about walking and crossing the street, talk about midblock crossings, and take a look at the designs for a variety of pedestrian applications to see what you like and don't like.

We're hoping to use your feedback to design an app that helps people cross the street, so we're going to show you pictures of a variety of apps used in different ways. Please tell us what you like and don't like about them so we can use that feedback to make a better app.

Walking

First, we'd like to ask you a few questions about walking, either as exercise or as a way of getting places.

1. Think about a street where it was easy to walk around. What made that place easy to walk around?
2. Think about a street where it was difficult to walk around. What made that place difficult to walk around?
3. Around where you live, are the streets easy or difficult to walk around?
4. What makes it easy or difficult to walk around where you live?
5. Think about a time where it was easy to cross a road. What made it easy to cross that road?
6. Think about a time where it was difficult to cross a road. What made it difficult to cross that road?
7. If you could use an application to communicate with drivers when you want to cross the street, what about that app would make you want to use it?
8. What about that app would make you recommend that application to a loved one or friend?

Midblock Crossings

Today we are concerned with midblock crossings, which are crossings that have signs and crosswalks, but are not at intersections. We're going to show you a few types of midblock crossings and see your thoughts.

A. This first crossing is a midblock crossing with a marked crosswalk and signs only.
    1. What do you like or dislike about this type of crossing?
    2. How would you explain to a pedestrian how they should use this type of crossing?
    3. What would you do to use this type of crossing?
    4. What about this crossing is safe or unsafe?
    5. What would you do to make this crossing safer?

B. This next crossing is a midblock crossing with rectangular rapid flashing beacons.
    1. What do you like or dislike about this type of crossing?
    2. How would you explain to a pedestrian how they should use this type of crossing?
    3. What would you do to use this type of crossing?
    4. What about this crossing is safe or unsafe?
    5. What would you do to make this crossing safer?

C. This next crossing is a pedestrian hybrid beacon.
    1. What do you like or dislike about this type of crossing?
    2. How would you explain to a pedestrian how they should use this type of crossing?
    3. What would you do to use this type of crossing?
    4. What about this crossing is safe or unsafe?
    5. What would you do to make this crossing safer?

D. This last crossing uses a traditional traffic signal.
    1. What do you like or dislike about this type of crossing?
    2. How would you explain to a pedestrian how they should use this type of crossing?
    3. What would you do to use this type of crossing?
    4. What about this crossing is safe or unsafe?
    5. What would you do to make this crossing safer?

Applications

Now we will take a look at a few crossing applications.

A. This first design is used to alert drivers that you would like to cross.
    a. What do you think of this screen?
    b. How would you explain what to do on this screen?
    c. What do you like or dislike about the way this looks?
    d. Are there any specific things you like or don't like?
    e. –REPEAT UNTIL END--
    f. Overall, what about this design feels trustworthy or reliable and what feels untrustworthy or unreliable?

   g. Overall, what about this app would you recommend this app to a friend or family member?

B. This next design is used to request crossings at signalized intersections.
   a. What do you think of this screen?
   b. How would you explain what to do on this screen?
   c. What do you like or dislike about the way this looks?
   d. Are there any specific things you like or don’t like?
   e. –REPEAT UNTIL END--
   f. Overall, what about this design feels trustworthy or reliable and what feels untrustworthy or unreliable?
   g. Overall, what about this app would you recommend this app to a friend or family member?

C. This next design is used to flash and increase screen brightness to make you more visible as you cross the street.
   a. What do you think of this screen?
   b. How would you explain what to do on this screen?
   c. What do you like or dislike about the way this looks?
   d. Are there any specific things you like or don’t like?
   e. –REPEAT UNTIL END--
   f. Overall, what about this design feels trustworthy or reliable and what feels untrustworthy or unreliable?
   g. Overall, what about this app would you recommend this app to a friend or family member?

D. This next design is used to alert drivers that you would like to cross the street.
   a. What do you think of this screen?
   b. How would you explain what to do on this screen?
   c. What do you like or dislike about the way this looks?
   d. Are there any specific things you like or don’t like?
   e. –REPEAT UNTIL END--
   f. Overall, what about this design feels trustworthy or reliable and what feels untrustworthy or unreliable?
   g. Overall, what about this app would you recommend this app to a friend or family member?

Messages

These apps use a variety of messages to tell you when you should cross. However, it is still up to the pedestrian to determine when it is safe. We’d like to ask you a few questions about how to help pedestrians without overwhelming users.

1. What about this message is useful or unhelpful?
2. Can you say this message in a different way?
3. Is there anything you would like to add or remove?

Conclusion

We've talked about a lot of things here today: how easy or difficult it is to walk, types of midblock crossings, and looking at several applications. After this we will complete a short survey about how well you trust these apps. Before then, over the course of this focus group, did your opinions change about anything we discussed? Do you have any questions?

Appendix B. Field Test - Order of Trial Conditions

Table 9. Predefined orders for app and car conditions

Trial	App Sequence 1	App Sequence 2	Car Sequence 1	Car Sequence 2
1	A	B	Y	N
2	B	A	N	Y
3	B	A	Y	N
4	A	B	N	Y
5	A	B	Y	N
6	B	A	N	Y
7	B	A	Y	N
8	A	B	N	Y
9	A	B	Y	N
10	B	A	Y	N
11	B	A	N	Y
12	A	B	Y	N
13	A	B	N	Y
14	B	A	Y	N
15	B	A	N	Y
16	A	B	Y	N
17	A	B	N	Y
18	B	A	Y	N
19	B	A	N	Y
20	A	B	N	Y

A = high-contrast flashing app. B = Mid-block pedestrian crossing app.

Table 10. Group conditions

Group	App Sequence	Car Sequence
1	1	1
2	2	1
3	1	2
4	2	2

Appendix C. Field Test - Survey Questions

Table 11. Attitude assessment items.

The system is…				
Useful				Useless
○	○	○	○	○
Pleasant				Unpleasant
○	○	○	○	○
Bad				Good
○	○	○	○	○
Nice				Annoying
○	○	○	○	○
Effective				Superfluous
○	○	○	○	○
Irritating				Likeable
○	○	○	○	○
Assisting				Worthless
○	○	○	○	○
Undesirable				Desirable
○	○	○	○	○
Raising awareness				Sleep inducing
○	○	○	○	○

Table 12. System acceptance items.

Item	Disagree				Agree
The system decreases my problems while crossing the road.	○	○	○	○	○
The system enables me to manage useful activities while crossing the road.	○	○	○	○	○
The system saves time that I would have lost crossing without it.	○	○	○	○	○
The system increases road safety.	○	○	○	○	○
The system prevents traffic violations.	○	○	○	○	○
The system supports the driver to detect hazards in time.	○	○	○	○	○
The system reduces the risk of a crash.	○	○	○	○	○
The system distracts me from detecting hazards in time.	○	○	○	○	○
I cross more safely without the system.	○	○	○	○	○
The system is vulnerable to hazards like hacker attack and issues with data safety.	○	○	○	○	○
To me, new risks that emerge from this type of system appear to be more serious than the reduction in crash risk.	○	○	○	○	○
Additional comfort and safety functions are of high value to me.	○	○	○	○	○
I would like to have this system on my smartphone.	○	○	○	○	○

I would consider using this system on my personal device.				
Disagree				Agree
○	○	○	○	○

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