Connecting Pedestrians with Disabilities to Adaptive Signal Control for Safe Intersection Crossing and Enhanced Mobility

2018 Field Test and Evaluation Report

Final – September, 2018
Publication Number: FHWA-JPO-18-706

U.S. Department of Transportation

Produced by Carnegie Mellon University, with support from Diyunu and Booz Allen Hamilton.
(Cover page figure source: US Department of Transportation)

U.S. Department of Transportation
Intelligent Transportation Systems (ITS) Joint Program Office

Notice

Quality Assurance Statement

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-JPO-18-706		

4. Title and Subtitle	5. Report Date
Connecting Pedestrians with Disabilities to Adaptive Signal Control for Safe Intersection Crossing and Enhanced Mobility: 2018 Field Test and Evaluation	Sept 2018
	6. Performing Organization Code
7. Author(s)	**8. Performing Organization Report No.**
Stephen Smith, Zachary Rubinstein, Bernadine Dias, Sara Sarkhili, Huthaifa Ashqar, Maurice Farber, Diego Lodato, Corey Harper	Task 1.3 Report
9. Performing Organization Name and Address	**10. Work Unit No. (TRAIS)**
Carnegie Mellon University 5000 Forbes Avenue Pittsburgh PA 15213	**11. Contract or Grant No.** DTFH6117C00014
12. Sponsoring Agency Name and Address	**13. Type of Report and Period Covered**
U.S. Department of Transportation ITS Joint Program Office 1200 New Jersey Avenue, SE Washington, DC 20590	Year 1 Field Test Evaluation Report
	14. Sponsoring Agency Code

15. Supplementary Notes

Govind Vadakpat (COR);

16. Abstract

PedPal is a prototype mobile (smartphone) app designed to assist pedestrians with disabilities when crossing the street at signalized intersections. *PedPal* interacts directly with the traffic signal system controlling the intersection to communicate both crossing intent (eliminating the need to seek out and push a pedestrian call button) and personalized crossing constraints (ensuring sufficient time is allocated for the pedestrian to cross). Future versions of *PedPal* will incorporate the ability to monitor crossing progress and to dynamically extend the crossing time in situations where more time is needed to safely get across, as well as provide enhanced capabilities aimed at improving crossing efficiency and general mobility.

In this report, we summarize an initial series of user tests that were conducted with the *PedPal* mobile app and present the results that were obtained.

17. Keywords	18. Distribution Statement
pedestrians with disabilities, safe intersection crossing, smartphone app	

19. Security Classify. (of this report)	20. Security Classify. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	49	

Form DOT F 1700.7 (8-72)   Reproduction of completed page authorized

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Chapter 1. Executive Summary

Transportation and mobility are crucial for living today. However, people with disabilities (mobility, vision, hearing, and cognitive) often do not have equal access to transportation, which hinders their ability to experience a full life. The Accessible Transportation Technology Research Initiative (ATTRI) of the U.S Department of Transportation's (USDOT) Intelligent Transportation Systems Joint Program Office (ITS-JPO) aims at improving the mobility of travelers with disabilities through research, development, and implementation of transformative technologies, applications, or systems for people of all abilities to effectively plan their personal and independent travel. ATTRI research focuses on the needs of three stakeholder groups: persons with disabilities, older adults, and veterans with disabilities.

The ATTRI Broad Agency Announcement focuses on transformational changes and revolutionary advances in accessible transportation, personal mobility, and independent travel for all travelers that lead to offering a totally new travel experience in intermodal surface transportation in the United States. This involves research and development in three key application areas:

1. Smart Wayfinding and Navigation Systems
2. Pre-trip Concierge and Virtualization, and
3. Safe Intersection Crossing

This document is developed as a part of the Safe Intersection Crossing application area. It reports on test and evaluation activities of an app called *PedPal* that has been developed over the past year for this application area. *PedPal* is a prototype mobile (smartphone) app designed to assist pedestrians with disabilities when crossing the street at signalized intersections. PedPal interacts directly with the traffic signal system controlling the intersection to communicate both crossing intent (eliminating the need to seek out and push a pedestrian call button) and personalized crossing constraints (ensuring sufficient time is allocated for the pedestrian to cross). Future versions of *PedPal* will incorporate the ability to monitor crossing progress and to dynamically extend the crossing time in situations where more time is needed to safely get across, as well as provide enhanced capabilities aimed at improving crossing efficiency and general mobility.

In this report, we summarize the results obtained in an initial series of user tests of the current *PedPal* mobile app. Given that the state of the prototype is still preliminary and not without technical problems during the user tests, our evaluation will emphasize qualitative strengths and weaknesses that were observed and provide quantitative results where possible. We intend to perform one or more additional user tests in the second year of the project, as we continue to refine and harden the *PedPal* technology, and we expect to be able to provide a more quantitative overall cost/benefit analysis in these subsequent user tests. The good news is that, for all participants of this initial user test, we received overwhelmingly positive feedback and it is clear that the *PedPal* mobile app has the potential to significantly improve the safety of intersection crossing for persons with disabilities - especially for blind pedestrians, people using manual wheelchairs, and other pedestrians who need more time on average to safely cross traffic intersections.

The remainder of this report is organized as follows.

- Chapter 2 first summarizes the Year 1 version of the *PedPal* mobile app that was tested by prospective users.
- Chapter 3 then presents the design of the user field test, including descriptions of the field test location, the testing protocols that were adopted, and the data collection plan.
- Chapter 4 summarizes the group of participants that were recruited to take part in the field test study.
- Chapter 5 presents the results obtained and important observations.
- Chapter 6 finally draws some conclusions and catalogues some lessons learned as a result of the user testing, both of which could help support the wider deployment and implementation of safe intersection crossing technologies throughout the transportation network and contribute to the living catalogue of lessons learned that are being managed by the U.S. Department of Transportation (USDOT).

Chapter 2. The *PedPal* Mobile App

The *Safe Intersection Crossing* project is intended to develop and demonstrate assistive services that promote safe passage of injured veterans, older adults, and other persons with blindness, low vision, cognitive, or mobility related disabilities when crossing signalized intersections, and leverage smart traffic signal infrastructure to further provide these persons with significant mobility enhancements.

These services will be accessible to users via smartphones that are equipped with Dedicated Short-Range Communication (DSRC) capability, allowing them to (1) access real-time information from traffic signal infrastructure and nearby vehicles and (2) actively influence traffic signal control decisions and vehicle movements at the intersection. Essentially, the system is envisioned as a smartphone app, realized as the *PedPal* app, that will provide accessible interfaces that allow pedestrians to:

- Communicate personalized intersection crossing constraints (e.g., crossing direction, crossing time needed) to the signal system
- Receive sufficient crossing time, and necessary information (e.g., geometric information about the intersection) to facilitate safe crossing, and
- Be alerted when a crossing movement indicates safety concerns (e.g., moving outside of the crosswalk)

Real-time monitoring of crossing performance is used to automatically extend the green time in real-time when appropriate. *PedPal* is envisioned to also enable users to provide pre-planned pedestrian route and destination information (e.g., walking path and target bus stop) to the traffic signal infrastructure, which can be used in conjunction with other real-time information (e.g., bus locations and routes) to adapt signal phase timings preemptively as the pedestrian approaches the intersection, leading to shorter and more reliable pedestrian travel times, and more efficient travel connections.

The technical approach taken to provide these capabilities combines DSRC pedestrian-to-infrastructure communication with recent advances in real-time, adaptive traffic signal control, embodied in the surtrac traffic signal control system (http://www.surtrac.net). surtrac combines artificial intelligence with traffic theory to provide, for the first time, real-time optimization of traffic flows in complex urban road networks, where (in contrast to suburban corridors) there are multiple, competing dominant traffic flows that change through the day. SURTRAC takes a decentralized, collaborative online planning approach to signal control. Each intersection independently senses its locally approaching traffic and generates in real-time a signal timing plan that moves sensed traffic through the intersection so as to minimize cumulative wait time. Intersections then share their plans with downstream neighbors to achieve coordinated behavior at the network level. In the field, surtrac shows reductions of 25% in vehicle travel times, 30% in number of stops and 40% in vehicle wait times. In the current context, surtrac provides the ability to adjust signal timing plans on a second by second basis. As such, the *PedPal* approach should yield compound benefits in areas with large concentrations of disadvantaged pedestrians (e.g., near elder care facilities, retirement homes, schools for persons with disabilities, etc.).

Figure 2-1 identifies the principal components of the safe intersection crossing system.

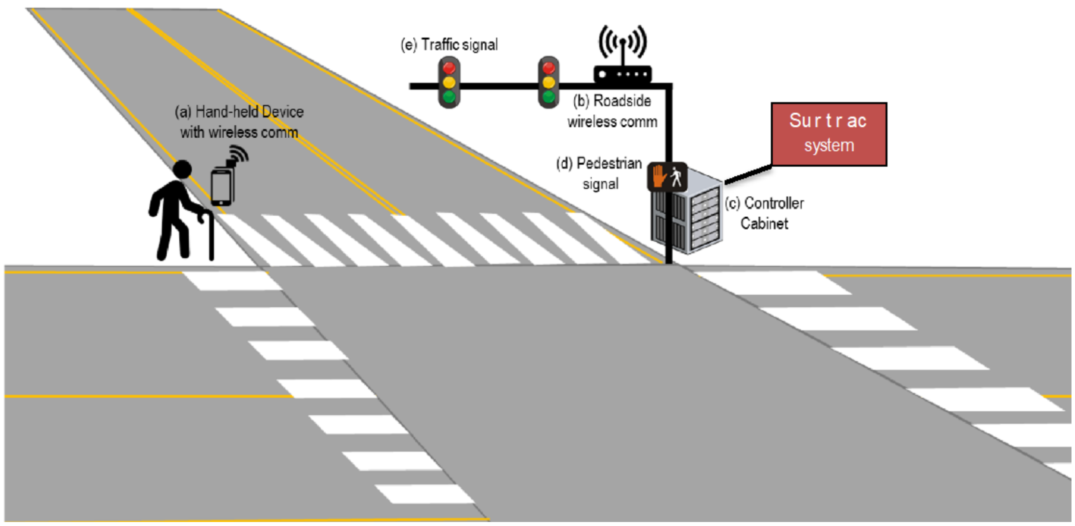

Figure 2-1: Components of the Safe Intersection Crossing System

2.1 Hardware Configuration

The basic design concept for the Year 1 *PedPal* prototype is shown in Figure 2-2. It consists of an iPhone 8 smartphone running the mobile app and communicating to an Arada DSRC sleeve to which it is attached via Bluetooth. The DSRC sleeve in turn communicates with the DSRC Road Side Unit installed at the intersection. Unfortunately, due to technical limitations with the latest release of the ARADA firmware that could not be fixed in time, the Bluetooth connection on the DSRC sleeve was non-functional and we were forced to use a hard-wired connection between the sleeve and the smartphone, as shown in Figure 2-3. For purposes of the field test, we decided to encapsulate the DSRC unit and hardware connection in a pouch that could be worn around the participant’s waist and have the participant either hold the iPhone or utilize a runner’s arm band, as shown in Figure 2-4. We are currently investigating options for rectifying this firmware problem in Year 2.

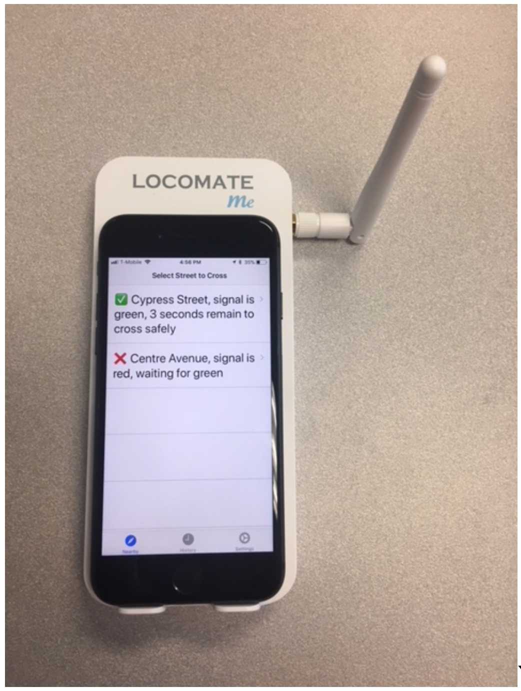

Figure 2-2: Year 1 *PedPal* Design Concept

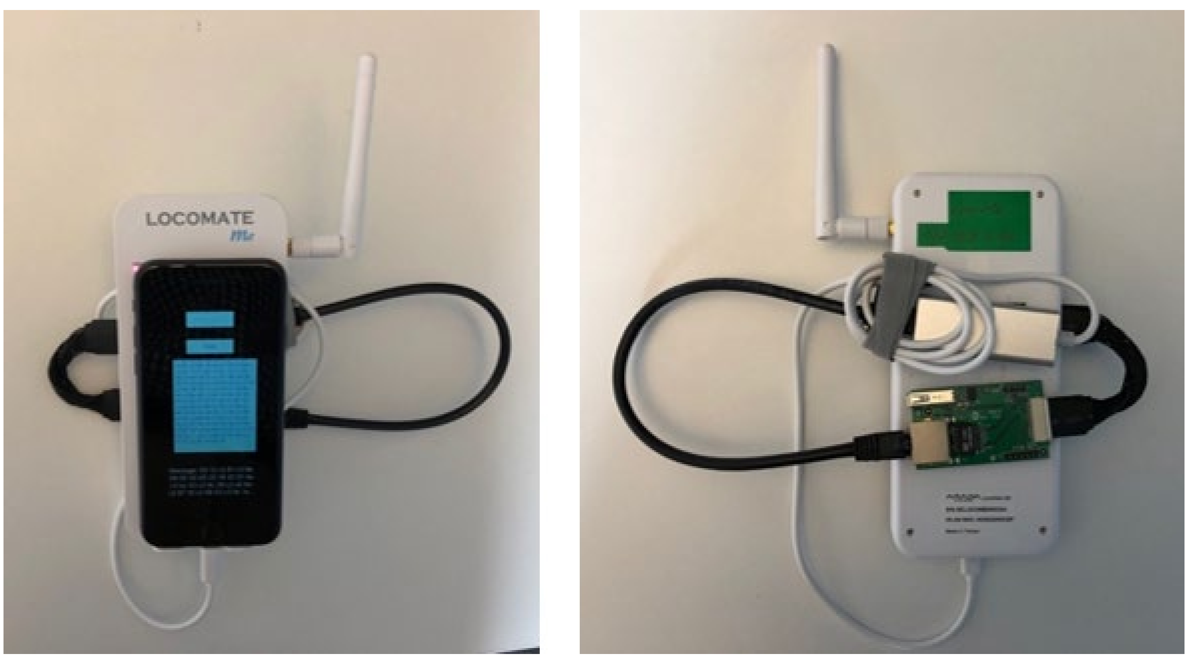

Figure 2-3: Configuration For The User Test

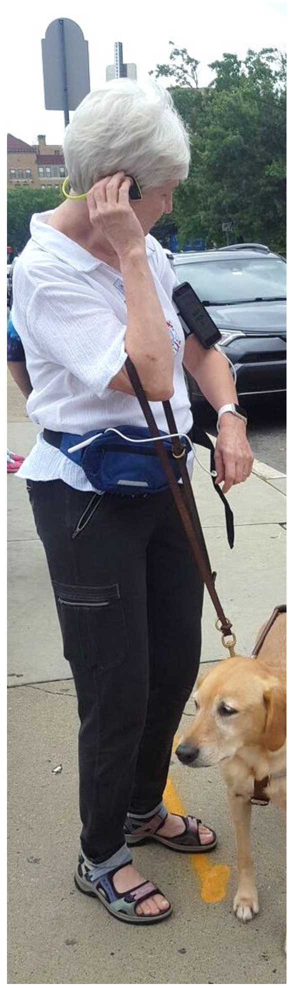

Figure 2-4: DSRC sleeve encapsulated in waist pouch with iPhone attached to arm and bone conducting Bluetooth headphones for use of voice over

2.2 *PedPal* Mobile App

The Year 1 *PedPal* prototype is designed to provide basic assistance to the user in crossing the intersection. *PedPal* is customizable to the user and knows the user's personalized crossing constraints. It allows the user to communicate crossing intent (eliminating the need for a pedestrian call button) along with the time that is required for safe crossing. If the request is made in advance of the green in the crossing direction, then an extension to crossing time will always be granted by the traffic control system. If the request is made when the signal is already green in the crossing direction, the traffic control system will determine whether there is enough time remaining to permit crossing and grant a time extension or if the pedestrian should wait until the next green cycle.

As shown in Figure 2-5, configuration of the app currently includes specification of a number of settings, including:

- Traveler Type – white cane user, guide dog user, wheelchair users, deaf, etc. This setting establishes the default baseline crossing speed for the user.
- Street Crossing Speed – crossing speed can be further tuned relative to the default speed using this setting.
- Show Diagonal Crossings – specifies whether diagonal crossings should be considered.
- Re-Sort Corners After Crossing – impacts user preference when using two crossings to accomplish a diagonal crossing
- Countdown Frequency (V0) – When operating with voice over on, this setting controls the verbosity of the spoken countdown.
- Device Orientation – fixed or dynamic

The app supports all of the native accessibility features of the iPhone, including voice-over, zoom, font enlarging, etc. These features are configured from the iPhone's Settings control.

Figure 2-6 illustrates the process of selecting the street to cross, which triggers the Signal Request Message (SRM) to allocate sufficient crossing time to the next green phase in the selected crossing direction. Receipt of MapData (MAP) and Signal Phase and Time (SPaT) messages enable generation of the screen on the left, and once the user selects the street to cross, an SRM is sent to the intersection. Once the crossing duration is set, it is reflected in the time remaining count shown on the screen. When the user is about to start to cross s/he taps "start crossing" and when the user has completed crossing, the "crossing completed" button is tapped.

Figure 2-5: Current Mobile App Settings

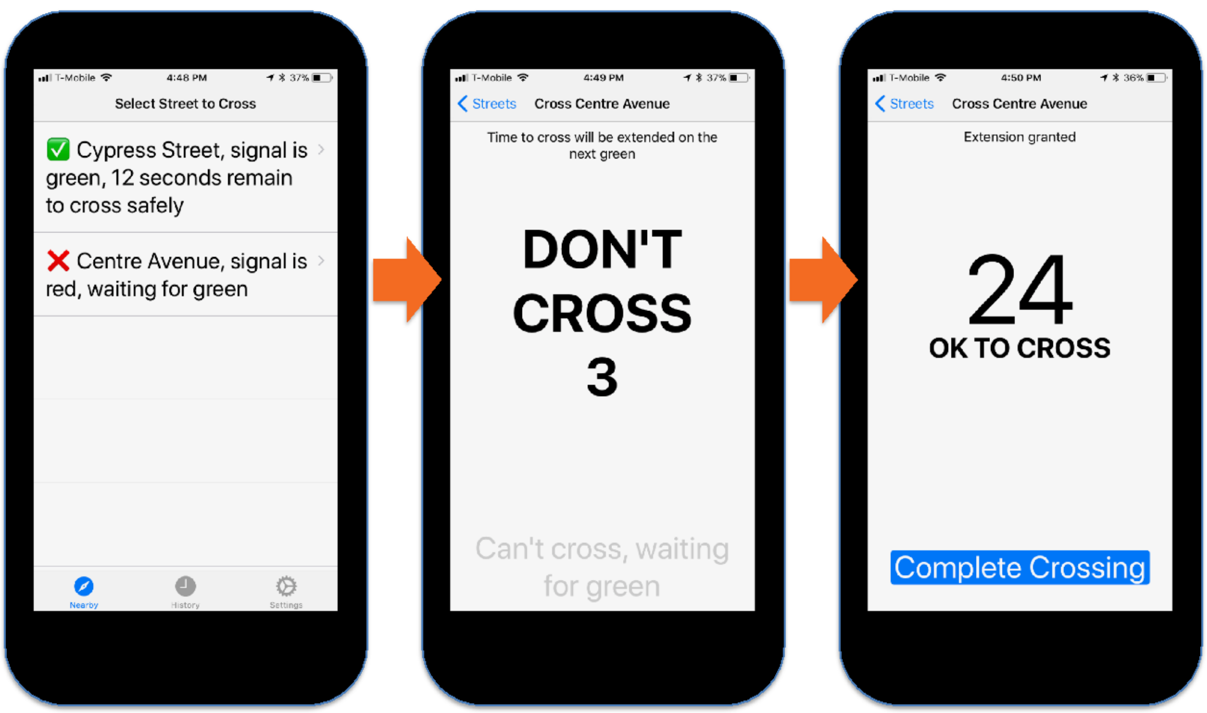

Figure 2-6: A Snapshot of the Mobile App

Chapter 3. Field Test Design

This chapter describes the overall design of Phase1 field test that was undertaken to evaluate the *PedPal* mobile application. This initial field test was carried out over the period from August 15 to August 30, 2018, and involved user testing by 12 volunteers recruited from the local disability community. These recruited participants included individuals with a range of disabilities, spanning visually impaired people (most prevalent), wheelchair users, elderly persons and a deaf individual.

Each volunteer was individually engaged for a 90 minute to 2-hour session, during which the prospective user was first asked to complete an information gathering pre-test survey, and then introduced to the *PedPal* mobile app running against a simple intersection traffic signal simulator. Once training was complete, the user was transported to the field site - the intersection of Centre Avenue and Cypress Avenue. At this intersection, a series of crossing tours around the intersection were performed, both with the assistance of the *PedPal* and without it (as the individual would normally cross the street). During these crossing tours, data and observations were collected on crossing times, cycles required to cross, trajectory anomalies, mobile app message traffic, impacts to vehicular traffic and other notable events. Following the testing of the device, the session concluded by conducting a post-test survey, where the participant was given the opportunity to comment on the potential of the app, what they liked and did not like, and any suggestions they might have for improvement.

In the following subsections, we summarize the basic objectives of the field study, the physical intersection where the testing took place, the overall testing protocols that were adopted and followed, and the methodology for collecting data.

3.1. Field Test Objectives

The primary objective in conducting the field test was to assess the extent to which the *PedPal* app is performing as intended and to gauge its usefulness (or potential usefulness) to pedestrians with disabilities. More specifically, the field test was designed to answer the following sorts of questions:

1. Does the application improve or hold the potential to improve (a) safety of crossing the intersection, (b) ease of crossing the intersection, and (c) time required to cross the intersection?
2. Has the application worked consistently for all tested users during their act of intersection crossing?
3. What are the applications strengths and weaknesses with respect to user acceptance?

4. For what types of users is the application likely to be most useful?
5. What is the impact of the application's use on vehicular and transit traffic flows?

3.2 Field Test Location

The target location for the field test was the intersection of Centre Avenue and Cypress Avenue in the vicinity of UPMC's Shadyside Hospital and Henry Hillman Cancer Center complex in the East End of Pittsburgh PA. A photo of the intersection looking northwest with the bus traveling west on Centre Avenue is shown in Figure 3-1. The intersection was chosen for the following combination of reasons: (1) the fact that both Surtrac and a DSRC Road Side Unit (RSU) were already installed and operational at the intersection, (2) because of its relatively large volume of pedestrian traffic, and (3) because of the relative simplicity of the intersection's geometry.

Figure 3-1: The intersection at Centre Avenue and Cypress Avenue

Centre/Cypress is a basic four-way intersection that consists of one travel lane in both the east/west and north/south travel directions. It is a simple two-phase intersection (i.e., no dedicated left turn phases) with the signal just cycling between east/west and north/south phases. Since the intersection is being controlled by the Surtrac adaptive signal control system, the green phase in either direction can (and will) vary from cycle to cycle, depending on the actual vehicle traffic on the road at any given moment.

The intersection design has a single curb cut at each corner rather than curb cuts directly interfacing with the crosswalks and, although there are pedestrian countdown signals, there are no audible pedestrian signals nor pedestrian push buttons available. The lack of audibles, corner curb cut design, and the changing amount of green time in a given direction over time, make this an extremely challenging intersection to cross for blind pedestrians.

3.3. Field Test Protocol

The user testing protocol was designed to proceed in three phases, as shown below in Figure 3-2. During the first Pre-Test Phase, initial information was obtained from the participant and he/she was introduced to the *PedPal* app and given training in its use. This phase was carried out at the offices of Rapid Flow Technologies Inc., due to its relative proximity to the both the field test site and several bus lines.[1] During the second Test Phase, the participant was transported to the Centre/Cypress intersection, and a series of street crossings were performed both with and without the assistance of the *PedPal* app. After testing was completed, the participant was transported back to the Rapid Flow offices for the third Post-Test Phase of the protocol, where the participant was asked to complete a Post-test survey and captured data was downloaded to a secure server. All testing and data handling were carried out in compliance with the Institutional Review Board (IRB) standards and protocols of Carnegie Mellon University.

Table 3-1 summarizes the complete protocol and identifies the field test personnel (and roles) required to execute each step. The field test team consisted of 6 IRB-approved individuals, and roles were rotated from participant to participant to accommodate schedules. Each step of the protocol is described in more detail in the subsections below.

[1] Rapid Flow Technologies Inc is a CMU spinout company that is engaged in commercializing the surtrac technology, and is an in-kind contributor to the Safe Intersection Crossing project.

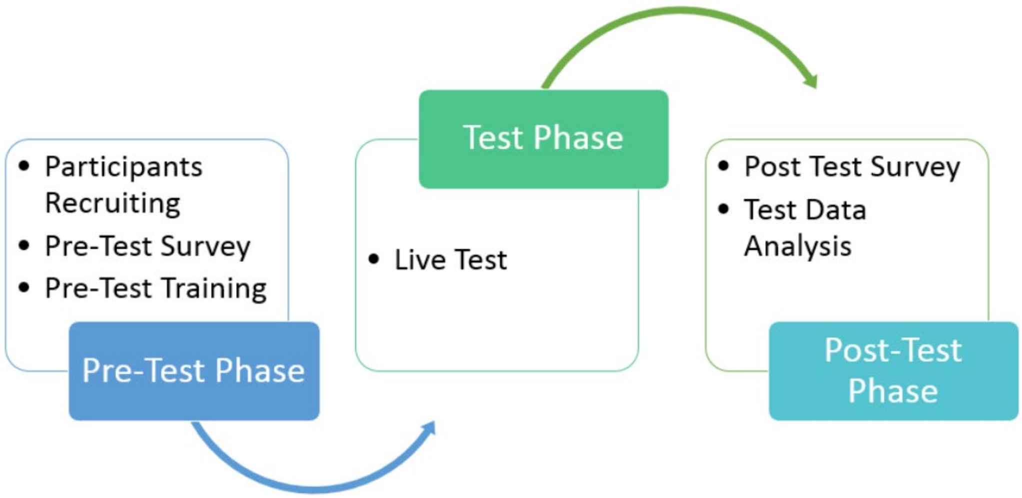

Figure 3-2: Overview of Field Test Protocol

Table 3-1: User testing protocol

Duration	Task	Personnel Required	Notes
5-10 mins	Meet and Greet	Researcher	
5-10 mins	Consent Form	PI or PM	
15 mins	Pre-survey	Researcher (1)	
	Equipment Config.	Researcher (2)	Check status of iPhones and DSRC sleeve
20 mins	*PedPal* Training	App Trainer	Train user on how to use app and explain field test
30 mins	Field Test	Safety Person Observer Videographer (1) Videographer (2)	2 loops with app 1 loop without app
15 mins	Post-Survey	Researcher (1)	
	Data download and label	Researcher (2)	
5 mins	Wrap up and escort to vehicle or other desired location for departure	Researcher	

3.3.1. Pre-Test Survey

The pre-test survey was aimed at collecting base information on the participant's level of ability and experience in crossing different intersections, user's level of experience with smartphone technology, frequency of traffic intersection crossing, desired features of the mobile app, current challenges crossing traffic intersections, guidance tools used (wheelchair, cane, dog, etc.), and demographic information (gender, age range, disability, and ethnicity). This information was used to inform the app training session (Section 3.3.2) and the configuration of the app for the field test, as well as to provide a basis for better understanding the potential utility of the app. The Pre-test Survey that was used is provided in Appendix A.

3.3.2 *PedPal* Training

During the training session, the participant was introduced to the *PedPal* technology solution, and given a chance to get familiar with its use. The phone, sleeve, and Mobile App interface layout of the app were all presented to the participant in an accessible manner (which naturally was varied according to each user's needs and preferences). After all participant questions about its use were addressed, the participant was guided through a few exercises using a traffic intersection simulator that was developed for this purpose. The participant was then asked to independently use the *PedPal* app to cross the (simulated) intersection, while being observed. For blind participants, the voice-over capabilities provided by *PedPal* and how to adjust relevant settings was also explained (although in several cases, the participant's expertise with iPhone accessibility features was already greater than that of the trainer). All questions, errors, and difficulties encountered in each training session were documented to inform future testing sessions.

3.3.3 Live Test Session

At the test site, each participant was provided with a *PedPal* equipped iPhone8 that was coupled to the DSRC sleeve in the manner described in Section 2.1 and configured in a manner similar to that shown Figure 2-3. Each participant was given the option of using the runner's arm band or holding the device in his/her hand, and whether to additionally use the bone conducting headset. For most of the field test, we experienced DSRC connectivity issues, where the phone would sometimes lose connectivity and then take substantial time to reacquire a new MAP message and resume normal operation. To try to minimize these effects we adopted a practice part way through the field test of having a member of the field test team carry the DSRC sleeve and walk alongside of the participant (instead of encapsulating the DSRC equipment with its wires in the waist pouch as originally planned). Toward the end of the field test, we identified a policy implemented in the *PedPal* app that could be adjusted to mitigate this problem.[2]

The basic structure of the field test entailed the participant making two tours around the intersection (i.e., 4 consecutive street crossings per tour) with the app and one tour around the intersection without the app's assistance. The order in which these were accomplished were varied from participant to participant. Similarly, the direction in which the tours were conducted were also varied. For all crossings, one member of the field test team assumed the role of safety person (walking with the participants to provide protection against vehicular traffic but not otherwise interfering with participant), a second member served as observer (recording crossing times, wait times and other relevant observations), and two additional members handled video recording duties.

Although the particulars of the sequence of interactions with *PedPal* crossing the street varied across participants with different types of disabilities and assistive aids, execution of a crossing trial followed the same overall process:

- Approach the intersection and receive crossing options
- Select the desired street crossing
- Wait until informed that it is safe to walk, inform the app that you are about to "start crossing" and start walking
- Inform the app that "crossing is completed" once you have traversed the intersection.

3.3.4 Post-Test Survey

The Post-Test Survey consisted of 8 questions centered around user-friendliness of *PedPal*, impact on user confidence, useful features, training session effectiveness, and suggestions for improvement. The Post-Test Survey used is included in Appendix B.

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[2] Specifically, the mobile app was designed to assume that if it doesn't receive a SPaT message within a certain time period *t*, then it must have lost connectivity and in this case, the app just pauses and waits for the next MAP message to reinitialize itself. As a default, *t* was set to *2 seconds*. Examination of message traffic logs made it clear that there were frequently gaps in SPaT messages greater than 2 seconds, but rarely gaps greater than 4 seconds. By setting *t = 6 seconds*, this connectivity problem was effectively resolved (even though the root cause for these gaps in message broadcasts remains unknown at this point).

3.4 Data Collection Methodology

3.4.1 Observational Data

One primary source of user test data was recorded by the user test *Observer* (see Section 3.3.3). At the outset of each user test, basic test conditions were recorded, including weather conditions (sunny, cloudy, raining, etc.), traffic conditions (time of day, free flow, congested, etc.) and assistive crossing tools (guide dog, white cane, walker, wheelchair, etc.). Then, for each crossing loop around the intersection undertaken by the participant (both with and without the app), the following basic set of data was recorded:

- Direction of each cross
- Start time of each cross
- End time of each cross
- Number of green cycles missed before making the next cross
- Whether or not the app was being used
- Level of observed confusion (1 to 5)
- Level of observed fatigue (1 to 5)
- Level of observed frustration (1 to 5)
- Number of safety interventions
- Other notable events that were observed.

The information sheet attached as Appendix C was developed to facilitate this data collection.

3.4.2 Video recordings

As a backup for verifying various aspects of the data collected by the *Observer*, street crossings were also video recorded for each participant that gave videotaping consent (and in fact all participants granted video recording consent).

3.4.3 Phone Data Logs

Finally, for each participant's crossing, phone data logs were collected and recorded in addition to the observation logs, to obtain a more detailed understanding of the app-to-infrastructure communication behavior, the *PedPal* user interface, and overall performance of *PedPal*. A JSON data logging structure was developed to record the following event information:

- The receipt of every MAP message, SPaT message, and Signal Status Message (SSM) by *PedPal*, including the time received, the message ID, and other relevant content information (i.e., the time-remaining value from SPaT messages, the status value for SSMs)

- The transmission of every SRM that was sent by *PedPal* to the intersection, including the time sent, the message ID, and the crossing duration requested.
- All “start crossing” and “crossing completed” inputs provided by the user as they executed street crossings.
- Location readings at predefined intervals

The transmission and receipt of messages provides a basis for assessing basic performance characteristics of the app such as round-trip times for crossing requests, levels of dropped messages, etc. The capture of “start crossing” and “crossing completed” events can be contrasted with observed data to see how effective users were in communicating this information.

Chapter 4. Field Test Participants

As indicated above, 12 individuals participated in the initial round of user tests of the *PedPal* mobile app. These individuals were recruited via contacts that were developed during the initial user stakeholder meeting held in October 2017 at the outset of the project, and through other prior contacts known to the project team. In the following subsections we characterize the demographics of these 12 individuals and their perspectives on needs and requirements, as aggregated from data provided through the pre-test survey.

4.1. Demographics

From the data collected during the pre-test survey, the demographics of the set of individuals participating in the user test is summarized in Table 4-1.

Table 4-1: Participant Demographics

Gender	M	F		
	7	5		
Ethnicity	Caucasian	Hispanic		
	11	1		
Age	26-45	46-65	over 65	
	3	5	4	
ATTRI Target Population	Persons w/ disabilities	Veterans w/ disabilities	Older adults	No Answer
	8	1	6	1
Disability Types	Vision	Mobility	Hearing	Cognitive
	7	4	1	0

As can be seen, we achieved a reasonable amount of diversity in the types of disabilities covered by participants. For this first user test, we explicitly excluded consideration of individuals with cognitive disabilities, recognizing that this is perhaps the most challenging user group. We intend to extend the scope to consider such individuals in the second year of the project. It is also of note that there are some dimensions along which we could obviously improve our user testing pool. Our ethnic diversity, for example, is extremely low. Over the course of conducting these tests, we have observed several additional candidates in the East Liberty neighborhood that we did not reach and could address this shortcoming, and we are considering the possibility of compensation to attract these individuals to our Year 2 evaluation.[3]

Our user population is also somewhat skewed toward older individuals, and we are discussing ways to attract additional younger users. Nonetheless, we believe that the set of individuals that participated represented a nice cross-section of potential users of the *PedPal* technology.

4.2. Intersection Crossing Tendencies

Another goal of the pre-test survey was to understand the intersection crossing practices and tendencies of the recruited participants, to provide a better basis for assessing the impact of *PedPal* on pedestrian crossing. Table 2 summaries the intersection crossing practices and tendencies indicated by the 12 participants in the pre-test survey. Notice that all participants currently cross intersections independently.

[3] East Liberty is both a socio-economically and racially diverse neighborhood that has undergone significant transition and economic development in the past 5-10 years as high-tech companies such as Google Pittsburgh and Duolingo have moved into this area and there has been a large influx of younger engineers and professionals into this historically underprivileged and largely African-American neighborhood. Although most residents would agree that this is good for the neighborhood, there is still a significant disadvantaged community and it is common to see individuals with disabilities on the street (e.g., disabled veterans, others with severe mobility challenges). Some form of compensation would likely provide a fair incentive for such individuals to participate,

Table 4-2: User Street Crossing Practices and Tendencies

Crossing Frequency	**Daily**	**Couple Times/week**		
	8	4		
Crossing Independence	**Self**	**W/ Human Assistance**	**W/ Technology Assistance**	
	12	2	2	
Assistive Tools Used	**Guide Dog**	**White Cane**	**Wheelchair (Motorized)**	**Wheelchair (Manual)**
	3	7	3	1

4.3. Smartphone experience

PedPal is currently implemented on an iPhone smartphone platform. Therefore, another relevant consideration is the participant's experience with this device. Table 4-3 summarizes the level of familiarity of participants with iPhone and features relevant to the use of *PedPal*.

Table 4-3: User Familiarity with the iPhone

Familiarity w/ iPhone	**Very**	**Somewhat**	**None**
	7	4	1
Voiceover Familiarity (if relevant to the user)	**Yes**	**No**	
	5	1	
Voiceover Experience (years)	**Range**	**Average**	
	2 - 9	5.14	

4.4. Crossing challenges

Participants were also asked what their most significant challenges were in crossing signalized intersections. A range of challenges in crossing a signalized intersection were identified, and varied according to the pedestrian's type of disability:

Blind Individuals:

1. Knowing (or learning) the characteristics of an unfamiliar intersection was identified as a big challenge. Information such as the number of different signal phases in a cycle through all vehicle approaches to the intersection, the distance across the intersection in different directions, the presence of left turns, the intersection's physical configuration (e.g., T, +, 5 way), the presence of one-way streets, and the presence of angled crosswalks are all important factors to know for safely crossing an intersection.
2. Knowing if pedestrian call buttons are present at the intersection and if so, locating them is another challenge
3. Determining where the crosswalks are and then avoiding veering outside of them during crossings, particularly in the absence of other crossing pedestrians
4. Absence of an auditory device at an intersection that announces phase changes. Determination of when it is ok to cross requires listening to vehicle traffic and/or learning the duration of different phases. In the case that there is sporadic traffic, quiet intersection, or inconsistent duration of green signals across cycles this problem is an even greater challenge.
5. Avoiding cars that are turning at the intersection, either in right-turn-on-red or in permissive left turn situations
6. People driving while talking on their cell phones

Mobility Impaired Individuals (e.g., Wheelchair users, Older Adults):

1. Lack of curb cuts at the intersection
2. Accessibility and/or proper functioning of pedestrian call buttons at the intersection
3. Navigating around cars that are blocking the cross walk
4. Insufficient time allocated to make it across the intersection before the signal changes

Deaf Individual:

1. Inability to hear emergency vehicles (with their sirens) approaching the intersection

4.5. Desired features in a street crossing app

Finally, participants were asked what features they would find most important in an app that assists in safely crossing the intersection. The following features were identified as important:

1. Indication of when it is OK to cross in a given direction (accessible via voice-over)
2. Indication of how much time is left to get across the street, along with a countdown
3. The ability to provide information about the intersection, such as how far is it to get across the street in the desired direction
4. Alert capability if crossing trajectory moves outside of the crosswalk
5. Dynamic sound level control if there are loud vehicles or construction work at the intersection
6. Indication of the name of the street that the user is on, as well as the streets that could be crossed
7. Ability to control the verbosity of information provided when in voice-over mode
8. The ability to inform the intersection of crossing intention, eliminating the need for pedestrian call buttons
9. Android implementation that can be easily accessed via widgets/hot buttons for the few intersections that are frequently traversed

Chapter 5. Results

In this chapter, we summarize the principal findings of the user testing performed with the *PedPal* mobile app. We start with the qualitative assessment and user experience impressions provided by the participants themselves in the Post-Test Survey that was conducted. Next we consider the supporting quantitative evidence and additional conclusions that can be drawn from the observational and log data that was collected.

5.1 Qualitative Assessment and User Experience

All participants in the user study were provided with an opportunity to answer questions and provide feedback about their experience using the *PedPal* prototype. IRB-certified researchers from our team asked each user about their thoughts on specific issues such as the best features of the app and enhancements they wish to see in future iterations of *PedPal*. Users were also given the opportunity to comment on anything relevant to the project, beyond answering the specific questions. The answers and comments provided by the users in these post-test interviews are summarized in the following sections.

5.1.1. Best features

Three features of the *PedPal* app were commonly cited as the best features of the app. These included:

1. *PedPal*'s ability to tell the user when it was safe to cross the intersection in a particular direction,
2. the countdown provided for the remaining crossing time (i.e. letting the user know how much time they have left to cross), and
3. the extended time provided to cross the street for those who needed it.

Some users also mentioned the convenience of avoiding the problems of locating and pushing the pedestrian crossing request button as a desirable feature. Users additionally noted that *PedPal* would especially be useful to visually impaired users at intersections with no audibles.

Some visually impaired users also mentioned that the feature of *PedPal* initiating vibrations on the phone when starting to cross was useful, that the app was very easy to use, that the *PedPal* interface was intuitive, and that the auditory output from *PedPal* was clear. One user commented that, for visually impaired pedestrians, knowing when to cross the street makes the *PedPal* app “worth its weight in gold”. It should be noted that users indicated that *PedPal* is not much use for people using powered wheelchairs or people with hearing disabilities, but it is very useful to people who need more time to cross the street (such as people using manual wheelchairs) and people who have visual impairments.

5.1.2. User friendliness and perceived impact on safety and confidence

All participants rated the user friendliness of *PedPal* between 1 and 3 on a scale of 5, where 1 means extremely user friendly, 3 means neutral, and 5 means extremely difficulty to use. The average score was 1.92. Some participants mentioned that the user friendliness score would improve once they had more time to get used to *PedPal*, and one participant mentioned that the user friendliness score was impacted by their experience of not being able to hear the start crossing message 75% of the time during the test. A few participants also had difficulty getting the phone to register their taps and swipes on the screen. All participants thought the instructions for using *PedPal* were relatively easy to follow and that the user friendliness would be extremely good once it was working as intended and they had time to get more practice using it.

Participants were also asked if they thought *PedPal* would impact their safety and confidence when crossing traffic intersections. All visually impaired participants definitely agreed that *PedPal* would have significant impact on their safety and confidence at traffic intersections, and this was visible even during the testing by observers on the research team. When visually impaired users crossed the intersection without *PedPal* versus with *PedPal*, there was a notable difference in their level of tension and stress. Perhaps counterintuitively, visually impaired participants crossed the intersection more quickly without *PedPal* than they did when they used *PedPal.* However, this was because they seemed to rush as fast as possible across the street in a stressed state when they crossed without *PedPal* since there was always a degree of uncertainty of how much time remained for them to complete the cross without the benefit of the countdown feedback they received from *Pedpal*. When they were using *PedPa*l, they seemed visibly calmer and walked at a steady and confident pace.

Even participants who did not think they would use the app in their daily lives (for example, participants who had hearing disabilities or used powered wheelchairs) rated *PedPal* highly in terms of having a positive impact on pedestrian safety and confidence when crossing traffic intersections. Some specific comments were that *PedPal* will be particularly useful in terms of safety at lights that are not consistent or lights that change their patterns through the day, and on quieter streets where traffic patterns are not easily distinguished without the sounds of moving vehicle and, therefore, cannot be used by visually impaired pedestrians to discern the state of the traffic light.

5.1.3 Enhancements for future iterations

Participants had several useful suggestions for enhancements they thought would be useful in future iterations of *PedPal*. Suggested enhancements include

- using a clicking noise or tone when the pedestrian is about to cross instead of counting,
- having voiceover speak when the user swipes to land on a button in the app,

- providing a countdown for the red light as well as for the time remaining during the crossing phase (note that this capability was actually added for later participants in the testing),
- removing any confusion when selecting the street to cross, due to lags between the audio and the buffered gestures (e.g., the audio might be reading out a street name, but the on-screen selection may have already moved on to the next selectable item),
- monitoring for when the pedestrian veers off the crossing (perhaps simply using a tone in the relevant side of the headset),
- removing the necessity of having to tap “start crossing” and “complete crossing” buttons,
- communicating the travel distance and intersection geometry (especially at complex intersections) to the pedestrian via the app,
- providing a bigger target to hit for buttons and selections on the screen,
- adding the capability to protect a walker by turning all lights red in certain difficult intersections,
- enhancing the app interface to meet the needs of pedestrians with cognitive disabilities,
- adding more customization to the countdown vocalization in the app,
- enhancing the ability to attach the phone to something while maintaining the pedestrian’s ability to touch the screen (for example, have the phone attached to the wheelchair),
- balancing extra features with maintaining simplicity of the app interface,
- providing an indication to alert pedestrians when emergency vehicles are approaching,
- providing embossed dots on the screen to enhance orientation, and
- ensuring that touch selection is still active while Voiceover is turned on.

Looking back more generally to the set of crossing challenges that were articulated by participants in completing their pre-test survey (see Section 4.4), we can see that the current *PedPal* prototype provides support for only a subset and leaves several challenges unaddressed. Some unaddressed challenges (e.g., monitoring for veering outside of the crosswalk) have been identified as part of the project’s work scope from the outset of the project and we expect to address them in the coming second year. Others, such as filling in knowledge gaps and providing information on the key characteristics of an unfamiliar intersection, like crossing distance, number of signal phases, presence of left turn phases, one way streets, presence of curb cuts and whether they are angled, and presence of pedestrian call buttons, were not previously called out in the work scope but appear to be fairly straightforward extensions to the current *PedPal* app with slight expansion of the information already included in the MAP message. Still other challenges, either require significant additional technology advances (such as orienting and navigating users to the cross walk or curb cuts) or are orthogonal to mobile app development (e.g., the introduction of a flashing blue light at the intersection to indicate to deaf individuals when an emergency vehicle is approaching).

5.1.4. Enhancements for *PedPal* training and evaluation sessions

Participants were additionally given the opportunity to comment on ways in which both the training and testing sessions for *PedPal* might be improved for future testing. Participant suggestions for training session enhancements included making YouTube video demos of the app available to participants, providing an overview of the layout of the screen and what elements will remain static when training visually impaired users, providing the app to the user earlier if the user is familiar with smartphone, and increased training about where exactly to tap on the screen for visually impaired users. Most participants however said the training session was fine and they would not change anything. One participant even stated that the training may not have been necessary, and that the participant could have learned to use the app easily during the testing phase. Participants had fewer suggestions for improving the testing session. Some comments were that it was good to train and test one person at a time, a suggestion to make sure the test was done at least a couple of times around the intersection, and to include both clockwise and counterclockwise loops around the intersection when testing, and providing the users with the ability to do the surveys and interviews at the location of the testing.

5.1.5. Future test interest and other optional comments

Finally, all participants were asked if they would be willing to participate in future tests of *PedPal* and were given the opportunity to comment on anything else they wished to say about the project. All participants said they would be willing to test *PedPal* again in the future if scheduling allows.

Participants also made a variety of other comments. Some commented that they enjoyed the testing and that it was fun. One participant observed that obstacles are not always a negative thing since they can help visually impaired people navigate, but if the obstacles are unexpected they can cause problems. Another participant commented that the phone app will not be a replacement for other training in orientation and mobility. Some participants suggested that *PedPal* should be integrated with a navigation app. A couple of participants talked about how it was difficult for them to cross large intersections due to the width of the intersection and the corresponding difficulty to stay on course when the pedestrian is blind. It was also suggested that it might be worth asking if users have been in accidents before since it could change how they cross intersections. One blind participant mentioned that s/he does not go out when there are fireworks because they obscure auditory cues and make it difficult to determine what is happening in their surroundings. Several participants mentioned the need to keep the app simple since sometimes new technology can be really complicated. One participant suggested that *PedPal* use the phrase “okay to cross” and one participant suggested that the traffic signals should have an additional light (perhaps blue) to indicate to deaf drivers and pedestrians that an emergency vehicle is approaching. All participants thought that *PedPal* was a promising development and several participants mentioned that they were really excited about *PedPal.*

5.2 *PedPal* Application Performance

This section provides insights on several important factors in using *PedPal*, including wait time for the crossing phase, crossing duration, and overall App's performance.

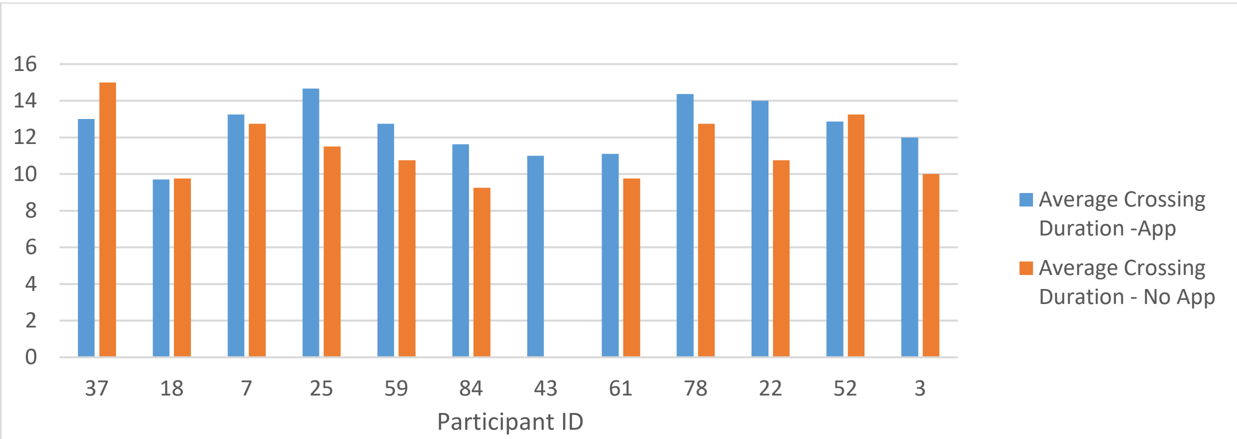


Figure 5-1: Average Crossing Duration (Seconds) Per Participant

5.2.1 Time to Cross an Intersection

The time to cross an intersection varied per participant and also according to whether the participant was using *PedPal* or walking independently. Figure 5-1 shows the average crossing time per participant.[4] As the data shows, in 9 of 11 cases, the crossing duration is shorter when the participant is not using *PedPal*. Given observations that were mentioned earlier, this trend might be attributed to the fact that participants were generally feeling safer when using *PedPal* and as a result were not rushing through their crossing; i.e. they were crossing with more peace of mind.

Figure 5-2 characterizes crossing time duration according to type of disability. Recognizing the fact that we are working with a small sample size, we can make a couple of observations. First, the longest crossing duration when using the *PedPa*l app is observed for people with a mobility disability and the shortest is for people with hearing disability. When operating without the PedPal app, pedestrians with hearing disabilities remain the fastest, but the slowest in this case

[4] Note that no data recordings were obtained for participant #43 for the without *PedPal* assistance case.

are pedestrians with visual disabilities. Second, the only set of pedestrians to exhibit a decrease in intersection crossing time when using the *PedPal* app were those with visual disabilities. Both observations are suggestive of the usefulness of *PedPal* to pedestrians that are visually impaired.

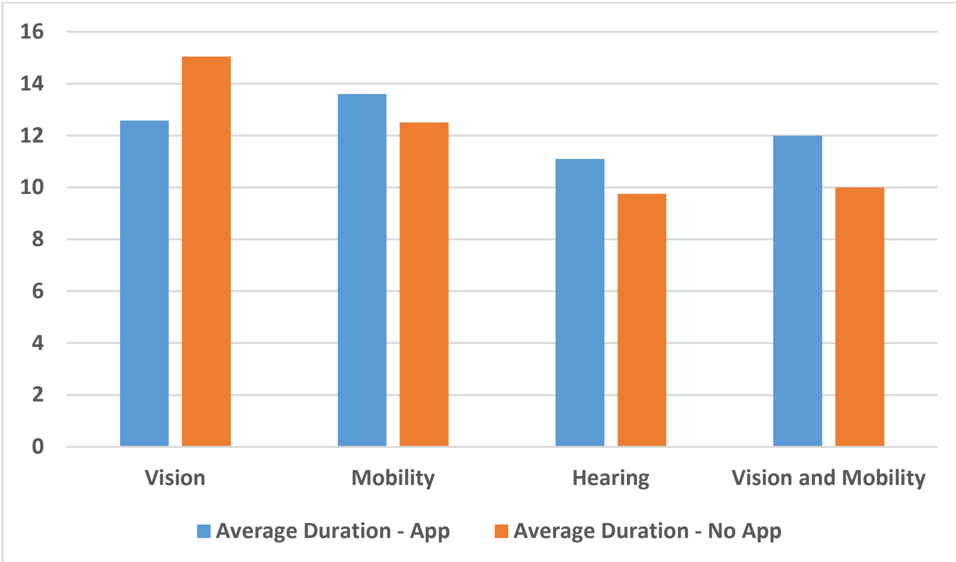


Figure 5-2: Average Crossing Duration (Seconds) by Disability Type

Figure 5-3 (Left) shows a histogram of all crossings completed by all participants without the assistance of *PedPal* (40 total). Crossing time in this case varies from 8 to 18 seconds with an average of 11 seconds. Figure 5-3 (Right) alternatively, shows a histogram of all the crossings completed by all participants when using *PedPal* (96 total). Crossing time in this case varies from 8 to 17 seconds with an average of 12.5 seconds. This comparative data is consistent with the hypothesis that users may be more relaxed and comfortable crossing with the assistance of the app. In the case of blind participants, the seemingly opposite trend can be explained by the fact that without the app it was sometimes necessary for the individual to wait for extremely long periods before crossing, to become convinced that the traffic opposing the crossing direction had indeed stopped.

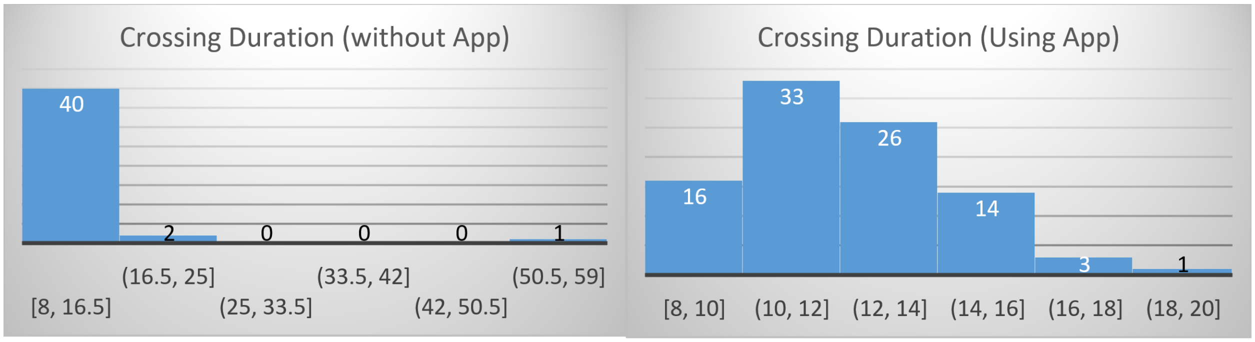


Figure 5-3: Crossing Duration with and without *PedPal* (binned into 2 second intervals)

5.2.2 Wait Time To Cross

The wait time before a pedestrian starts to cross also varied by participant and whether or not *PedPal* was being used. Figure 5-4 shows the average wait time per participant both with and without *PedPal* assistance. As can be seen, the average wait time without *PedPal* assistance is generally lower than with its assistance (9 of 11 participants). We contribute this in part to the fact that the participants were new to *PedPal* and were taking more time to learn how to use it, and in part to technical connectivity problems that required participants to wait until the MAP message was reacquired and normal operations of the app were restored.

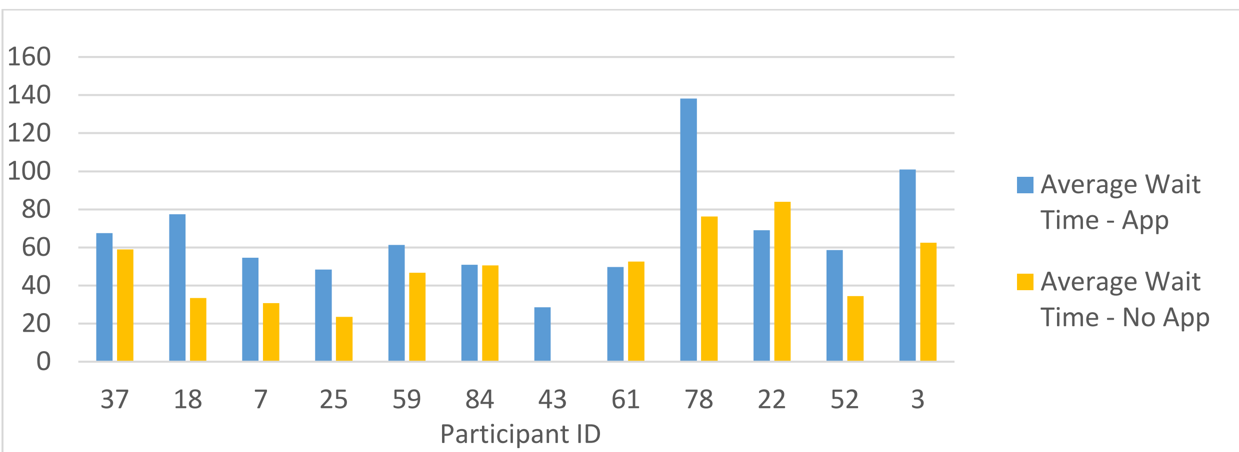


Figure 5-4: Average Wait Time Per Participant

5.2.4 Number of Missed Green Phases

Figure 5-5 shows average number of missed green phases per participant across all crossing trials, both with and without the assistance of the *PedPal* app. So, for example, participant #37 missed an average of 0.25 cycles per crossing when using the app and never missed a green phase when not using the app. Note that the number of missed green phases contributes to the average wait time and Figures 5-5, 5-6, and 5-7 below are consistent with the wait time results that were just discussed. As can be seen from Figure 5-5, participants #7, #25, #43, #52 and #61 did not have any missed green phases using *PedPal* or otherwise.

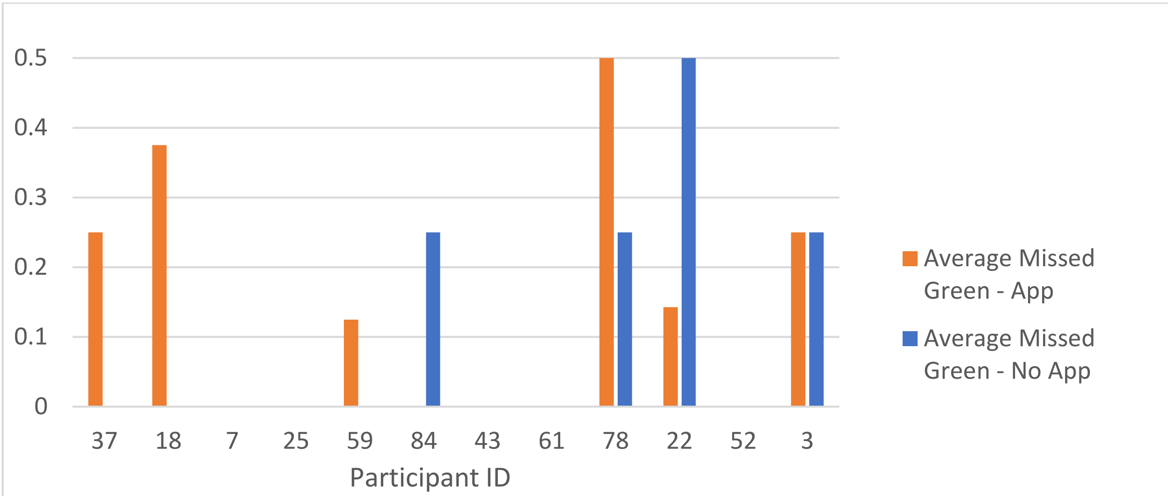


Figure 5-5: Average Missed Green Phases Per Participant

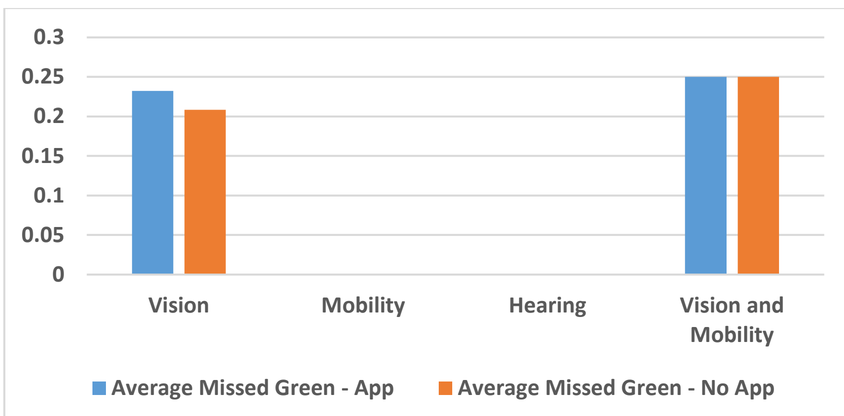


Figure 5-6: Average Missed Green Phases by Disability Type

Figure 5-6 shows the average missed green phases before crossing by disability type. It appears that (again with the caveat of a small sample size) people with vision disability and vision/mobility disability were most likely to miss a green phase before crossing.

Figure 5-7 (Left) shows the wait time for all the crossings made without *PedPal* assistance by all 12 participants. The wait times in this case varies from 6 to 245 seconds with an average of 50 seconds. Figure 5-7 (Right) provides the histogram of wait time for all the crossings that occurred using *PedPal*, also over all participants. The wait times in this case varies from 0 to 227 seconds with an average of 67 seconds.

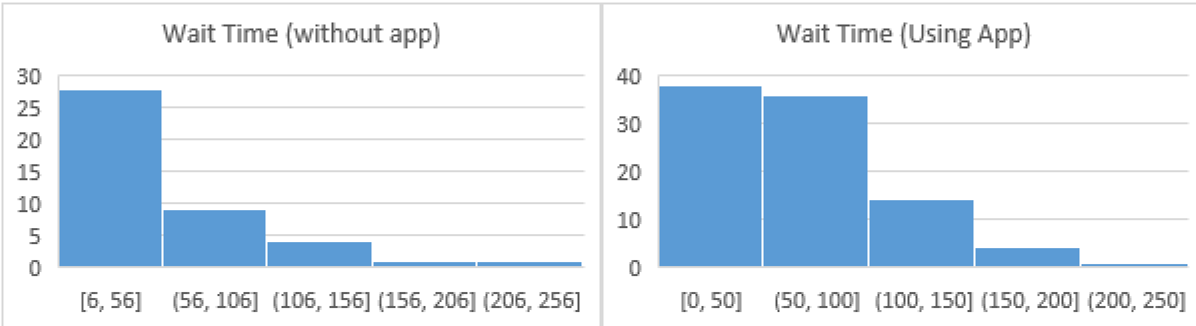


Figure 5-7: Wait Time with and without *PedPal* assistance

5.2.5 *PedPal* App Button Usage

Figure 5-8 shows the difference between the actual crossings completed by each participant versus what was recorded in *PedPal* app. The difference is mostly due to participant difficulties in tapping the Start Crossing and Complete Crossing buttons consistently. When the difference is positive, it means that there were more crossings conducted than recorded, which is likely due to participant forgetting to push the relevant buttons. When the difference is negative, it means that there were less crossings completed than the phone recorded, which is likely due to participants pushing the buttons excessively. Zero difference in the cases of participants #18, #59, and #84 indicates that the buttons were used consistently with crossings which is an ideal outcome.

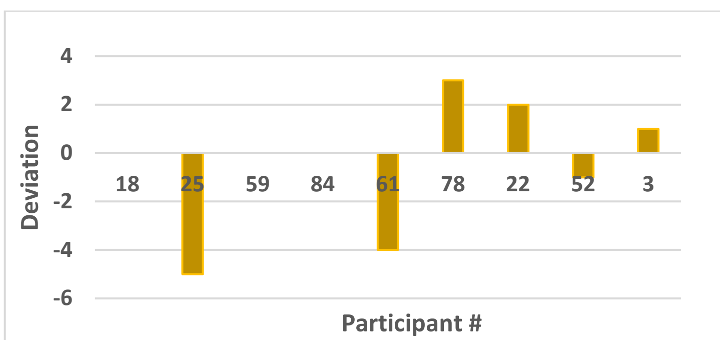


Figure 5-8: Difference in Number of Crossings versus the number recorded by PedPal.

5.2.6 DSRC Connectivity

During the field testing there were several occasions when the *PedPal* App unexpectedly lost connectivity with the intersection and the traffic control system (this point was mentioned previously in Section 3.3.3). To understand this issue, the message logs recorded on the phone during user tests were examined for message loss, and it was discovered that gaps were routinely observed in the receipt of SPaT messages from the intersection's Road Side Unit (RSU). Figure 5-9 shows a plot of the observed times between consecutive SPaT messages for participant #22 over this specific user test. As can be seen, gaps ≥ 2 seconds are quite common, despite the fact that SPaT messages are being broadcast (in theory) at a rate of 1Hz (once a second).

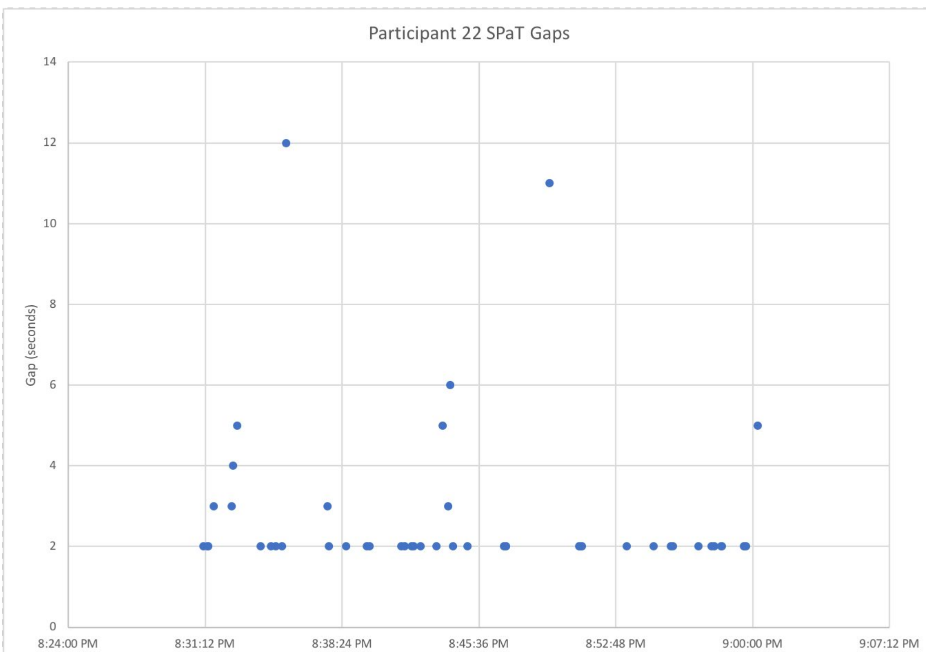


Figure 5-9: Gap in SPaT Messages for Participant #22

Although the cause of these gaps is not yet understood, the connectivity policy adopted in the *PedPa*l app caused it to disconnect from the intersection any time a new SPaT message was not received within 2 seconds, and the subsequent process of reacquiring a new Map message was quite lengthy. We have been able to mitigate this problem by extending the threshold for receiving SPaT messages to 6 seconds and the behavior of the app has improved tremendously with this parameter change.

Chapter 6. Conclusions and Lessons Learned

6.1 Conclusions

The user field testing of the prototype *PedPal* app summarized in this report was undertaken to understand its potential usefulness to pedestrians with disabilities in enhancing their ability to cross signalized intersections and increasing their safety. To this end, comparative street crossing trials were carried out by 12 volunteers both with and without the assistance provided by the *PedPal* app. The feedback obtained from participants, although varying according to specific user disabilities and needs, was overwhelmingly positive. Individuals with visual impairments (the type of disability with the largest representation in the study) were especially enthusiastic. Participants identified 3 basic advantages provided by the current *PedPal* app: (1) to receive an announcement when it is time to cross, (2) to receive a countdown of the time remaining while crossing, and (3) the ability to actually receive extra time to cross. Although some participants had usability problems (i.e., problems interacting with the app and/or the physical device), these were generally attributed to not having enough experience with the app yet, and overall the potential of the technology to provide useful assistance was clearly seen by all participants.

A range of quantitative data was also collected for each crossing tour, via direct observation in the field, through video recording of crossing trials, and through retrieval of data log files generated on the *PedPal* smartphone. However, given the lack of robustness in the current app, and the DSRC connectivity losses that were periodically experienced during user tests, the quantitative conclusions we were able to draw from this data was limited. We expect that user testing in the coming year will become much more stable as the *Pedpal* app matures, which in turn will lead to more quantitative comparative analysis results.

Many suggestions have been provided to us by field test participants on how to refine and improve the app, which gives us valuable guidance as we move into Phase 2 of the project.

6.2 Lessons Learned

Following our user test experiences and observations, we can identify a number of lessons learned that we can take forward into Year 2:

- **Data Privacy** – A number of participants had questions about what would happen to their data if they were to adopt such a mobile app, and some just assumed that we would use their data for commercial purposes. In future testing, we intend to make it clear to everyone, especially in this day and age, that there is no intension to collect their data in any permanent way, but rather any historical data will live on their phone strictly for their records and for learned customization of the app for their use. It is important to think more deeply about privacy concerns and communicate our data policy clearly to users.

- **Compensation and more flexible testing hours could increase participant diversity** – The type of participants recruited for this initial user study was largely skewed toward older, non-working individuals in the local disability community, and potential participants that were not able to take off work, or were otherwise economically disadvantaged were largely excluded. To rectify this deficiency, we are considering the possibility of providing some compensation in future user tests. We are also considering the idea of expanding testing hours to include weekends or after work hours, to attract participants that work during the day.
- **Need for broader recruitment** – Along the same lines, we were unsuccessful in attracting individuals with certain disabilities and plan to increase our recruitment network for future testing to include people with cognitive disabilities, veterans, and older adults with mobility challenges (for example people who use a walking cane or walker).
- **Crossing time may not be a useful indicator of pedestrian safety and confidence when crossing intersections** – We often observed pedestrians (particularly individuals that were visually impaired) moving faster through the intersection without the app, in an effort to get across the street and out of potential danger as quickly as possible. With the app, alternatively, these same pedestrians appeared more relaxed and moved at a more comfortable speed, as the app clearly communicated the amount of time remaining. Hence, our original thinking that crossing time would be an indicator of app effectiveness was somewhat naïve.
- **Extension of crossing time duration may be beneficial to vehicular traffic** – Another phenomenon that was observed was that pedestrians (and especially visually impaired pedestrians) crossed earlier in the signal phase that they did without the app (when they were gauging vehicle noise to determine whether it was ok to cross). One observed consequence of this behavior, together with the fact that a longer phase duration has been granted as a result of their crossing request, was that there was sufficient green time remaining after the pedestrian had crossed to allow facing vehicles wanting to make a left turn to get through the intersection! In Year 2, we intend to try to quantify this benefit to vehicular traffic by measuring traffic flow efficiency through the intersection.
- **Length of testing period** - Spreading out the testing over a few weeks and offering different times of day for testing was useful for both minimizing overall impact to traffic at the test intersection and satisfying the variety of timing constraints that govern schedules of participants. Our original intension had been to conduct the field test according to a

much more compressed schedule (with several participants being tested each day). However, we now clearly see the logistical advantages of a more extended testing time period.

- **Use of test phones** – To carry out the user tests, we utilized a set of 2 iPhone8 smartphones that were pre-loaded with the *PedPal* app. However, users tend to be more stressed to use a different phone than their own, and their individual phone settings were difficult to replicate quickly on a test phone – this was especially true for visually impaired users. Providing the app for users to download to their phone could be a more effective approach to testing in the later stages of this work.
- **Testing protocols** – Several aspects of the user testing protocol can be improved. First, more complex intersections are likely to yield richer results in terms of the impact of the app. Second, providing the opportunity for training and testing and interviews to happen in the same location could save time and streamline testing logistics. Third, it will also help to move the consent and pre-test survey to an online format so that those could be completed prior to the test if users are able to access them. We intend to make all of these adjustments for future user testing.

Appendix A. Pre-Test Survey

PedPal User Study: Pre-Test Survey

Prior to carrying out the user test, we would like to learn more about you and your preferences, habits, strategies and experiences when traveling around the city. We appreciate your time and effort answering the following questions.

1. Demographic information:

    - Gender
        - Male
        - Female
        - Other (please specify):
        - Prefer not to answer

    - Age range
        - 18-25
        - 26-45
        - 46-65
        - Above 65
        - Prefer not to answer

    - Do you identify as part of any of the following ATTRI (Accessible Transportation Technology Research Initiative by the U.S. Department of Transportation) target populations? Please select all that apply.
        - Persons with disabilities
        - Veterans with disabilities
        - Older adults
        - Prefer not to answer

    - Do you consider yourself a person with any of the following disabilities targeted by ATTRI (Accessible Transportation Technology Research Initiative by the U.S. Department of Transportation)? Please select all that apply.
        - Vision
        - Mobility
        - Hearing
        - Cognitive
        - Prefer not to answer

- Ethnicity
  - Please list all ethnic groups you identify with
  - Prefer not to answer
- Optional comments about demographic information:

2. What challenges, if any, do you face when crossing traffic intersections?

3. How often do you cross traffic intersections? Please select the one answer that best describes your regular habits.
   - Daily
   - A couple of times a week
   - Once a week
   - Once every few weeks
   - Rarely
   - Never

   Optional comments:

4. How do you usually cross the street at traffic intersections? Please select all that apply.
   - Independently
   - With assistance from a human guide
   - With assistance from technology or other tools
   - Other (Please specify):

   Optional comments:

5. What tools, if any, do you use for guidance when traveling? Please select all that apply.
   - Guide dog
   - Cane
   - Walker
   - Wheelchair
     - Motorized

- Manual
- Other (please list any other tools that you use):

Optional comments:

6. What technology, if any, do you use to assist you with travel? (e.g. dedicated GPS device, smartphone apps such as BlindSquare, etc.)

7. What features/characteristics do you think will be important in a smartphone app designed to assist you to cross traffic intersections?

8. How would you rate your familiarity using an iPhone?
   - Very familiar
   - Somewhat familiar
   - Unfamiliar

9. If you are visually impaired, how familiar are you with voiceover capabilities on an iPhone or similar iOS device:
   - Very familiar
   - Somewhat familiar
   - Unfamiliar

10. If you use voiceover on an iOS device, how many years of experience do you have using voiceover capabilities on an iPhone or similar iOS device?

11. How familiar are you with the intersection of Centre Avenue and Cypress Avenue?
    - Very familiar
    - Somewhat familiar
    - Unfamiliar

12. Optional comments on anything further you wish to tell us.

Appendix B. Post-Test Survey

PedPal User Study: Post-Test Survey

Now that you've tried out the *PedPal* intersection crossing app, we are interested to get your impressions of its potential usefulness if it were to be further developed into a publicly available product, and also any suggestions and thoughts you might have about how the mobile app could be improved.

1. What features of the mobile app did you find the most promising or helpful? Please explain your answer and provide as much detail as possible.

2. How would you rate the user-friendliness of the mobile app?
    - Highly user-friendly
    - User-friendly
    - Neutral
    - Not user-friendly
    - Extremely difficult to use

3. How likely is it that a solution such as mobile app can increase your safety and confidence when independently crossing an intersection in the future?
    - Safety:
        - o Highly likely
        - o Likely
        - o Neutral
        - o Unlikely
        - o Highly unlikely
        - o Not sure
    - Confidence:
        - o Highly likely
        - o Likely
        - o Neutral
        - o Unlikely

- ○ Highly unlikely
- ○ Not sure

4. What enhancements would you suggest for future iterations of this solution to enhance safe intersection crossing for pedestrians?

5. What enhancements, if any, would you suggest for improving the training session for using the mobile app?

6. What enhancements, if any, would you suggest for improving the testing session for evaluating the mobile app?

7. Would you be interested in testing future versions of this technology?
    - Yes
    - No

8. Is there anything else you would like to tell us about your experience during this test or about this project in general?

Appendix C. Data Collection Sheet

ATTRI *PedPal* Crossing Test Information Sheet

Participant #:	**Date:**
Arrival Time:	**Departure Time:**
Weather Condition: ☐ Sunny ☐ Cloudy ☐ Rainy ☐ Other, specify	**Traffic Condition:** ☐ Rush hour traffic ☐ Free flow ☐ Accident ☐ Congested ☐ Other, Specify
Assistive Crossing Tools: ☐ Guide dog ☐ Cane ☐ Walker ☐ Wheelchair ☐ Other, specify ☐ None	

Simulation Trial #:	
Simulation Trial Start:	Simulation Trial End:

Notes:

1. How many times does the user need assistance?
   - ☐ None ☐ 1 ☐ 2 ☐ 3 ☐ Other, specify

2. What types of assistance does the user need?

3. What questions does the user ask?

4. How many and what mistakes does the user make?
   - ☐ None ☐ 1 ☐ 2 ☐ 3 ☐ Other, specify

5. What is the % completion rate of assignments by the user?
   - ☐ None ☐ 20% ☐ 50% ☐ 100% ☐ Other, specify

6. What is the observed frustration level of the user when completing the assignments? (on a scale of 1-5, 1: no frustration, and 5: completely frustrated)
   - ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

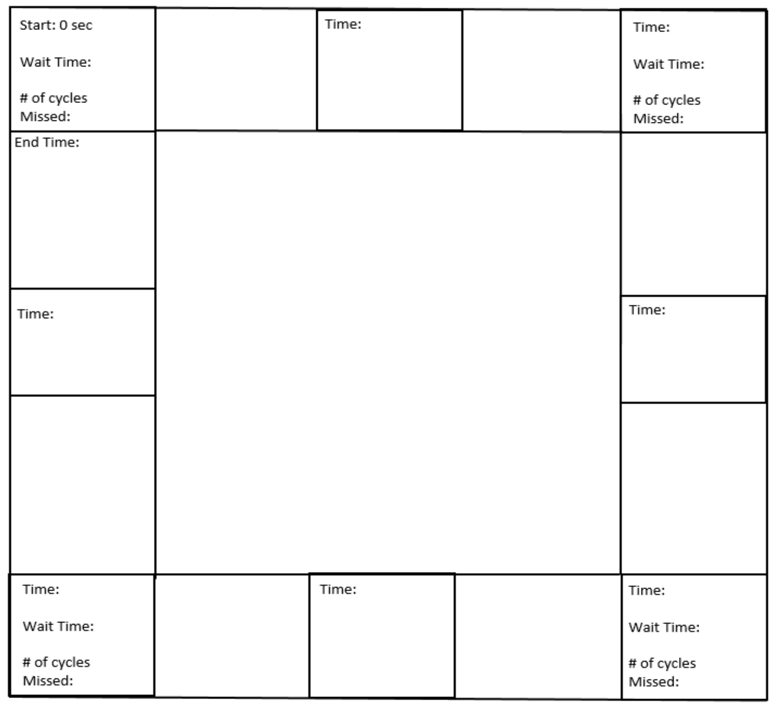
7. Observed confusion (on a scale of 1-5, 1: no confusion, and 5: completely confused)
   - ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

8. Observed fatigue (on a scale of 1-5, 1: no fatigue, and 5: completely fatigued)
   - ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

9. Did the user agree to do the road test?
   - ☐ Yes ☐ No

10. Any other relevant observations

C	
Start Time:	**End Time:**



Notes:

- Observed confusion (on a scale of 1-5, 1: no confusion, and 5: completely confused)
  ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- Observed fatigue (on a scale of 1-5, 1: no fatigue, and 5: completely fatigued)
  ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- Observed frustration (on a scale of 1-5, 1: no frustration, and 5: completely frustrated)
  ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- Number of safety interventions by safety personnel:
  ☐ None ☐ 1 ☐ 2 ☐ 3 ☐ Other, specify
- Number of green phases missed before pedestrian crosses:
  ☐ None ☐ 1 ☐ 2 ☐ 3 ☐ Other, specify

- Other Observations:

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FHWA-JPO-18-706

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