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

Concept of Operations

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16. Abstract

This project aims to develop PedPal, a mobile app that enables pedestrians with disabilities to more safely and more efficiently cross signalized intersections. The proposed technology concept is a smart phone app that interacts directly with a real-time, adaptive traffic signal control system at the intersection via 3G/4G wireless ration technology or via Dedicated Short Range Communication (DSRC) radio technology. Basic capabilities will enhance safety by allowing the user (1) to communicate crossing intent and required crossing time, and receive an extended crossing duration, (2) to receive feedback if movement outside of the crosswalk is detected during crossing, and (3) to dynamically extend the crossing duration if slower than expected crossing progress is observed. Advanced capabilities will include anticipation of the user's arrival at the intersection and minimizing wait time and (2) utilizing real-time bus information to better synchronize user arrival times at bus stops. This document details the overall Concept of Operations of the proposed system, including a discussion of the current use state, rationalization for the changes, the range of user scenarios that it is intended to support, and its impact.

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1 Introduction

This Concept of Operations (ConOps) was developed in support of the Accessible Transportation Technology Research Initiative (ATTRI) program of the U.S Department of Transportation's (USDOT) Intelligent Transportation Systems Joint Program Office (ITS-JPO). The objective of the ATTRI program is to: (a) advance technology applications that enhance accessible transportation and independent mobility choices for travelers with disabilities; and (b) to improve opportunities for a seamless and complete trip that meets the diverse needs of travelers with mobility, vision, hearing and cognitive disabilities and provides them the ability to plan and execute an on-demand trip anytime of the day and from any location. ATTRI research focuses on the needs of three stakeholder groups: persons with disabilities, older adults, and veterans with disabilities. One of the ATTRI program's objectives is to help ensure safe intersection crossing assistance for all unique travelers as they interface with existing traffic, signals, all types of vehicles, and assistive devices.

To help meet this objective, the ATTRI program has initiated a project to build a Safe Intersection Crossing system in which a mobile (smart phone) application could assist people with disabilities to cross signalized intersections safely, independently and confidently. This proposed system will provide guidance, notifications and alerts that assist pedestrians and all users of the transportation system, navigate safely through intersections and focus on providing precise and concise information when it is needed to promote decision-making and actions. The technological solution introduced by the proposed system will be specifically designed for people with blindness, low vision, limited mobility or cognitive issues.

1.1 Purpose and Overview of the Document

This document describes the Concept of Operations (ConOps) for a Safe Intersection Crossing Application. This ConOps describes the current state of operations, establishes the reasons for change, and defines operations for the future in terms of functions/features and supporting operations. This document will be used to present the vision, goals and direction for the project and support the detailed systems engineering development process.

The primary objective of the ConOps is to communicate with the end user of the system during the early specification stages to ensure that operational needs are clearly understood and the rationale for performance requirements is incorporated into the decision mechanism for later inclusion in the system and lower level specifications. Other objectives are:

1. To provide traceability between operational needs and the captured source requirements
2. To establish a basis for requirements to support the system over its life
3. To establish a basis for verification planning and system-level verification requirements
4. To generate operational analysis models to test the validity of external interfaces between the system and its environment, including interactions with external systems
5. To provide the basis for computation of system capacity, behavior under/overload, and mission-effectiveness calculations
6. To validate requirements at all levels and to discover implicit requirements overlooked from other sources.

The primary audience for this document is USDOT staff and other stakeholders who are leading and supporting the development of the safe intersection crossing application for pedestrians with disabilities. Additional audiences include other system developers, engineers, and others are developing other applications that support, interface with, or integrate with the safe intersection crossing application.

This ConOps will identify:

- The purpose of the project
- Who will use the system, and for what they will use it
- How and when the system will be used
- The environment in which will the system be used
- Who will maintain the system and how it will be maintained
- The roles and responsibilities of the various parties using the system
- How the effectiveness of the system will be measured
- How the new system will impact stakeholder operations

The project plan spans two years, with each year consisting a systems development cycle containing phases for ConOps and requirements specifications, system design, development, test and demonstration of safe intersection crossing features. In the first year, work focused on basic features for safe intersection crossing, leading to development and field testing of an initial prototype mobile app called PedPal. The plan for the second year is to refine and harden these basic capabilities for safe intersection crossing and to incorporate additional advanced features aimed at enhancing mobility. This "Year 2" ConOps document encompasses both Year 1 and Year 2 features.

1.2 Project Scope

The technology concept under investigation is a system called PedPal, in which a mobile app installed on a smartphone is capable of interacting directly with a traffic signal control system at the intersection and influencing its control decisions. Most basically, it will allow the pedestrian to communicate crossing intent and issue requests for sufficient crossing time to allow the pedestrian to safely cross the intersection. The PedPal mobile app will also monitor the pedestrian's progress, providing feedback if movement outside of the crosswalk is detected during crossing, and dynamically extending the crossing phase duration if progress is determined to be slower than expected. Finally, more advanced capabilities aimed at increasing mobility will be provided, including (1) using "route" information (obtained via a third party navigation app like Blindsquare) to anticipate the pedestrian's arrival time at the intersection and factor this information into real-time traffic control decisions to streamline crossing time and (2) using real-time bus information to better synchronize pedestrian arrival times at near-side bus stops.

To provide these capabilities, the technical approach includes coupling the smartphone's PedPal mobile app with the Surtrac, real-time adaptive traffic signal control system, which is designed specifically for multi-modal urban road networks [1,2,3]. To maximize accessibility and use of real-time vehicle information, alternative communications paths using Dedicated Short Range Communication (DSRC) radio technology and 3G/4G cellular technology will be provided. Independent of the communications technology, a uniform approach to data exchange based on established data messages and constructs already developed for DSRC communications[1] has been taken. A universal design approach has been taken to the PedPal mobile app's user interface, and our broad goal is to aid individuals across a spectrum of disabilities, including visually-impaired users, wheelchair users, deaf users, users with other mobility difficulties and individuals with cognitive disabilities. The PedPal mobile app developed for this system will be a prototype application, intended for limited distribution, and will require training and supervised practice on the part of the user.

[1] As defined in SAE J2735

2 Current State

2.1 Background

The USDOT ATTRI program is trying to leverage recent advances in vehicle, infrastructure, and pedestrian-based technologies, as well as accessible data, mobile computing, robotics, artificial intelligence, object detection, and navigation. The ATTRI program, through continued research and application development continues to work toward improving the mobility of travelers with disabilities and to provide enhanced capabilities for all travelers to reliably and safely execute independent travel.

Technologies conceived, developed and used by the ATTRI program should provide almost ubiquitous access to a wealth of real-time situational data sources, including data specific to transportation, municipalities, points of interest, crowd-sourced information, and, above all, accessible data. Based on extensive research and information solicitation, USDOT has determined four priority areas for the development of ATTRI applications:

1. Smart Wayfinding and Navigation
2. Pre-Trip Concierge and Virtualization
3. Safe Intersection Crossing
4. Shared Use, Automation, and Robotics

This project is focused on the *Safe Intersection Crossing* application. This application area provides safe crossing assistance at signalized intersections for all types of travelers and its key focus areas include the signals and communications, all types of vehicles and all types of assistive devices. It is imperative that technological solutions, designs and deployments, focus on assistive tools for people with visual, cognitive, hearing and mobility disability. Assistive tools may be in the form of personal mobile devices, wearable technologies and kiosks on street corners to allow for ubiquitous access to connected services.

Applications in this area should provide guidance, notifications and alerts in various communication formats that assist all pedestrians to safely cross signalized intersections. The applications should focus on providing precise and concise information when needed and at the right moment to enhance decision making. These applications should address a number of challenges, including the pedestrian interface with traffic signals, vehicles, nomadic devices, and other technologies (e.g., beacons, RFID tags etc.) that combine to provide automated intersection crossing assistance. They should include support for multiple languages and sharing of real-time information. They should also provide contextual information including GIS and crowdsourced based information on curb cuts, bus stop locations, side walk grade and slope, and any disruption of the built environment (damaged infrastructure, dead ends, potholes) to aid all travelers.

2.2 Users and Other Involved Stakeholders

The local disability community will be the primary stakeholder group of the safe intersection crossing app. Individuals from this community will play two roles within the process. First, individuals will be engaged during the Phase 1 design process to develop understanding of user requirements, needs and challenges. Second, a larger number of individuals will be recruited to participate in Phase 3 field test experiments of the prototype device. While our app development perspective will be on universal design, our prototyping effort and field–testing will focus on blind pedestrians.

On October 24, 2017, an initial meeting of stakeholders was held to illicit important user requirements. The meeting included individuals from the following local Pittsburgh organizations in addition to members of the Safe Intersection crossing project team. This group will be responsible for the design, development and evaluation of the safe intersection crossing app:

1. Blind and Vision Rehabilitation Services of Pittsburgh (BVRS) – Representation from BVRS included the Associate Director of Accessibility Technology and an Orientation and Mobility (O&M) Specialist. O&M Specialists are the individuals responsible for training blind individuals to safely cross signalized intersections. An experienced O&M Specialist has trained 100s of individuals, and consequently, can be expected to bring a much broader range of user experiences and requirements to the app design effort than the singular perspective of an individual person with visual disabilities
2. Golden Triangle Council of the Blind – Three individuals from this organization participated.
3. Disability training and technology experts –In addition to the O&M specialist mentioned above, participation also included
    a. Tessa McCarthy, an Assistant Professor at the University of Pittsburgh who runs a MS program in Teaching for the blind or low vision users. This is a program that certifies O&M Specialists and offers a second source of expertise in mobility for people who are blind or have low vision.
    b. Catherine Getchal, the director of Disability Services at Carnegie Mellon University (CMU) and herself a blind person.
    c. Aaron Steinfeld, a Research Professor of Robotics at CMU who heads the Rehabilitation Engineering Research Center on Accessible Public Transportation and has had a long line of involvement in accessibility research.
4. The Pittsburgh Cultural Trust – Vanesa Braun, director of accessibility and herself a blind person participated from the Pittsburgh Cultural Trust.
5. The Western Pennsylvania School for Blind Children (WPSBC) – Jillian Pritts, a senior administrator from WPSBC, also participated. During the meeting, WPSBC offered the project use of a simulated intersection that they maintain on their grounds in the Pittsburgh East End for purposes of teaching intersection crossing skills to their students. It is anticipated that the project will make use of this intersection to perform periodic added capability demonstrations.
6. The Western Pennsylvania School for the Deaf (WPSD) – Joyce Marawich of the WPSD attended, along with 4 deaf individuals of different ages, to provide perspective on the crossing challenges faced by deaf individuals.
7. Goodwill Industries – Adirenne Tolentino of Goodwill Disabilities Services, and a member for the Port Authority of Allegheny County's Committee for Accessible Transportation, was also a participant.

Underrepresented at this initial meeting were older adults, people with mobility disability, and veterans with disabilities. To address this issue, the project team has subsequently reached out to and met separately with the following organizations:

8. PathVU – PathVU is another recipient of a 2017 ATTRI award, to further develop their wheelchair-based navigation technology. The project team has had several discussions with Eric Sinagra, the project PI, about possible synergies and opportunities for collaboration between our respective projects. These discussions have also sharpened user requirements for people with mobility disabilities.
9. University of Pittsburgh Human Engineering Laboratories – Major focus of these laboratories is on technology and services for disabled veterans. Rory Cooper, the director, was unable to join our initial stakeholder meeting due to a conflict but has expressed his interest and willingness to contribute to our design analysis. We have subsequently met with researchers in his lab to better understand unique requirements of disabled veterans, and to seek help in recruiting such individuals for the year two field tests.
10. Older adults – Older adults represent another segment of the population who can have difficulties in safely navigating signalized intersections, and appropriate organizations (e.g., local centers for independent living) were contacted to find one or more representatives from this community to support user requirements analysis. The project team has also reached out to local centers and to communities of older adults and invited them to subsequent meetings to ensure that their unique needs are captured in our design.
11. The Port Authority of Allegheny County – Since the Port Authority provides a major mode of transportation around the city for individuals with disabilities and is actively exploring the use of DSRC-based communication with Surtrac controlled intersections, their inputs into the Phase 1 design process are also important. Further, since our Year 2 development plan includes a capability to help synchronize pedestrian and bus arrivals at a given bus stop, our refinement of this part of the overall ConOps necessarily requires their involvement.

2.3 Operational Environment

This section discusses the major support components of the operational environment that are required for the proposed system to successfully operate. In Year one, the operational environment included Surtrac adaptive traffic signal control system (Section 2.3.1) connected via DSRC radios to the PedPal mobile app (Section 3.2.2). For Year Two, additional 3G/4G communications capabilities will be introduced to provide a cellular communication alternative to DSRC (Section 2.3.3), and additional sensors will be added to the operational environment to enhance PedPal's localization capability (Section 2.3.4).

2.3.1 Surtrac Traffic Control System

The capabilities for safe and more efficient intersection crossing to be provided by the proposed PedPal mobile application (app) will depend on interaction and interoperability with the Surtrac system. Surtrac is a real-time adaptive traffic signal control system designed specifically for optimization of traffic flows in complex urban road networks, where there are competing dominant flows that change significantly through the day. Surtrac takes a totally decentralized approach to traffic control. Each intersection allocates its green time independently in real-time based on actual incoming vehicle flows, as seen through video or radar detection, and projected outflows are then communicated to neighboring intersections to increase their visibility of future incoming traffic. Reliance on decentralized intersection control ensures maximum real-time responsiveness to actual traffic conditions, while communication of projected outflows to downstream neighbors enables coordinated activity and creation of green corridors. The system is inherently scalable to road networks of arbitrary size, since there is no centralized computational bottleneck.

The Surtrac online planning algorithm approaches optimization of multi-modal traffic by constructing a predictive model of approaching traffic that uses weighting to consolidate multi-modal flows and give relative priority to various travel modes. The core optimization objective is actually weighted minimization of cumulative wait time. The Surtrac predictive model combines individual traffic elements (e.g., passenger vehicles, buses, pedestrians, bicyclists) into clusters (platoons, queues) based on proximity, and these aggregate clusters are the entities that get scheduled through the intersection when generating a timing plan. The weight of a given cluster is determined from the weights associated with its constituent mode elements, and hence for any given intersection, priority can be given to clusters that contain particular mode elements (e.g., pedestrians, buses, pedestrians with disabilities, etc.) in addition to passenger vehicles.

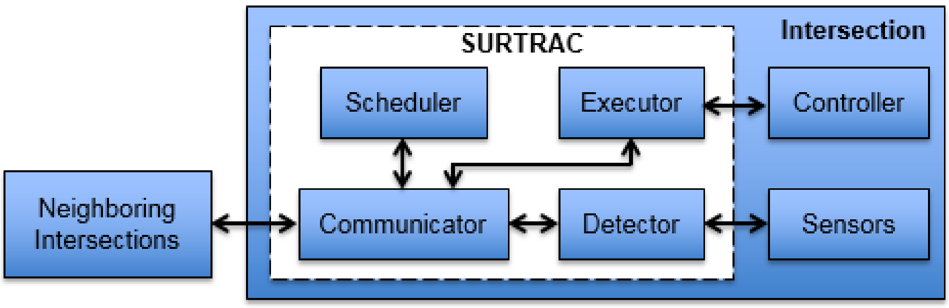


Figure 2-1: Surtrac High-Level System Architecture

Figure 2-1[1] gives a high-level architectural view of the Surtrac system module that is installed in the cabinet at each signalized intersection. At the beginning of every planning cycle (i.e., every couple seconds), information on the currently detected traffic , including motor vehicles, bicycles, scooters and pedestrians within or approaching the intersection along its various approach routes is pulled from the intersection sensors (e.g., video cameras, radar, DSRC-enabled RSU) by the Detector subsystem and used to develop a predictive model of when detected vehicles (or pedestrians) will reach the intersection. This predictive model is then communicated to the Surtrac Scheduler, which generates in real time an intersection timing plan that is optimized for the actual traffic on the road. This timing plan is communicated to the Executor subsystem, which then issues a command to the actual hardware controller (the device that actually runs the signals) to “stay in the current phase” or “move to another phase”. The timing plan is also communicated to each of the intersection’s downstream Surtrac neighbors to provide an expectation of the traffic load that is coming down the pike (according to the plan) supplementing the traffic that can be seen by the downstream intersection’s local sensors, allowing each intersection to construct a longer horizon timing plan. Although not strictly necessary for operation,

[1] Figure 2-1 first appeared in: S.F. Smith, G.J. Barlow, X-F. Xie, and Z.B. Rubinstein, “Smart Urban Signal Networks: Initial Application of the SURTRAC Adaptive Traffic Signal Control System”, *Proc. 23rd Int. Conf. on Automated Planning and Scheduling,* Rome, Italy, 2013)

intersections can be tied back to a backend traffic management system to enable remote monitoring of individual intersections and system performance.

Within this architecture, the proposed PedPal mobile app, will be integrated as an additional sensor/effector, providing additional information to the detector and executor subsystems.

2.3.2 Equipped and Accessible Intersections

The proposed PedPal mobile app will be designed to interact with the Surtrac adaptive traffic control system to influence traffic control decisions, and therefore the first prerequisite for use at a given signalized intersection is that the Surtrac system is deployed and operational at that intersection. In Pittsburgh, Surtrac is currently deployed at 50 inter-connected intersections in the East End of Pittsburgh, and the City of Pittsburgh has recently obtained Federal DOT funding to enable deployment at an additional 150 intersections in the city over the next 2-3 years.

Rapid Flow Technologies, LLC, a startup company that spun out of CMU in 2015 to commercialize the Surtrac technology, has started to deploy the system in other US cities. Surtrac is now deployed in Atlanta GA (24 intersections), Portland ME (8 intersections, with 15 more planned), Needham MA (5 intersections), and Quincy MA (11 intersections), with additional deployments pending in Kane County IL, Beverly Hills CA, Quaker Town PA and Manchester CT. Surtrac presence in US cities is expected to increase significantly over the next few years, and it is also expected that the proposed PedPal mobile app (if it is subsequently commercialized) will provide further incentive for adoption of Surtrac.

The proposed system will be field-tested at selected intersections in Pittsburgh where Surtrac traffic signal control systems are currently deployed and have been enhanced to support the proposed safe pedestrian crossing functionality. The Year 1 evaluation was conducted at the intersection of Centre Avenue and Cypress Avenue, which is currently running the Surtrac system (see Figure 2-2). For Year 2, the user field test trials will be expanded to include the intersections of Centre Avenue and Highland Avenue (which is more asymmetric), and Baum Avenue and Liberty Avenue (which has more complex traffic signal phasing) in addition to Center and Cypress.

Figure 2-2: Year 1 Test Site Location

2.3.3 Communications Infrastructure

The proposed system will use one or more of the following two options for systems communications.

DSRC

System communications will be provided through deployed DSRC wireless technology and the accompanying IEEE 1609 Wireless Access in

a Vehicular Environment (WAVE) standards. DSRC enabled Road Side Units (RSU), which have been installed at the selected intersections will provide the DSRC communications capability for the Surtrac traffic signal control system. In addition to providing DSRC communications between the Surtrac traffic signal control system and DSRC equipped emergency or transit vehicles, the RSU provides the medium by which a DSRC equipped prototype PedPal mobile app could communicate directly with Surtrac traffic signal control system. **Error! Reference source not found.** shows a DSRC-enabled RSU installed at o ne of the Surtrac controlled intersections in the Pittsburgh deployment. Each of the Surtrac traffic signal control systems in the intersections targeted for the proposed system will have operational DSRC RSU units.

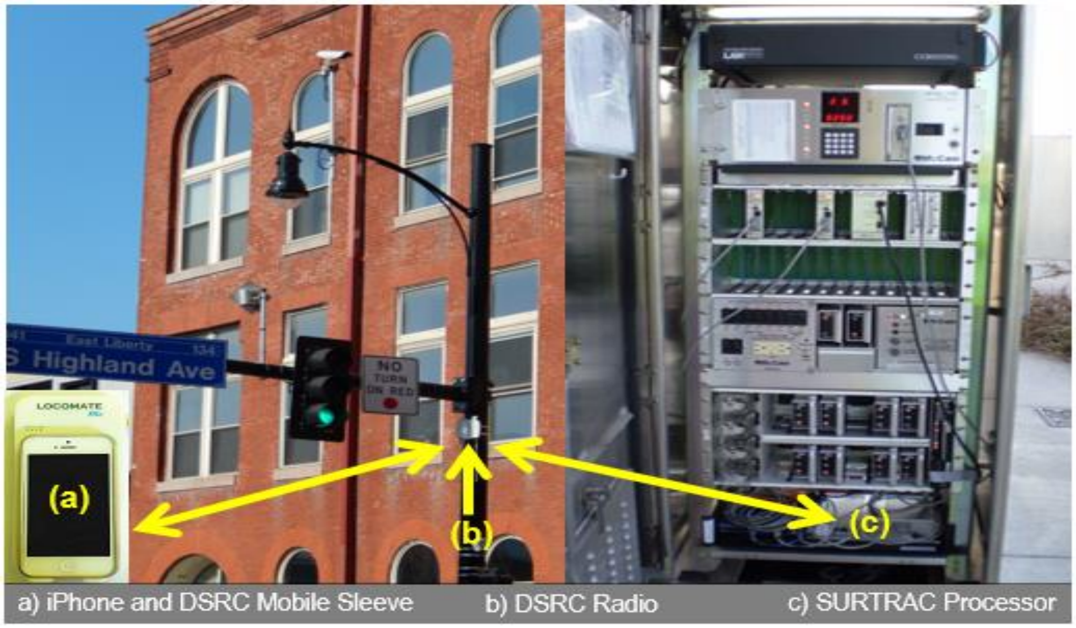


Figure 2-3: Pittsburgh Intersection with DSRC RSU Equipped Surtrac

3G/4G Cellular Communications

In Year 2, System communications will also be provided through IP based data exchange over 3G/4G cellular communications. 3G/4G wireless radios, or alternative backhaul communications equipment, which have been installed at the selected intersections will provide the IP communications capability for the Surtrac traffic signal control system. This IP-based communication will be indirectly established between the pedestrian device's PedPal mobile app and the Surtrac adaptive traffic signal control system through a remote cloud-based server which will relay messages to and from the Surtrac. The appropriate Surtrac for the data exchange will be determined by the server based on the location information provided by the Pedestrian Device. In addition to providing the establishment and management of the communication bridges between the two communications sessions, the cloud-based server will provide any required translation or formatting changes needed to ensure end-to-end connectivity between the PedPal mobile app and the Surtrac signal control system. To the fullest extent possible, both message dialogs and the message structures, formats and content will mirror those used for DSRC communications, as described above.

2.3.4 Localization Service

The localization service (e.g. GPS, or augmented GPS) available to the system at the selected intersections will play a critical role in the success of the planned use cases for the safe pedestrian crossing. It is well known that the accuracy of a smartphone's GPS signal can be less that satisfactory and is typically rated at no better than +/-1-meter accuracy, and that GPS accuracy can be further reduced in specific locations such as found in urban locations. The Year 1 evaluation of the pedestrian device's (smartphone) localization accuracy at the intersection yielded marginally satisfactory results, and an enhanced solution is being pursued in Year 2 to improve the systems performance. Our baseline strategy will be to place additional BlueTooth beacons at known locations at the intersection, to provide a basis for triangulation with the smartphone GPS signal. This approach is discussed in more detail in Section 4.2.2 below.

3 Justification for and Nature of Changes

State and local agencies follow different methods to manage their traffic signals based on existing challenges and needs of respective regions. Most of these methods include updating timing plans, installing new adaptive signal controllers or redesigning intersections to improve traffic mobility. There was little focus on applications for pedestrians. However, in recent years there has been an increasing number of fatalities of pedestrians with almost 5,400 deaths in 2015 (NHTSA Report)[2]. As a result, state and local agencies have been focusing on implementing applications to improve pedestrian safety.

The challenge of providing pedestrian safety applications is especially amplified for people with disabilities who might need more time or assistance in crossing busy intersections. Some states have taken steps to address these challenges for people with disabilities. For example, NYCDOT's Accessible Pedestrian Signals (APS) have devices affixed to pedestrian signal poles to assist pedestrians, who are blind or have low vision, in crossing the street. APSs are wired to a pedestrian signal and send audible and vibrotactile indications when pedestrians push a button installed at the crosswalk. However, more needs to be done to make intersection crossings safe for everyone.

3.1 Justification of Changes

For most people, crossing the street is a routine and simple process. However, for people who are blind or who have other disabilities, crossing the street can be a stressful experience at best in a traffic system not always designed with their needs in mind. As a result, there is a need for researching smart traffic signals that can communicate directly with the user's smartphones and adjust green-light times to accommodate user preferences or needs. Although navigation is not the main focus of this application at this stage, it is envisioned that in the future user drift from the path will be monitored for safety. If the user is detected to be losing his or her direction the application should be able to notify the individual and direct them to the right direction.

At any given time, people who are blind or have other disabilities can travel and cross streets using a human guide, a long white cane to identify and avoid obstacles, a guide dog, special electronic aids, or no additional aid. Crossing the street may include the following actions with focus on blind or low vision pedestrians[3].

2 https://www.nhtsa.gov/road-safety/pedestrian-safety
3 http://www.apsguide.org/appendix_d_understanding.cfm

1. **Recognize an Intersection** — First, pedestrians who are blind determine when they reach a street intersection. This is typically accomplished using a combination of cues, including the curb or slope of the ramp, traffic sounds and detectable warnings.

2. **Recognize the Street** — Next, pedestrians recognize or determine to which street they have come. This information is only occasionally provided in any accessible format, so pedestrians who are blind or have low vision develop a mental map and keep track of where they are within that map, usually by counting blocks and street crossings. Assistance may be sought from other pedestrians.

3. **Assess the Intersection** — Next, pedestrians who are blind obtain critical information about intersection geometry, including the location of the crosswalk, the direction of the opposite corner, the number of intersecting streets, the width of the street to be crossed, and whether there are any islands or medians in the crosswalk. Vehicular sounds, where there is a stream of traffic on each street at the intersection, are used to infer intersection geometry.

   Blind pedestrians also need to identify the type of traffic signal control system at an intersection. This may be determined by listening to traffic patterns through several light cycles, and by searching the sidewalk area for poles with pushbuttons. However, it has become difficult or impossible to determine the type of traffic control at many intersections by listening. The inability to determine whether a crosswalk is pedestrian actuated may result in failure to use pedestrian push buttons and crossing at times other than the pedestrian phase.

4. **Cross the Roadway** — After determining the geometry of the intersection, aligning to face towards the destination curb, determining that the intersection is signalized, and having pushed a button (where necessary), pedestrians who are blind must recognize the onset of the walk interval. In the most common technique utilized for crossing at signalized intersections, pedestrians who are blind begin to cross the street when there is a surge of through traffic on the closest side of the street parallel to their direction of travel. Once pedestrians who are blind have begun to cross the street, they must maintain a heading toward the opposite corner. Turning traffic can make it difficult to establish a correct initial heading, and in the absence of traffic on the parallel street, pedestrians who are blind may veer toward or away from the intersection.

   Additionally, pedestrians with limited or restricted mobility face the challenge of adjusting their pace accordingly to complete the crossing in the default signal phase length allotted by the traffic signal control system.

In the case where an intersection has pedestrian actuation, blind pedestrians have the additional challenges of locating and pushing the button and then crossing on the next pedestrian phase to be assured of having enough time to cross. At these types of intersections, blind pedestrians have the following three types of problems:

1. They cannot wait through a traffic signal cycle to assess and refine their heading by listening to vehicular trajectories before crossing at the next pedestrian phase because they have to locate and push the button again (and re-establish their heading).

2. At a location with little vehicular traffic, they may not be able to detect the onset of the walk interval if there is no through traffic on the street parallel to their crossing.

3. They may not be aware that there is a pushbutton and/or they may be unable to locate the pushbutton. In addition, some locations do not include a pedestrian phase, and at times when vehicular volume is low, there may not be enough time to cross the street.

In the past twenty years, significant changes in intersection geometry, signalization, driver behavior, and the technology of automobiles have affected the ability of blind travelers in the United States to obtain the information they need to cross streets independently and safely. Traffic clearing the intersection also commonly overlaps the pedestrian phase by as many seconds as the duration of the walk interval. In such cases, blind pedestrians will first perceive the pedestrian phase, and initiate crossing, after the onset of the pedestrian change interval. These changes have increased the requests for APS by blind pedestrians. Municipalities and states need a documented procedure to respond to such requests as required by the program access requirements of the Americans with Disabilities Act.

3.2 Description of Desired Changes

The proposed system will address the identified changes discussed above incrementally over the two-year project. The user needs that are envisioned as features of the proposed system are given in Table 3-1: Desired Changes / User Needs, along with an indication of the project year in which each feature will be introduced. The effectiveness of some of these features will ultimately depend on the accuracy of the PedPal mobile app localization capability and the data it provides. Following our experience in the Year 1 pilot test, enhancements to the baseline localization capability of the smart phone will be put in place in Year 2.

Table 3-1: Desired Changes / User Needs

#	Desired Change / User Need	Y1	Y2
1	**Interacting with the Traffic Signal Control System:** Address pedestrians' interface with traffic signals, vehicles, nomadic devices, and automated intersection crossing assistance	X	
2	**Obtaining Real-Time Information about the Intersection:** Information about the intersection, street names, number of streets, and other data that better help the pedestrian visualize and prepare would be very helpful.	X	
3	**Assisting Crossing the Intersection:** Provide guidance, notifications and alerts to assist pedestrians and all users of the transportation system in navigating safely through intersections	X	
4	**Locating and Recognizing the Intersection:** Provide contextual information, including information on which corner, the presence and type of curb cuts at this corner, bus stop locations at the intersection, and presence of traffic islands.		X
5	**Positioning and Orienting:** We expect the above contextual information about the current corner to help pedestrians (especially those with visual disabilities) position and orient themselves for the subsequent crossing.		X
6	**Confirming**: Regular confirmation is very important for people with blindness when crossing the street to ensure the path that's taken is correct, facing correct direction, and not making unsafe mistakes.		X

#	Desired Change / User Need	Y1	Y2
7	**Customizable Assistance:** Provide flexibility in any assisting tools developed for intersection crossing. For example, if one is traveling a route every day, he/she may not need the same level of details for those intersections as would be needed for less familiar ones. Fewer details could be provided for old routes and more detail for new routes. Similarly, countdown information should be configurable to be presented with more or less frequency. Pedestrians with different types of disabilities will prefer different interaction modalities (e.g., voice-over versus visual display) and aspects of each modality choice (e.g., voice-over speed, font-size) should also be configurable to specific individual's preferences.	X	X
8	**Supporting Hands-Free Option:** Design the user interaction with the phone so it does not require holding it out constantly. With some of the current apps, if the phone is in someone's bag, the direction he/she gets could differ. There may be a need for a remote to communicate with the app/phone remotely instead of holding it in hand.		X
9	**Interacting with other PedPal mobile apps:** it would be very helpful to minimize the number of PedPal mobile apps that people with disabilities need to use to navigate to their final destinations safely. If this proposed PedPal mobile app could interact with or be integrated with other PedPal mobile apps that pedestrians already use, for example BlindSquare or another navigation app providing pre-planned routing, it would make it easier for them to navigate.		X
10	**Supporting Audio Communication:** For blind individuals, this is a critical option to be able to follow directions. Audio communication should be clear, especially for streets that have similar names. Moreover, the communication should be repeatable in case the user misses a step.	X	
11	**Integrating a Pre-planned Itinerary:** It would be additionally helpful to utilize a pre-planned itinerary to minimize the user's time spent assessing navigation routes, and subsequently entering data into the PedPal mobile app while in in transit.		X
12	**Incorporating Transit Bus Arrivals:** For pedestrians planning to navigate to a transit bus stop and to board a transit vehicle operating on a specific route, it would be helpful if the PedPal mobile app could communicate this information to traffic signal control system. The traffic signal control system could then determine (using DSRC based messaging) if the transit route of an arriving transit vehicle matches the pedestrian's desired route, and if needed, adjust the signal phase length(s) to increase the pedestrian's likeliness of boarding the arriving transit vehicle.		X

3.3 Priority of Desired Changes

The following list identifies the highest priority features, from the user's perspective, necessary for a mobile device providing intersection crossing assistance. However, the features listed below are not listed in any prioritized order. It is important to note that achieving a complete solution for some of these features will rely very heavily on highly accurate underlying localization technologies which may not be attainable during the project's duration. To the extent feasible, the system will incorporate workarounds to increase the accuracy of the system's localization capabilities.

1. **Locating and Recognizing the Intersection**
2. **Positioning and Orienting**
3. **Interacting with the Traffic Signal Control System**
4. **Obtaining Real-Time Information about the Intersection**
5. **Assisting Crossing the Intersection**

3.4 Changes Considered but Not Included

Some other desired changes that may not be possible to address immediately are as follows:

1- **Speed Coordination:** A pedestrian's speed can change based on the season and road condition, whether an assisting tool (wheelchair, crutches) is used, urban setting, street condition such as construction, health condition, type of shoe/dress worn by the pedestrian, number of pedestrians, and familiarity with the road. As such it would be very helpful that any assisting tool could dynamically adapt to the speed of the pedestrian.

2- **Positioning and Orientation Guidance at the Corner:** Initially it was thought that smartphone localization could be used to guide the user to the crosswalk and position them in the right direction for crossing. However, this has proved to be too much of a challenge and must be deferred until there are further technology advances in smart phone and/or wearable sensing.

3- **Distinguishing the Street from Sidewalk in all Weather Conditions:** depending on the weather condition, it may be very difficult for a person with blindness to recognize where the sidewalk ends and where the street starts. If there is snow on the ground this can be especially difficult.

4- **Notification of Emergency Vehicle:** For a person with a hearing disability, it is not easy to know that an emergency vehicle is approaching. Assistance in being notified of an approaching emergency vehicle is very helpful for these people.

5- **Group Crossing:** Guiding a group of deaf pedestrians to cross the intersection can be very challenging. The dimension of the group adds to the complexity, and it is very difficult for their guide to get their attention. A natural extension to this system would be to add the capability to coordinate a group crossing with the traffic signals.

6- **Converting Audio to Braille Text:** Where audio-to-text features are provided. This will provide an option of converting the text to Braille, allowing deaf and blind or blind users get better access to the information.

4 Concepts for the Proposed System

4.1 Operational Concept

The purpose of this project is to develop a smart phone application that will ensure safe passage of visually-impaired users, wheelchair users, deaf users, users with other mobility difficulties and individuals with cognitive disabilities when crossing signalized intersections. The application will leverage Surtrac (described earlier) to provide these persons with significant mobility enhancements. These services will be accessible to users via smartphones using either inherent 3G/4G cellular communications capability, or if so equipped via DSRC capability, allowing them to do two important things, namely:

- Access real-time information from traffic signal infrastructure and nearby vehicles and
- Actively influence traffic signal control decisions and vehicle movements at the intersection.

The smartphone app will provide accessible interfaces that allow pedestrians to communicate personalized intersection crossing constraints (e.g., required time, crossing direction) to the signal system and ensure that it allocates sufficient crossing time, to receive geometric and obstacle information (e.g., curb cut locations) about the intersection that will facilitate safe crossing, and to be alerted when a crossing movement indicates safety concerns (e.g., moving outside of the crosswalk). Real-time monitoring of crossing performance will also be used to automatically extend the green time in real-time when appropriate. The app will 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. Moreover, since the real-time traffic signal control system is optimizing all detected traffic flows at a given intersection, the approach will yield compound benefits in areas with large concentrations of disadvantaged pedestrians (e.g., the vicinity of elder care facilities, retirement homes, schools for persons with disabilities, etc.).

4.2 Subsystems

This section provides a summary description of the subsystems and a high-level overview of the subsystem changes required to meet the user needs defined in Section 3.

4.2.1 Intersection Infrastructure Subsystem

The Intersection Infrastructure subsystem will have the following components.

Surtrac Adaptive Traffic Signal Control System

Installed within the intersection's roadside cabinet, the Surtrac system performs the following key functions with respect to the proposed system.

1. The Surtrac system accepts detector data from cameras, pedestrian call buttons, and other sensors at the intersection.

2. The Surtrac system generates timing plans, in real time, for moving currently sensed traffic through the intersection efficiently

3. The Surtrac system issues commands to the Traffic Signal Controller, the device that controls the state of the traffic signal heads

4. The Surtrac system communicates predicted outflows to downstream intersections.

5. The Surtrac system uses the current timing plan to generate SAE J2735 defined Signal Phase and Timing (SPaT) messages

6. The Surtrac System can receive over DSRC and process the contents (as required) from all relevant SAE J2735 defined messages (e.g. Basic Safety Message (BSM), Signal Request Message (SRM))

7. The Surtrac system broadcasts the following SAE J2735 defined messages over DSRC at specified intervals.
    a. Signal Phase and Timing (SPaT)
    b. Map Data (MAP)
    c. Signal Status Message (SSM)

The Surtrac system will require the following functional enhancements to support interactions with the PedPal mobile app.

1. Extension to allow a pedestrian's required crossing time to serve as the system's minimum crossing time constraint in the pedestrian's target direction.

2. Extension to allow for dynamic extension of this minimum crossing time constraint if an unexpected delay is detected.

3. Extension to enable acceptance of user travel routes and incorporation of this knowledge when generating signal timing plans to anticipate pedestrian arrivals.

4. Extensions to enable adjustments to generated signal timing plans to ensure synchronized arrival of pedestrians and buses at nearby bus stops.

5. Communications using standards-based variants of SAE J2735 based messages as well as newly defined messages to effect necessary communication of pedestrian goals and constraints, as well as Surtrac system generated commands, guidance, and alerts back to the mobile device.

Traffic Signal Controller

This device controls the state of the traffic signal heads, and as it is already integrated with the Surtrac system, it will require no changes for the proposed system.

DSRC Roadside Unit

The Surtrac systems deployed at the selected intersections have been equipped with DSRC radios. These radios have been used to establish basic vehicle-to-infrastructure (V2I) communications with DSRC enabled vehicles, including transit vehicles and emergency vehicles. The proposed system will not require changes to the DSRC Roadside Unit.

3G/4G Wireless Communication Unit

Data exchange between the pedestrian device's PedPal mobile app and the Surtrac adaptive traffic signal control system can also be enabled through IP-based communications. In this case, a cloud-based server will manage the communication between the pedestrian and the appropriate intersection computer running Surtrac. If at least one pedestrian has selected an intersection with which to interact, the server will subscribe to that intersection and maintain a mirror state of the intersection (MapData, SPaT, and SSM state) that it will report back to the appropriate pedestrians' PedPal mobile apps. The server will also relay messages from each PedPal mobile app to the appropriate Surtrac, e.g., SRM messages. To the fullest extent possible, both message dialogs and the message structures, formats and content will mirror those used for DSRC communications. The communications server will be a new component developed for the proposed system, and it will support the following data exchange scenarios:

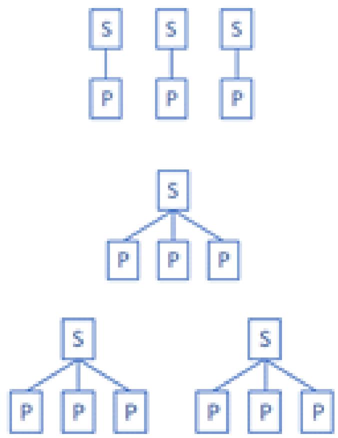


Figure 4-1: 3G/4G Data Exchange Scenarios

- Concurrent support for single sessions between distinct pairings of a single PedPal mobile app and a single Surtrac traffic signal control system node. (Multiple 1:1)
- Concurrent support for single sessions between different PedPal mobile apps and a single Surtrac traffic signal control system node. (Single N:1).
- Concurrent support for multiple sessions between different PedPal mobile apps and a single Surtrac traffic signal control system node. (Multiple N:1)

Traditional Intersection Infrastructure

The selected intersections are already equipped with the necessary traditional intersection infrastructure components – i.e., traffic signal heads and hardware controller, vehicle detection (video or radar), and (optionally) pedestrian call buttons, auditory cues and/or pedestrian signal heads. If pedestrian signal heads are present, the walk/don't walk and countdown information they provide will be synchronized with that provided to the user through the pedestrian device subsystem.

4.2.2 Pedestrian Device Subsystem

The Pedestrian Device Subsystem (PDS) consists of the PedPal mobile app and a computation platform (i.e. a smartphone) for hosting (e.g. installing and operating) the PedPal mobile app. The PDS' computational platform should have accurate localization services, native 3G/4G communication capability, and optionally an extension for DSRC communication capability. Additionally, the PDS' computational platform must support the configurable feedback options (audible, visual or tactile) required for the planned user interface.

The proposed PDS consists of the PedPal mobile app hosted on an Apple iPhone[4] which in addition to offering localization services, and 3G/4G communications capability, will optionally be connected to one of two external mobile, DSRC-enabled device types, each of which will provide full DSRC/WAVE capabilities with native applications for integration with smartphones to facilitate the user-interface.

Device Localization Services

As observed earlier, the accuracy of the localization service (e.g. GPS, or augmented GPS) provided by the pedestrian device is key to the effectiveness of the proposed PedPal mobile app's progress tracking capabilities. In the Year 1 field test, the GPS-based localization service provided by the smartphone was found to be marginally satisfactory in supporting these capabilities, and we intend to augment these capabilities in year 2. Specifically, our baseline extension will be to introduce Bluetooth beacons as additional sensors at the intersection. In (Laio13)[5] the use of two or more Bluetooth beacons were used to boost the accuracy of a mobile phone and enable some amount of tracking of pedestrians through the intersection. Under this approach, the known fixed locations of the beacons provide some error correcting capability through triangularization. At the time this work was done, the resulting accuracy obtained was about +/- 1-meter accuracy (basically equivalent to the accuracy of current day smartphones). However, since smartphone localization has improved substantially in recent years, we expect the use of beacons to give us the accuracy we need. In our case, we will minimally install one beacon per intersection corner. We have gotten access to a state-of-the-art GPS signal integration algorithm from Kris Kitani's group in the CMU Robotics Institute and will install this as a library on the target smart phone.

If time permits and there are still localization problems with the beacon solution, our fallback position will be to acquire a more expensive higher accuracy capability provided by companies like 5D Robotics (now Humantics). Although we believe this approach will be too expensive for general transition of our technology, we also believe that a cheaper alternative is likely to appear on the market in the not too distant future.

Cellular (3G/4G) Radio

This is an inherent component included within all smartphones. It will not require any changes for the proposed system.

[4] iPhone was the device preferred by majority of the user community that attended the ConOps stakeholder meeting held in the CMU Campus in early November 2017. The team thus decided to start the development process on the iOS platform and evaluate addition of an Android later on. One advantage of the iPhone is its commitment to accessibility, and the PedPal mobile app that is developed will be programmed to take full advantage of iPhone accessibility features.

[5] Using a Smartphone Application to Support Visually Impaired Pedestrians at Signalized Intersection Crossings, Chen-Fu Laio, *Transportation Research Record*, No. 2393, 2013.

Mobile DSRC Radio

If configured for DSRC based communications, there are two supported options for incorporating DSRC radios into the PDS, described below, which will be developed as part of the proposed system.

Device Type 1: The first prototype mobile device type will couple an iPhone to a mobile DSRC/WAVE capable device sleeve using a wired connection to enable end-to-end connectivity between the PedPal mobile app and the Surtrac signal control system. Scripts will be developed to enable the programmable DSRC sleeve unit to translate messages between the PedPal mobile app and the sleeve's DSRC radio. This device is shown in Figure 4-2.

Figure 4-2: DSRC Sleeve (taken from http://www.aradasystems.com/locomate-me/)

Device Type 2: The second prototype mobile device type will couple an iPhone to a small portable DSRC on board unit (OBU) using a Bluetooth (or Wifi) dongle connection to enable end-to-end connectivity between the PedPal mobile app and the Surtrac signal control system. Scripts will be developed to enable the portable DSRC unit to translate messages between the PedPal mobile app and the DSRC radio.

PedPal mobile app

The PedPal mobile app provides basic assistance to the user in crossing the intersection and supports all the native accessibility features of the iPhone, including voice-over, zoom, font enlarging, etc. These features are configured from the iPhone's Settings control. Furthermore, it is customizable to each 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 the particular user requires 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.

The PedPal mobile app will be designed to utilize, to the extent feasible, applicable standards for the user interface (e.g. Wayfindr), and communications between the PedPal mobile app and the traffic signal control system (e.g. IEEE 1609.x, SAE J2735, SAE J2945). The proposed system will introduce new or extended standards-based messages as needed, when the required functionality has not been anticipated by the standards process. For example, the system is expected to utilize a standards-based variant of the SAE J235 defined Signal Request Message (SRM) to notify the Surtrac traffic control system of pedestrian arrival at the intersection and to communicate user crossing constraints. The variant could leverage existing, but unused data elements in the SRM message to convey additional pedestrian crossing information to the traffic signal control system.

The PedPal mobile app will support the following user customizable user settings.

- Traveler Type – white cane user, guide dog user, wheelchair users, hearing impaired, etc. – as a means of establishing a baseline crossing speed.
- Street Crossing Speed – crossing speed can be further tuned relative to the default speed.
- Show Diagonal Crossings – specifies whether diagonal crossings should be considered when presenting options to the user in the case of intersections that have an "All-Ped" phase
- Re-Sort Corners After Crossing – impacts user preference when using two crossings to accomplish a diagonal crossing
- Countdown Frequency – When voice over is activated, this setting controls the verbosity of the spoken countdown.
- Device Orientation – fixed or dynamic

The PedPal mobile app's user interface (UI) will provide the following functional capabilities:

- *Communication of Personalized Crossing Constraints*

  An initial user interface will be developed for the PedPal mobile app that supports personalized crossing for a pedestrian, and which allows the pedestrian to communicate his/her crossing goals and constraints to the Surtrac traffic signal control system upon arrival at the intersection and prior to crossing. In the simplest case, this information consists of crossing direction and travel speed (the latter of which is maintained internally by the PedPal mobile app). In more complex settings the pedestrian may alternatively specify a destination location, and request that the traffic signal control system suggest the appropriate crossing sequence. Depending on the current state of the intersection, the PedPal mobile app will convey different instructions to the user (e.g., "wait", "proceed to cross"), and provide support for aligning the pedestrian in the right direction to cross.

  In scenarios involving multiple intersections, traffic islands, or other complicating factors, the PedPal mobile app's UI may employ multiple different application views or data entry forms. Furthermore, asymmetric intersections may require additional interaction with the user to indicate which direction (e.g. side of the crosswalk) is relevant.

- *Crossing Assistance*

  The PedPal mobile app UI will also provide crossing assistance to the pedestrian during his/her trip across the intersection (once the command indicating that it is OK to cross has been given). The app will periodically monitor the pedestrian's location in the intersection and take appropriate action in specific circumstances. If the PedPal mobile app detects that the pedestrian has moved outside of the crosswalk, an alert will be issued with an indication of how the pedestrian should adjust her/his heading to get back into the safety zone. If it is detected that the pedestrian is traveling slower than expected, the pedestrian (with certain exceptions[6]) will be encouraged to speed up and if necessary the green time in the current direction will be dynamically extended to give the pedestrian more time to cross.

To provide this UI subcomponent, the user interface will be extended to provide active assistance during crossing, including monitoring and communication of crossing progress, alerting the user if necessary, and conveying real-time extensions to the phase length. In the event of unreliable GPS, it must also be possible for the pedestrian to communicate progress events (e.g., stuck, completely across). The team will work to integrate and refine these interaction capabilities to interoperate with complementary extensions that will be concurrently made to Surtrac.

- *Use of Pre-Planned Routes*

  The PedPal mobile app UI will also provide the pedestrian with the ability to communicate its planned route to the traffic signal control system in advance of execution, so that the traffic signal control system can anticipate the arrival of the pedestrian at various intersections along the route and factor this information into its optimization of relevant signal timing plans.

  To provide this functionality, the PedPal mobile app will include interfaces to enable a pedestrian to import a travel route that has been pre-planned with the use of a third-party mobile, wayfinding app. The input will be transformed into a route format consistent with emerging open standards, and the system development effort will rely on interaction with Wayfindr to support this objective.

- *Synchronizing with Bus Arrivals*

  Finally, the PedPal mobile app UI will allow pedestrians to designate destination bus stops and desired bus routes in advance, so that the traffic signal control system can try to synchronize bus and pedestrian arrival times at the bus stop. Complementary research at CMU Robotic Institute is currently using DSRC to obtain real-time bus information and factor this more accurate arrival time information into the signal timing plans that Surtrac generates. This information can be used to communicate bus arrival time status to the mobile device and issue warnings to the pedestrian of the need to speed up. Behind the scenes, the Surtrac traffic signal control system will use the communicated information to generate signal timing plans that ensure synchronized arrival of the pedestrian either ahead of or simultaneous to the bus to be caught.

  For this UI component, the team will develop user interfaces to allow pedestrians with disabilities to take advantage of extended signal crossing times to facilitate making connections with arriving buses at nearby bus stops. The team will extend mechanisms for communicating intent to the traffic signal infrastructure to include indication of the target bus route, and for receiving real-time information from the infrastructure about approaching buses (if one of several bus routes could be taken).

[6] Exceptions could include users with cognitive disabilities or those who created user profiles with certain preferences that would prevent such alerts. In such cases the green will be extended without an alert being issued to the user.

4.3 Operational Policies and Constraints

The ATTRI application developmental process seeks to spur innovation among accessible transportation concepts to provide inclusive and seamless door-to-door independent mobility to all travelers including those with disabilities. In developing this system, the following foundational considerations should be addressed:

Equipped Intersections and Users: One fundamental requirement for the PedPal mobile app to work is that both the intersection and the user must be properly equipped. The intersection must be equipped with the Surtrac traffic control system, and users operating the PedPal mobile app must have either a companion DSRC device or cellular connectivity to enable communication with the Surtrac system at the intersection.[7]

Standard Accessible Data Platform: Data standardization and interoperability is critical in developing applications which aspire to enhance the personal mobility of those with the greatest needs. Data must begin to work across service providers, utilize available real-time data sources and communicate in an efficient, succinct, and adaptable manner to meet individual user needs with various degrees of abilities. Technology applications to be considered for ATTRI development will provide almost ubiquitous access to a wealth of real-time, situational data sources, including data specific to transportation systems, municipalities, points of interest, crowd-sourced information in accessible formats utilizing inclusive information and communications technology (ICT). Applications may consider standardized data to create user profiles allowing smoother access and transferring between accessible transportation services.

As noted in Chapter 2, our design will refer to established standards such as NTCIP, IEEE 1609.2-4, IEEE 802.11p, SAE J2735, and SAE J2945/9 standards to ensure compatibility and effective system development.

Universal Design Standards: Universal design standards incorporate a philosophy that espouses to maximize the applicability of a technical solution to the needs of all user groups. In relationship to ATTRI application development, it is presumed that all work attributed to building applications for the use by ATTRI stakeholder groups pursue universal design principles including inclusive ICT solutions. Implementation of such principles in development could include leveraging existing solutions and enhancing them to meet the needs of all users, as such user center and responsive design approaches, personalization techniques are expected to be followed for applications including implementation of multiple communication modalities (visual, audible, haptic) where possible. Likewise, consideration should be given to incorporate user profiles and documented needs from all stakeholder and ability groups, and to create user experiences with information sharing on any display associated with such applications in built and pedestrian environments including wearable and nomadic devices. The feasibility

[7] Strictly speaking, the most basic functional capability that is planned – i.e., the communication of crossing direction and time required, and subsequent establishment of this time as the crossing minimum for the next occurrence of the relevant phase – can also be provided with a conventional traffic signal control.

of mainstream adoption of such technological solutions being developed for ATTRI should also be considered for all functional disability types.

Leverage Existing Technologies: To maximize the impacts of ATTRI and to respond most effectively to the needs of all users and stakeholders, any application being developed under ATTRI should leverage, to the degree possible, existing technologies, including but not limited to ITS-JPO, Application Program Interface (API), Software Development Platform, Software Development Kit, on-demand technologies, data standards, innovative smartphone and mobile technology, wearable technology, accessible transportation technologies, and other assistive and enabling technologies, operations, and/or techniques whether currently being pursued in research, or readily available in the market.

The ATTRI program completed research on institutional and policy issues as it relates to technology applications to improve mobility options for people with disabilities. The program published a report on the summary of its findings and identified three specific policy issues. Below are key pieces from this report[8] that will be taken into consideration when developing the system.

Awareness and Product Development: While there are many elements which influence how and when a technology or product is developed and distributed, awareness of user needs is the starting point of this process which the report found to be widely recognized as an issue. Market gaps can form when demand (while real and immediate for the individuals affected) is perceived to be too small to warrant the investment. Public and private industry policy may play a role in 1) evaluating and possibly correcting the perception of a limited market; 2) identifying ways to combine small market niches to make them more attractive; 3) providing subsidies to reduce the required investment, risk to serve the unmet demand. The research in this area indicates that there are existing initiatives that attempt to meet the needs of people with disabilities, but that there remains a significant policy issue for understanding the user needs, meeting the awareness and product development needs of people with disabilities.

Funding: Funding issues include funding for the direct utilization of accessible technologies by persons with disabilities, for the development and deployment of advanced accessible technologies, and for addressing the barriers to that development and deployment. Funding sources for people with disabilities are fragmented. Persons with disabilities are sometimes not aware that certain funding sources exist, while other funds may be locked behind specific eligibility requirements or exist as tax incentives instead of direct funding assistance. The background research indicates that funding for accessible technologies is a policy issue that should be examined both in terms of scope, organization, and availability.

Research and Development Incentives: It is essential that accessibility is considered early in the design process to promote accessible technologies for the population with disabilities. Integrating accessibility needs into technology development early lowers the costs relative to later retrofits; however, the biggest benefit is that new developments which have mass market appeal are the easiest way to encourage private companies to take the risk of developing those technologies with universal design and incorporating inclusive information and communication technologies (ICT) solutions. Ensuring that new

[8] Accessible Transportation Technologies Research Initiative (ATTRI) Institutional and Policy Issues Assessment, USDOT report, February 2017

technologies being deployed are useful not only for the population in general but also people with disabilities will help both the social acceptance and conversely the market reach of accessible technologies.

4.4 Modes of Operation

Safe Intersection Crossing

Service requests will be implemented through integration with a real-time adaptive signal control technology. The base service to be provided will ensure that a pedestrian has sufficient time to safely cross an intersection. By customizing the PedPal mobile app to the individual traveler, a pedestrian will issue personalized crossing requests to the traffic signal infrastructure, minimally communicating the desired direction of the cross, the pedestrian's required crossing time (based on the nominal traveling speed known to the PedPal mobile app and knowledge of the crossing distance provided to the app by the intersection) and the pedestrian's current location (at or approaching the intersection). The traffic signal control system will in turn adopt this required time duration as the appropriate phase minimum for the upcoming cycle. The pedestrian will also be added to the intersection's current model of approaching and waiting traffic, using the same provided information to compute an intersection arrival time for approaching and waiting pedestrians. When a waiting pedestrian gets the green, real-time localization information will be used together with infrastructure knowledge of the intersection geometry and its physical constraints to monitor pedestrian progress through the intersection, and issue alerts if appropriate (e.g., if movement outside of the intersection crosswalk is detected). If progress is slower than expected (e.g., due to a wheelchair needing extra time to traverse a damaged curb), the system will extrapolate the remaining time needed to cross the intersection and lengthen the current green phase accordingly in real-time.

Exploiting Pre-Planned Routes

Travelers with disabilities rely extensively on pre-planned routes. However, at each intersection along the route, the traveler can experience significant crossing delays. A second service to be provided is the ability to import a traveler's pre-planned route (e.g., spanning multiple intersections) and exploit this knowledge to expedite the traveler's movement along this path. Using the same travel speed and network/intersection distance and geometry information, the traffic signal infrastructure will project successive intersection arrival and crossing times and then factor them into its real-time computation of signal timing plans for intersections along this path along with other sensed (and predicted) traffic flows. This service will import routes in a format that adheres to open standards for emerging wayfinding systems. Note that the intention is not to give overall signal phase priority to the pedestrian, as this could have an uncontrolled negative effect on overall vehicle flows and cause significant congestion. Instead the use of this additional information is expected to lead to more pedestrian-aware signal timings along the pedestrian's route that result in less waiting time than the status quo.

5 Operational Scenarios

This section provides a list of use cases (operational scenarios) developed by the team and through engagement with stakeholders and system users. These use cases are intended to reflect the operations of the proposed system at a high level, indicating how the flow of information should occur between and among systems, users, and institutions. Use cases enable stakeholders and readers of the ConOps to grasp the operational significance of the proposed system and to clearly see what expected roles are.

To better understand the nuances for different type of users, the Table 5-1 below was constructed based on data gathered from stakeholders with different types of disabilities. This provides a deeper understanding of what type of difficulties each group deals with. It is important to note that this is not a comprehensive list but a sample that hopefully covers a good portion of features that these personas are looking for. Where possible, uses cases are logically connected to specific features highlighted in this table.

Table 5-1: Desired Design Features from User's Perspective

Disability Type	Description of Problem	Desired Design Features
Low Vision	Prefers using audio components	Audio enabled features (i.e. notifications, alerts, directions)
	Difficulty reading in brightly lit settings	White letters on a black background
	Difficulty reading small print	Increases text size and Magnification tool to make items on screen appear larger
	Difficulty using touch screens	Voice commands from user
Became Blind as an Adult	Seeking and obtaining information	Prefer audio-based communications to receive information.
	Confused by the use of cardinal directions	Use of relative directions (e.g. left, right, behind, in front of) when providing directional guidance
	Different needs and styles	Able to customize and adapt features for convenient use
	Directions must be very specific	Provide user with updates and confirmation throughout tasks (e.g. confirmation that user crosses street successfully); Break down tasks into smaller but specific steps

Disability Type	Description of Problem	Desired Design Features
Autism Spectrum Disorder	Receiving too much information at once is overwhelming	Option for user to turn some modes on and off to manage the amount of notifications user receives
	Gets frustrated when hearing the same piece of information multiple times	Slow delivery of aural information
	Noisy environments are a challenge	Noise cancelling headphones
	Images or videos can help guide user through activity	Visual directions
Multiple Sclerosis	Difficulty using touchscreen due to reduced upper body strength	Audio enabled features; Voice commands from user
	May accidently rest hand on screen	Multi-touch enabled screen
Hearing loss and Dementia	Speech is hard to follow when there is a big tonal range	Monotone aural information
	Has trouble dealing with uncertainty	App displays upcoming task or step with text descriptions
	Has trouble hearing when it's busy around	Vibrating or flashing alerts and notifications
Low Hearing or Deafness	Looks to visual cues for information	Flashing alerts and notifications / provide tactile alerts (vibration)
	Too much visual information can be overwhelming	simple and easy to follow text information
	Avoids settings that are strongly audio based	Audio disabled; Text only communication with user

Figure 5-1 below provides a high-level schematic of the general steps that occur when a pedestrian crosses an intersection using the proposed system:

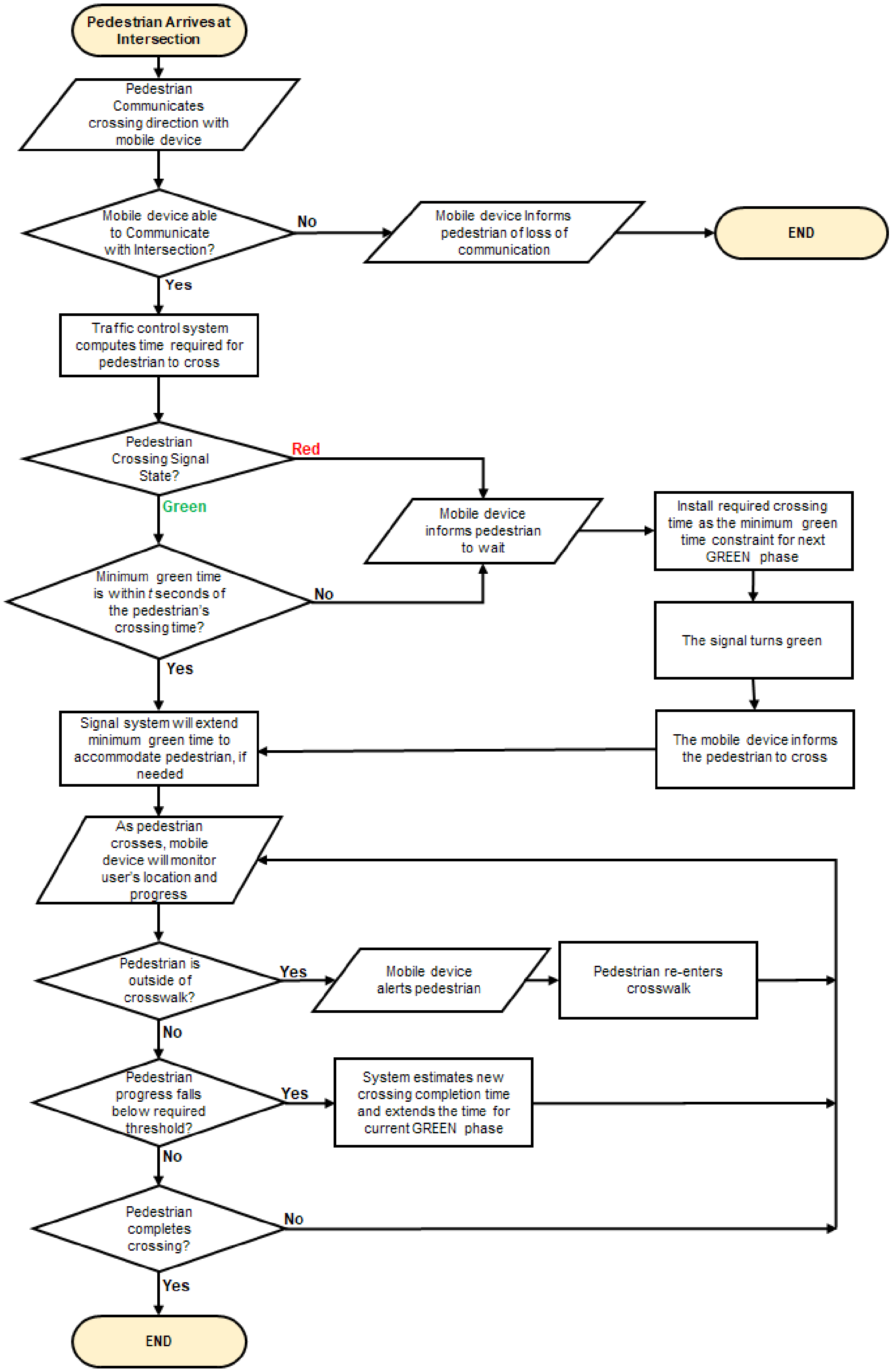


Figure 5-1: Flowchart of Steps Leading a Pedestrian to Cross an Intersection

Table **5-2** below lists the use cases that are described in the following subsections.

Table 5-2: List of Use Cases

UC #	Use Case Title
1.	Intersection Crossing – Signal Control is Red
2.	Intersection Crossing – Signal Control is Green (Enough Time)
3.	Intersection Crossing – Signal Control is Green (Not Enough Time)
4.	Intersection Crossing – Multiple Pedestrians -Signal Control is Green
5.	Intersection Crossing – System Communications Failure
6.	Intersection Crossing – Unsafe Trajectory Detected
7.	Intersection Crossing – Unexpected User Delay
8.	Intersection Crossing -- Dual Crosswalk During All Pedestrian Walk Phase
9.	Pre-Crossing – Notifying Pedestrian that Upcoming Traffic Signal is Red
10.	Pre-Crossing – Assisting Pedestrian to Prepare for Crossing
11.	Pre-Crossing – Pedestrian Requires Replay of Instructions
12.	Pre-Crossing – Pedestrian Decides Not to Cross
13.	Pre-Crossing – Approach of an Emergency Vehicle
14.	Pre-Crossing – Pedestrian Crossing Synchronized with Bus Arrival

In the set of tables that follow, a detailed description of each of these use cases is provided, identifying:

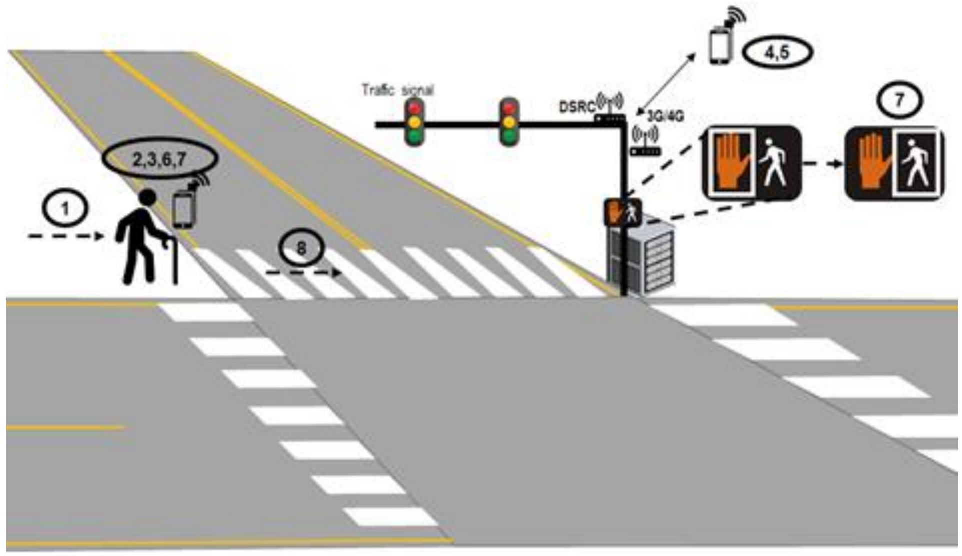
- The system and external elements and actors
- The assumptions necessary for the use case to successfully occur
- The initial state (preconditions) necessary for the use case to commence
- The sequence of events in terms of elements in the system diagram (which element does what action, and in what sequence)
- The ending state (post conditions) (i.e., what, if anything, changes as a result of the steps performed)
- Notes and comments

The use case descriptions below are followed by Table 5-3 below provides a mapping of the User Needs, as defined in Section 3.2 above, to the appropriate Use Cases just defined. The left two columns of each row indicate the number and description of each User Need. The next fourteen columns are used to indicate which of the fourteen defined Use Cases are relevant to and reflect the corresponding User

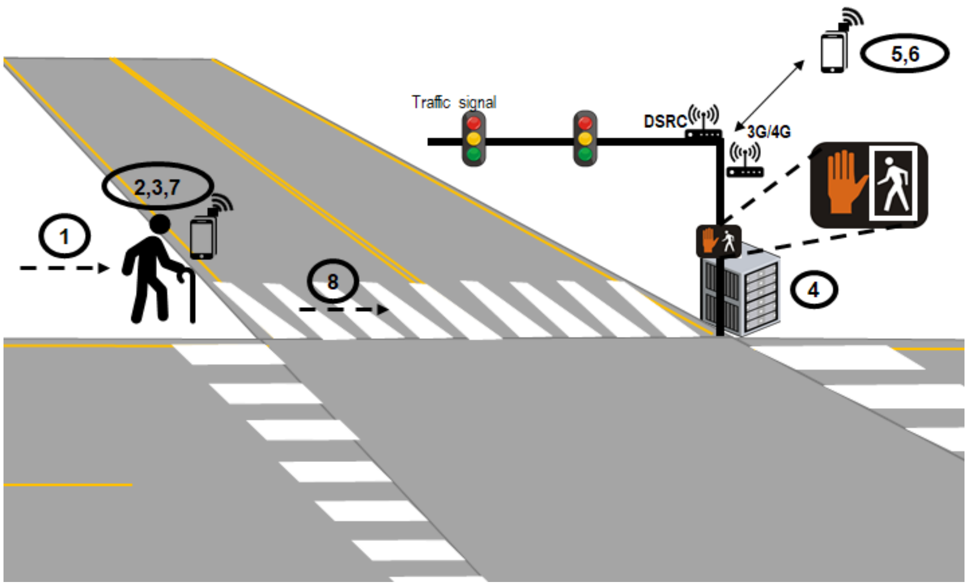
Need. A cell containing an “X” indicates that the User Need specified in the same row is met through exercising the corresponding Use Case (indexed by Use Case number).

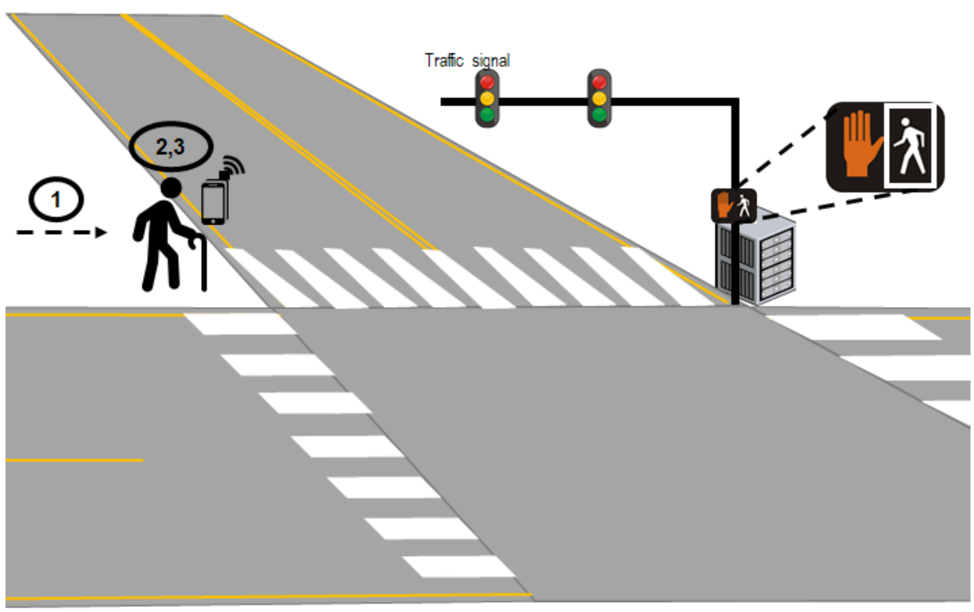
Table 5-3 that provides a mapping of the User Needs, as defined in Section 3.2 above, to the appropriate use cases.

Use Case 1: Intersection Crossing – Signal Control is Red	
Actors/System Elements:	Pedestrian, PedPal, Traffic Signal Control System (TSCS)
Assumptions:	1. PedPal is connected to TSCS, and receiving intersection status 2. Pedestrian’s mobile device localization services are operational 3. Pedestrian is trained to use PedPal 4. PedPal may have access to a pre-planned itinerary 5. Traffic signal is red when Pedestrian arrives at the intersection
Preconditions:	1. Pedestrian arrives at an intersection that is currently red in the crossing direction
Sequence of Events:	1. Pedestrian arrives and stops at intersection and communicates crossing direction to PedPal 2. PedPal calculates “time to cross” using crosswalk geometry from the MAP message, and its knowledge of Pedestrian’s anticipated crossing speed. 3. PedPal communicates the Pedestrian’s crossing direction and estimated “time to cross” to TSCS for use as the minimum green time constraint for next GREEN phase in Pedestrian’s crossing direction 4. TSCS communicates acceptance of the request to PedPal 5. TSCS adjusts SPaT message broadcasts accordingly 6. PedPal monitors intersection status and informs Pedestrian to wait 7. When the signal subsequently turns GREEN in Pedestrian’s crossing direction, PedPal signals Pedestrian that it is time to start crossing.
Post Conditions:	1. Pedestrian crosses the intersection 2. PedPal monitors intersection status and Pedestrian’s progress through the intersection

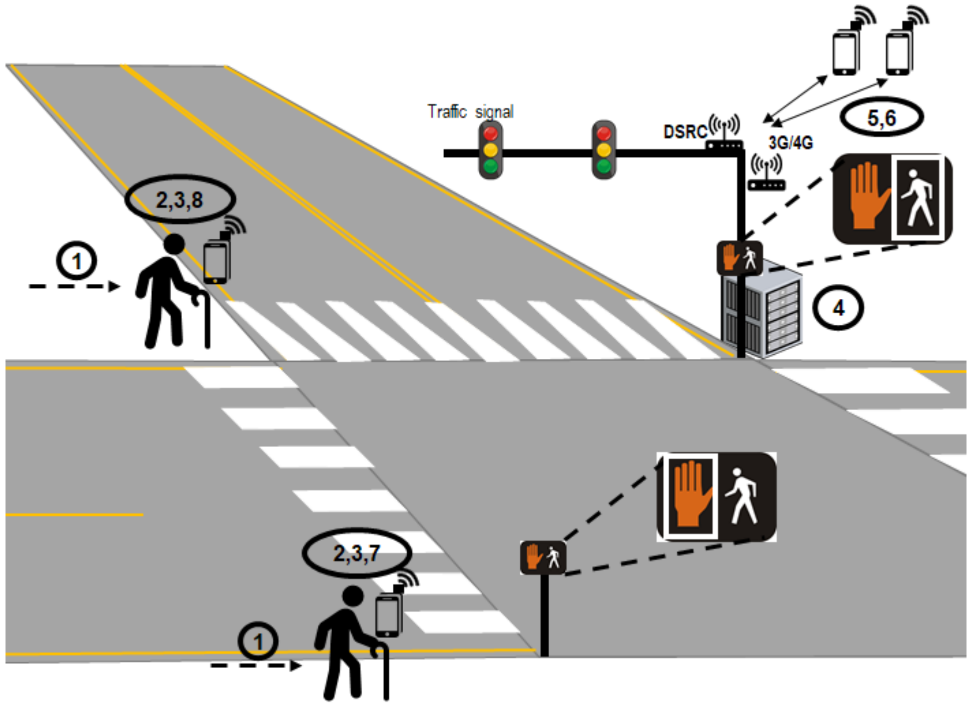
Use Case 1: Intersection Crossing – Signal Control is Red	
Notes/Comments:	

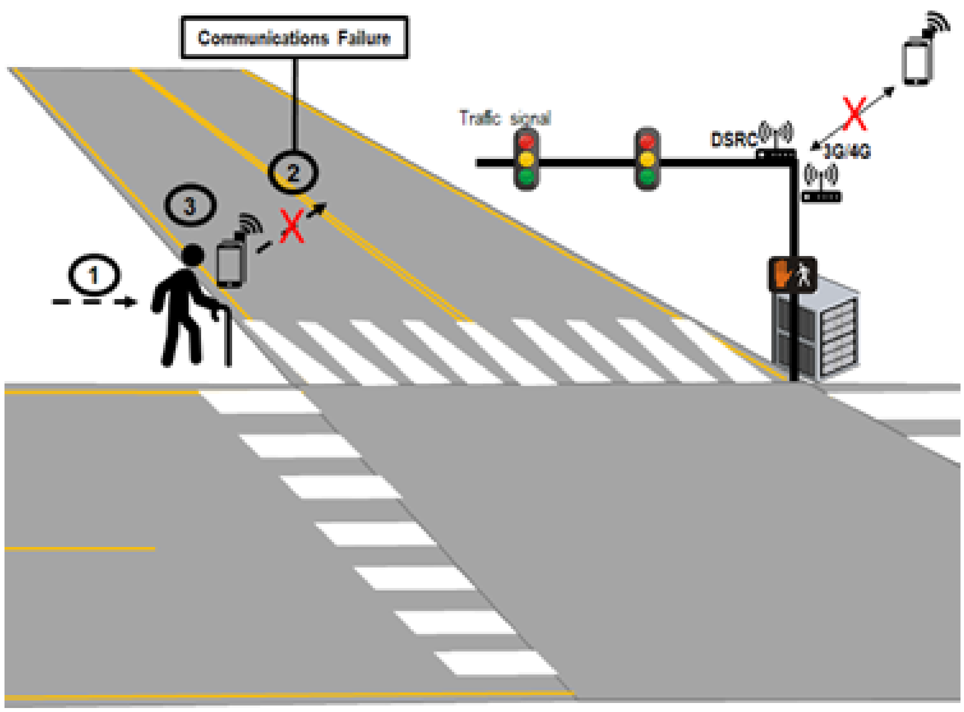
Use Case 2: Intersection Crossing – Signal Control is Green (Enough Time)	
Actors/System Elements:	Pedestrian, PedPal, Traffic Signal Control System (TSCS)
Assumptions:	1. PedPal is connected to TSCS, and receiving intersection status 2. Pedestrian's mobile device localization services are operational 3. Pedestrian is trained to use PedPal 4. PedPal may have access to a pre-planned itinerary 5. Traffic signal is green when Pedestrian arrives at the intersection
Preconditions:	1. Pedestrian arrives at an intersection that is currently green in the crossing direction
Sequence of Events:	1. Pedestrian arrives and stops at intersection and communicates crossing direction to PedPal 2. PedPal calculates "time to cross" using crosswalk geometry from the MAP message, and its knowledge of Pedestrian's anticipated crossing speed. 3. PedPal communicates the Pedestrian's crossing direction and estimated "time to cross" to TSCS. 4. The remaining minimum green time is within t seconds of Pedestrian's crossing time, so TSCS extends the minimum green time to accommodate Pedestrian 5. TSCS communicates acceptance of the request to PedPal mobile app 6. TSCS adjusts SPaT message broadcasts accordingly 7. PedPal mobile app informs Pedestrian to cross
Post Conditions:	1. Pedestrian crosses the intersection

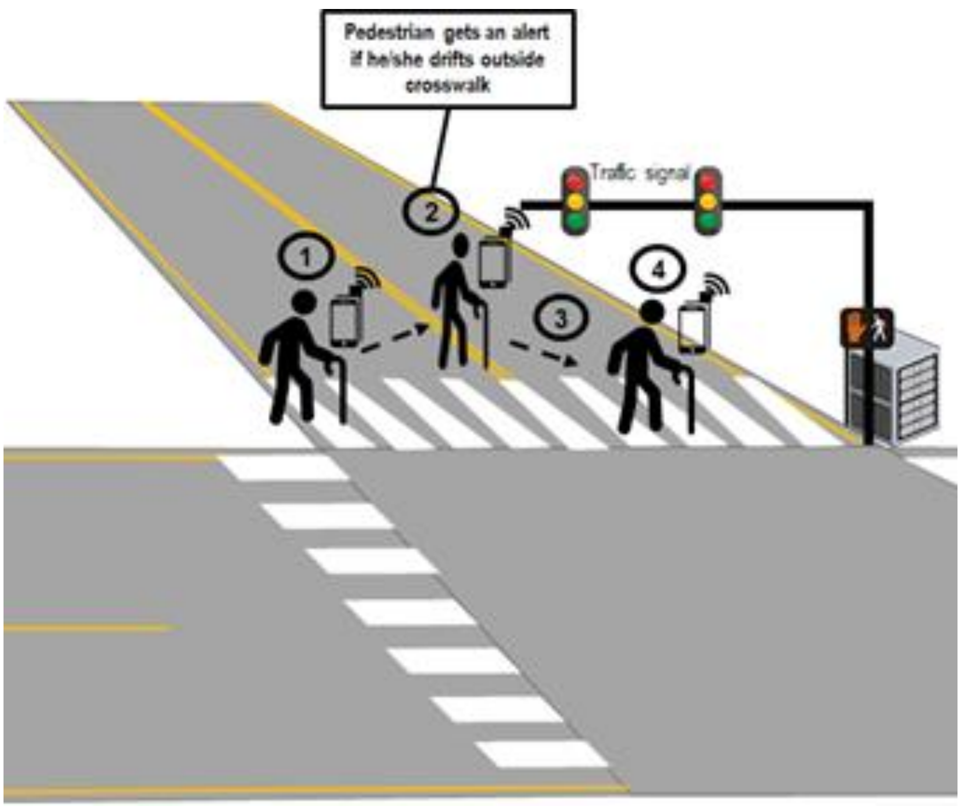
	Use Case 2: Intersection Crossing – Signal Control is Green (Enough Time)
	2. PedPal mobile app monitors intersection status and Pedestrian's progress through the intersection
Notes/Comments:	

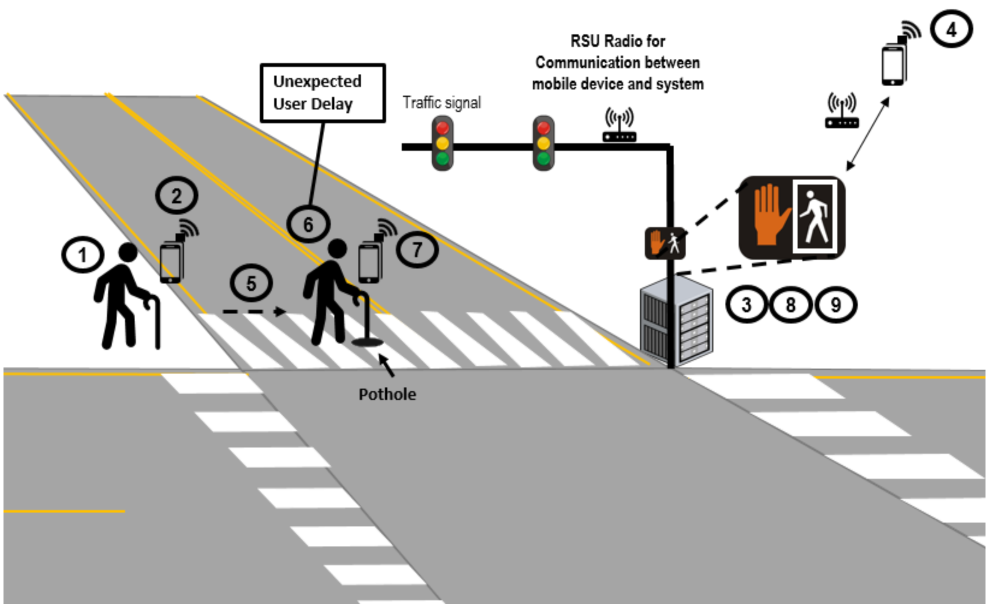
	Use Case 3: Intersection Crossing – Signal Control is Green (Not Enough Time)
Actors/System Elements:	Pedestrian, PedPal mobile app, Traffic Signal Control System (TSCS)
Assumptions:	1- PedPal mobile app is connected to TSCS, and receiving intersection status 2- Pedestrian's mobile device localization services are operational 3- Pedestrian is trained to use PedPal mobile app 4- PedPal mobile app may have access to a pre-planned itinerary
Preconditions:	1- Traffic signal is green when Pedestrian arrives at the intersection
Sequence of Events:	1- Pedestrian arrives and stops at intersection and communicates crossing direction to PedPal mobile app 2- PedPal mobile app calculates "time to cross" using crosswalk geometry from the MAP message, and its knowledge of Pedestrian's anticipated crossing speed. 3- The remaining green time is NOT within t seconds of Pedestrian's crossing time, and PedPal mobile app will inform Pedestrian to wait and will also remind Pedestrian to resubmit crossing request for the next cycle.
Post Conditions:	1- Pedestrian waits for the next signal
Notes/Comments:	

	Use Case 4: Intersection Crossing – Multiple Pedestrians – Signal Control is Green
Actors/System Elements:	Pedestrian, PedPal mobile app, Traffic Signal Control System (TSCS)
Assumptions:	1- Each PedPal mobile app is connected to TSCS, and receiving intersection status 2- Each Pedestrian's mobile device localization services are operational 3- Each Pedestrian is trained to use PedPal mobile app 4- PedPal mobile app may have access to a pre-planned itinerary
Preconditions:	1- Multiple Pedestrians arrive at an intersection within a short time span 2- Traffic signal is green when each Pedestrian arrives at the intersection
Sequence of Events:	1- Each Pedestrian arrives and stops at intersection and communicates crossing direction to their PedPal mobile app 2- Each PedPal mobile app calculates "time to cross" using crosswalk geometry from the MAP message, and its knowledge of respective Pedestrian's anticipated crossing speed. 3- Each PedPal mobile app communicates Pedestrian's crossing direction and estimated "time to cross" to TSCS. 4- These requests are received and processed sequentially by TSCS which determines the length of time to extend each cycle to accommodate the multiple requests, based on the fixed ordering of the phases in a cycle 5- TSCS communicates acceptance or rejection of each request to requesting PedPal mobile app 6- TSCS subsequently adjusts phase lengths, which are then reflected in the SPaT message 7- For rejected requests, each PedPal mobile app informs Pedestrian to wait and reminds Pedestrian to resubmit crossing request for the next cycle 8- For accepted requests, each PedPal mobile app monitors intersection status and directs respective Pedestrian to either wait (UC 1, steps 7 and 8), or cross (UC 2, steps 7 and 8)
Post Conditions:	Some pedestrians cross the intersection while others wait at the intersection until the signal turns green.

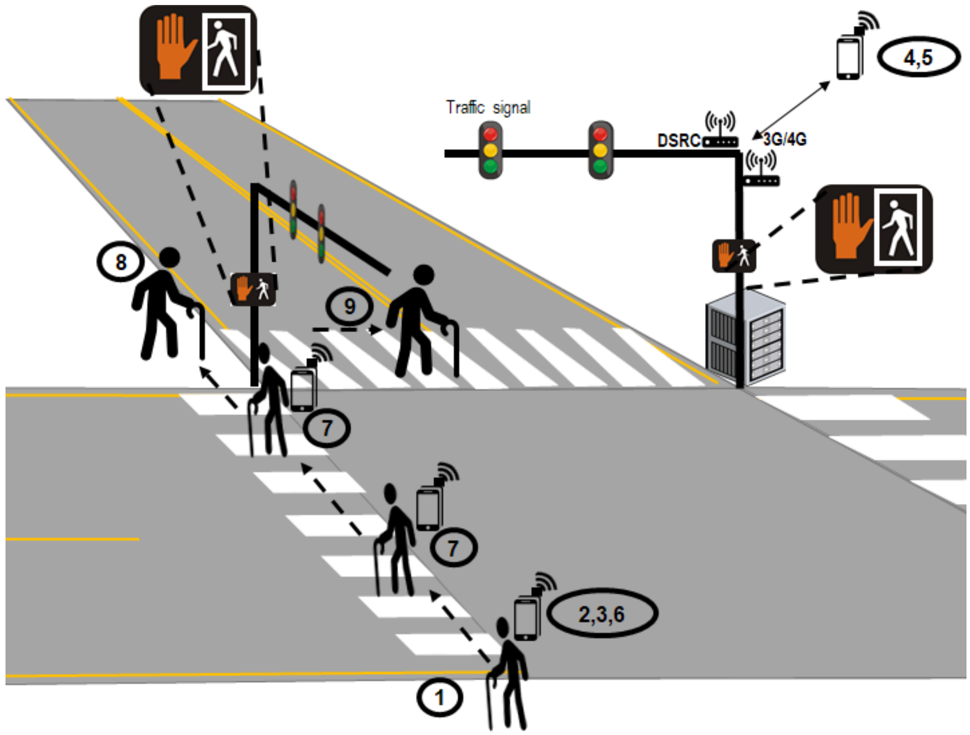
Use Case 4: Intersection Crossing – Multiple Pedestrians – Signal Control is Green	
Notes/Comments:	

	Use Case 5: Intersection Crossing – System Communications Failure
Actors/System Elements:	Pedestrian, PedPal mobile app, Traffic Signal Control System (TSCS)
Assumptions:	1- Pedestrian's mobile device localization services are operational 2- Pedestrian is trained to use PedPal mobile app 3- PedPal mobile app may have access to a pre-planned itinerary 4- Traffic signal is green when Pedestrian arrives at the intersection 5- PedPal mobile app can detect loss of communication with the intersection
Preconditions:	Pedestrian is walking towards an intersection, or has arrived at the intersection
Sequence of Events:	1- Pedestrian arrives and stops at intersection and communicates crossing direction to PedPal mobile app 2- Communication between PedPal mobile app and TSCS does not occur 3- PedPal mobile app notifies Pedestrian that communication with TSCS could not be established and reminds the Pedestrian to use caution when crossing the intersection.
Post Conditions:	Pedestrian stops relying on the PedPal mobile app for crossing this intersection.
Notes/Comments:	

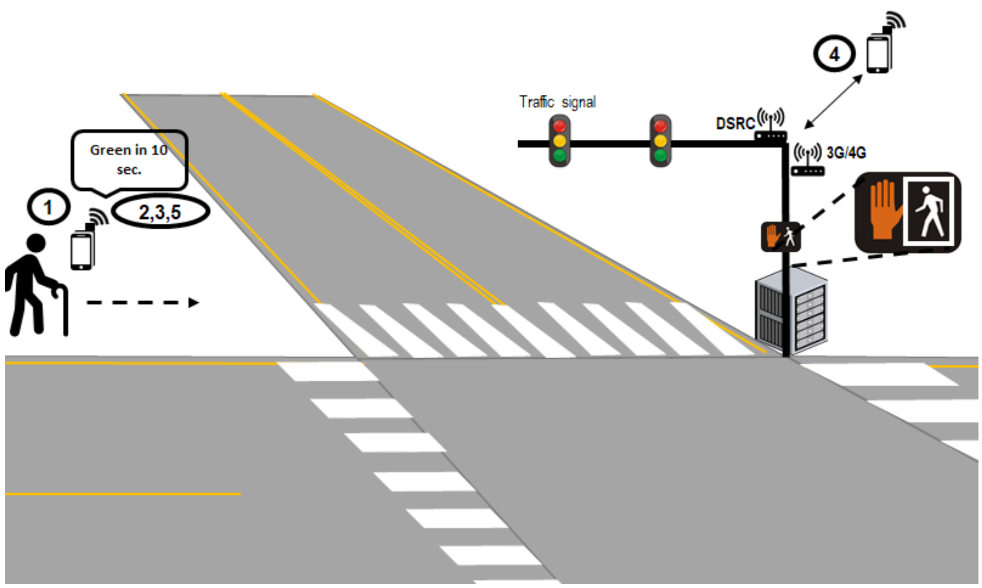
Use Case 6: Intersection Crossing – Unsafe Trajectory Detected	
Actors/System Elements:	Pedestrian, PedPal mobile app, Traffic Signal Control System (TSCS)
Assumptions:	1. PedPal mobile app is connected to TSCS, and receiving intersection status 2. Pedestrian's mobile device localization services are operational 3. Pedestrian is trained to use PedPal mobile app 4. PedPal mobile app may have access to a pre-planned itinerary
Preconditions:	1. Traffic signal is green when Pedestrian arrives at the intersection 2. PedPal mobile app has successfully made a request which has been granted 3. PedPal mobile app has instructed Pedestrian to start crossing the intersection
Sequence of Events:	1. While Pedestrian is crossing, PedPal mobile app will periodically consult the mobile device's localization service to determine the current location of Pedestrian. 2. If PedPal mobile app detects that Pedestrian has significantly drifted outside of the crosswalk, then it will alert Pedestrian and provide corrective guidance. 3. Pedestrian re-enters crosswalk
Post Conditions:	1- Pedestrian continues crossing the intersection. 2- PedPal mobile app continues monitoring Pedestrian's progress
Notes/Comments:	

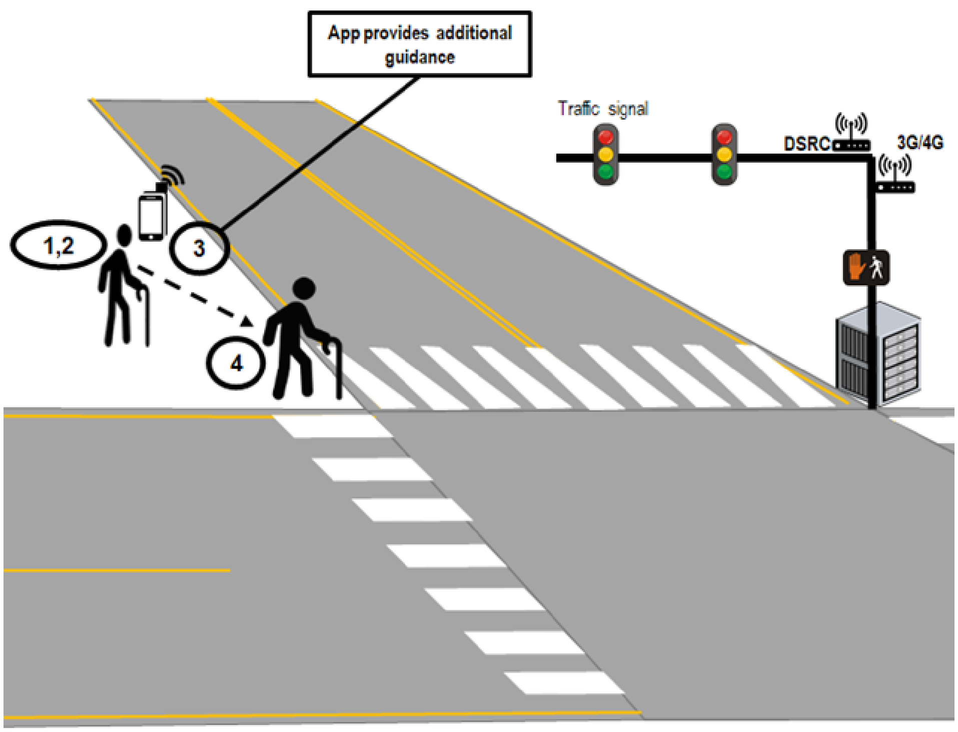
Use Case 7: Intersection Crossing – Unexpected User Delay	
Actors/System Elements:	Pedestrian, PedPal mobile app, Traffic Signal Control System (TSCS)
Assumptions:	1- PedPal mobile app is connected to TSCS, and receiving intersection status 2- Pedestrian's mobile device localization services are operational 3- Pedestrian is trained to use PedPal mobile app 4- PedPal mobile app may have access to a pre-planned itinerary
Preconditions:	1- Traffic signal is green when Pedestrian arrives at the intersection 2- PedPal mobile app has successfully made a request which has been granted 3- PedPal mobile app has instructed Pedestrian to start crossing the intersection
Sequence of Events:	1- PedPal mobile app will periodically consult the mobile device's localization service to determine the current location of Pedestrian and assess crossing progress. 2- PedPal mobile app detects that Pedestrian is taking longer to cross the intersection than anticipated. 3- PedPal mobile app makes an unconditional request to the TSCS to extend the current phase. 4- TSCS communicates acceptance of the request to PedPal mobile app 5- TSCS adjusts the current phase length to allow Pedestrian to fully cross the intersection, or just to an intermediate safe location (e.g. traffic island) if one is available. TSCS adjusts SPaT message broadcasts accordingly.
Post Conditions:	1- Pedestrian continues crossing the intersection. 2- PedPal mobile app continues monitoring Pedestrian's progress.
Notes/Comments:	

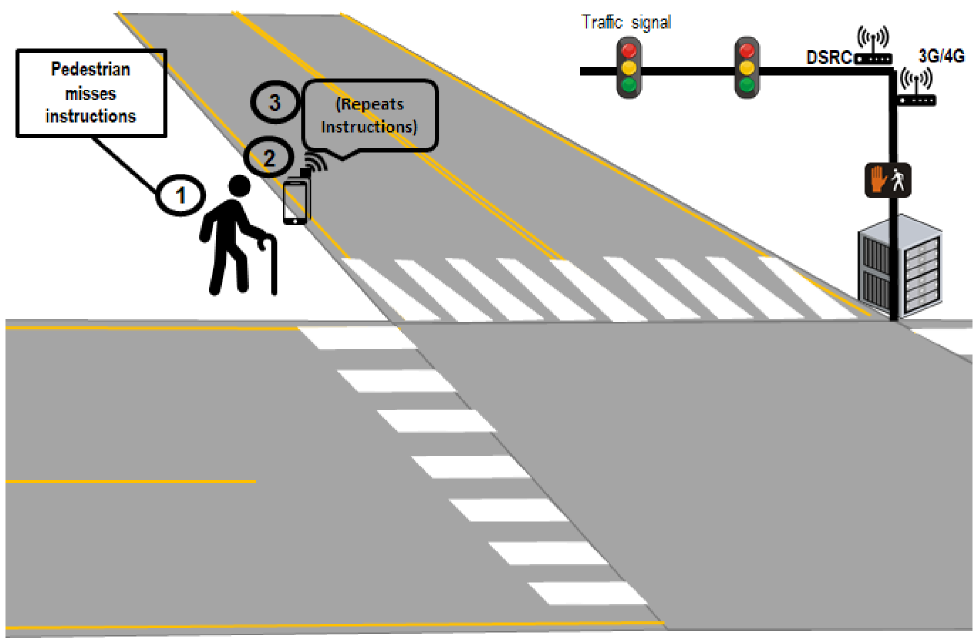
	Use Case 8: Intersection Crossing –Dual Crosswalk During All Pedestrian Walk Phase
Actors/System Elements:	Pedestrian, PedPal mobile app, Traffic Signal Control System (TSCS)
Assumptions:	1- PedPal mobile app is connected to TSCS, and receiving intersection status 2- Pedestrian's mobile device localization services are operational 3- Pedestrian is trained to use PedPal mobile app 4- PedPal mobile app may have access to a pre-planned itinerary
Preconditions:	1- Pedestrian is planning to diagonally cross an intersection with an all-pedestrian walk phase, but without a diagonal crosswalk. 2- Traffic signal is green when Pedestrian arrives at the intersection
Sequence of Events:	1- Pedestrian arrives and stops at intersection and communicates crossing direction to PedPal mobile app 2- PedPal mobile app calculates "time to cross" using crosswalk geometry from the MAP message, its knowledge of Pedestrian's anticipated crossing speed, and determines the optimal initial crossing direction. 3- PedPal mobile app communicates the Pedestrian's crossing direction and estimated "time to cross" to TSCS. 4- TSCS communicates acceptance of the request to PedPal mobile app 5- TSCS adjusts SPaT message broadcasts accordingly 6- The PedPal mobile app informs the pedestrian which crosswalk to cross first 7- The pedestrian makes the first crossing via Use Case 2,3, or 4, as appropriate 8- The PedPal mobile app notifies the pedestrian when to make the second crossing 9- The pedestrian makes the second crossing via Use Case 2,3, or 4, as appropriate.
Post Conditions:	The pedestrian has crossed the intersection diagonally.

Use Case 8: Intersection Crossing –Dual Crosswalk During All Pedestrian Walk Phase	
Notes/ Comments:	

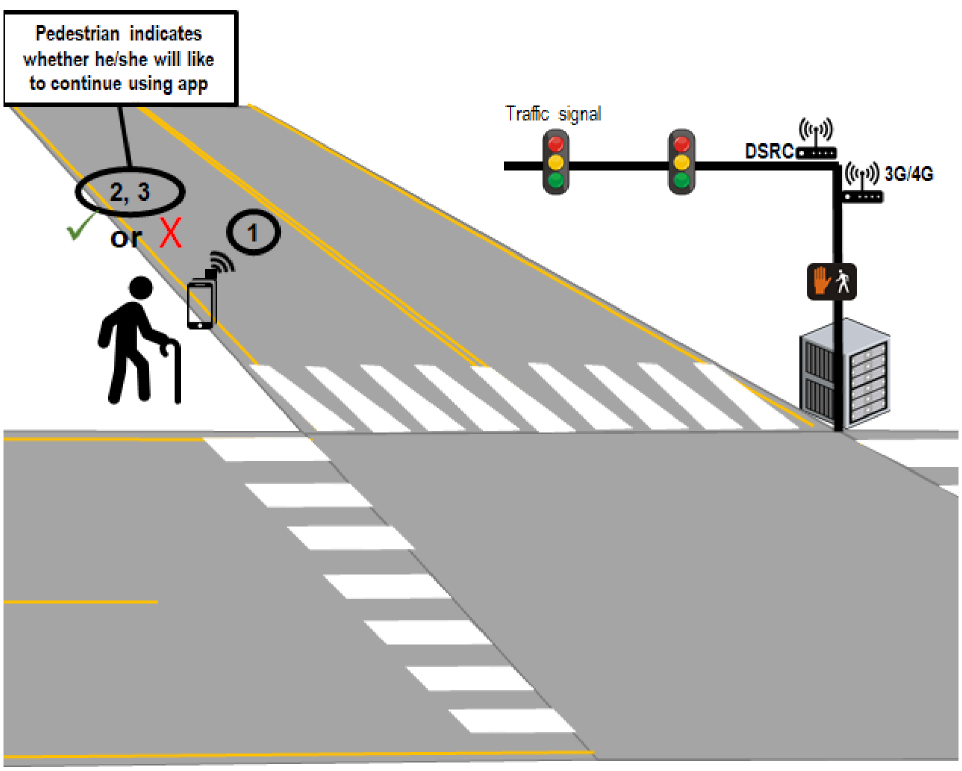
	Use Case 9: Pre-Crossing – Notifying Pedestrian that Upcoming Traffic Signal is Red
Actors/ System Elements:	Pedestrian, PedPal mobile app, Traffic Signal Control System (TSCS)
Assumptions:	1- PedPal mobile app is connected to TSCS, and receiving intersection status 2- Pedestrian's mobile device localization services are operational 3- Pedestrian is trained to use PedPal mobile app 4- PedPal mobile app may have access to a pre-planned itinerary
Preconditions:	1- Pedestrian is walking towards an intersection 2- Traffic signal is red
Sequence of Events:	1- Pedestrian communicates crossing direction to PedPal mobile app 2- PedPal mobile app calculates "time to arrive" using crosswalk geometry from the MAP message or from a pre-planned route map, and its knowledge of Pedestrian's anticipated crossing speed 3- PedPal mobile app notifies the TSCS of Pedestrian's estimated arrival time at the intersection in advance of Pedestrian's arrival at the intersection 4- TSCS communicates acceptance of the notification sent by PedPal mobile app 5- PedPal mobile app notifies Pedestrian of time until traffic signal will turn Green
Post Conditions:	The pedestrian approaches the intersection prior to Use Case 1, 2, 3, 4, 5 or 8
Notes/ Comments:	This is to notify the pedestrian of the status provided by the traffic signal control system so the pedestrian can set her/his pace accordingly

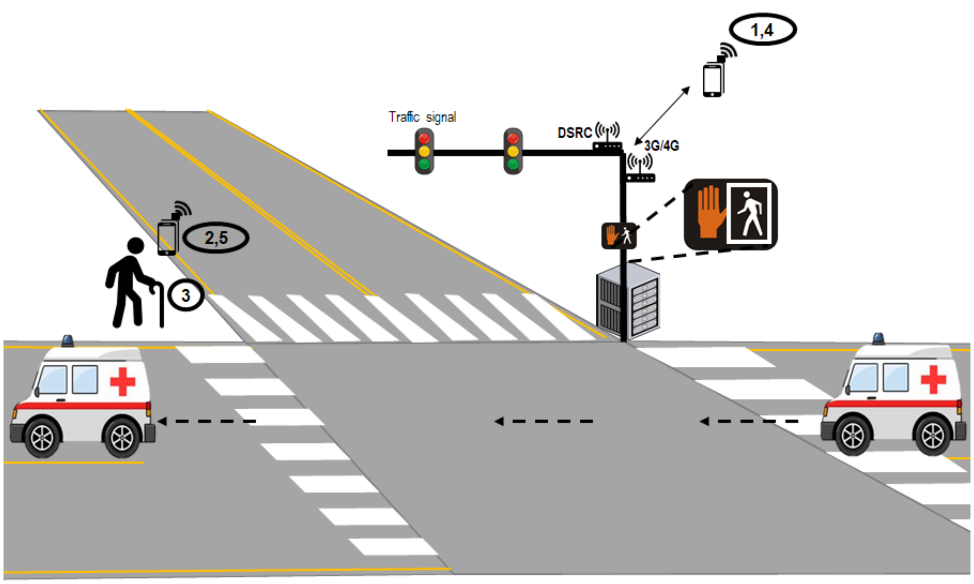


	Use Case 10: Pre-Crossing – Assisting Pedestrian to Prepare for Crossing
Actors/System Elements:	Pedestrian, PedPal mobile app, Traffic Signal Control System (TSCS)
Assumptions:	1- PedPal mobile app is connected to TSCS, and receiving intersection status 2- Pedestrian's mobile device localization services are operational 3- Pedestrian is trained to use PedPal mobile app 4- PedPal mobile app may have access to a pre-planned itinerary
Preconditions:	1- Pedestrian is walking towards an intersection and either needs assistance in aligning to the correct crossing direction, or might experience difficulty in determining where the sidewalk ends, and the crosswalk starts
Sequence of Events:	1- Pedestrian stops at the intersection and communicates intended crossing direction to the PedPal mobile app. 2- Pedestrian (may optionally) requests additional information from PedPal mobile app to assist in orienting to the correct direction for crossing. 3- PedPal mobile app provides information about obstacles and landmarks (e.g. single curb-cut at the corner, split curb cuts for each corner). 4- Pedestrian uses this information to navigate to the correct entrance for the crosswalk.
Post Conditions:	1- Pedestrian exercises Use Case 1, 2, 3, 4, 5 or 8 as appropriate
Notes/Comments:	

	Use Case 11: Pre-Crossing – Pedestrian Requires Replay of Instructions
Actors/System Elements:	Pedestrian, PedPal mobile app, Traffic Signal Control System (TSCS)
Assumptions:	1- PedPal mobile app is connected to TSCS, and receiving intersection status 2- Pedestrian's mobile device localization services are operational 3- Pedestrian is trained to use PedPal mobile app 4- PedPal mobile app may have access to a pre-planned itinerary
Preconditions:	Pedestrian is using PedPal mobile app to complete trip
Sequence of Events:	1- The pedestrian mishears, doesn't understand, or was unable to hear (e.g. due to traffic-related noise) the instructions provided by PedPal mobile app 2- The pedestrian uses standard voice-over accessibility feature of the PedPal mobile app to have the instructions repeated. 3- The PedPal mobile app repeats the required instructions.
Post Conditions:	1- Pedestrian continues listening to instructions and acts accordingly 2- Pedestrian exercises Use Case 1, 2, 3, 4, 5 or 8 as appropriate
Notes/Comments:	

Use Case 12: Pre-Crossing – Pedestrian Decides Not to Cross	
Actors/System Elements:	Pedestrian, PedPal mobile app, Traffic Signal Control System (TSCS)
Assumptions:	1- PedPal mobile app is connected to TSCS, and receiving intersection status 2- Pedestrian's mobile device localization services are operational 3- Pedestrian is trained to use PedPal mobile app 4- PedPal mobile app may have access to a pre-planned itinerary
Preconditions:	PedPal mobile app notifies pedestrian that it is safe to cross but pedestrian does not start crossing intersection
Sequence of Events:	1- If the Pedestrian chooses to cancel the crossing (selects the "Back" button) the PedPal mobile app reverts to the initial state ("Select Street to Cross") at the end of the green phase. 2- If the Pedestrian does nothing, the PedPal mobile app reverts to the initial state ("Select Street to Cross") at the end of the green phase. 3- PedPal mobile app stays on pause, until the pedestrian reselects the street to cross.
Post Conditions:	1- Pedestrian exercises Use Case 1, 2, 3, 4, 5 or 8 as appropriate
Notes/Comments:	Pedestrian changes his mind and does not cross the intersection after he is notified to cross. This could be a case when pedestrian gets busy with something: talking to someone, or answering a call or distracted for other reasons



Use Case 13: Pre-Crossing – Approach of an Emergency Vehicle	
Actors/System Elements:	Pedestrian, PedPal mobile app, Traffic Signal Control System (TSCS)
Assumptions:	1- PedPal mobile app is connected to TSCS, and receiving intersection status 2- Pedestrian's mobile device localization services are operational 3- Pedestrian is trained to use PedPal mobile app 4- PedPal mobile app may have access to a pre-planned itinerary
Preconditions:	1- The signal is green as Pedestrian approaches or arrives at the intersection; 2- TSCS has been made aware of an approaching emergency vehicle and will conduct a preemption event on behalf of the emergency vehicle.
Sequence of Events:	1- TSCS announces to PedPal mobile app, that preemption is imminent/occurring, and will subsequently deny all crossing requests until the preemption event has concluded. 2- Upon receiving the notification, PedPal mobile app unconditionally announces "don't' walk" regardless of crossing direction or traffic light status. 3- Pedestrian waits at the intersection corner. 4- Once the emergency vehicle has passed, the TSCS will assess whether there is enough green time left to allow passage, and if not inform PedPal mobile app to continue to wait. 5- When appropriate, PedPal mobile app announces resumption of normal operation to walk, etc.
Post Conditions:	1- Pedestrian exercises Use Case 1, 2, 3, 4, 5 or 8 as appropriate
Notes/Comments:	

	Use Case 14: Pre-Crossing –Pedestrian Crossing Synchronized with Bus Arrival
Actors/System Elements:	Pedestrian, PedPal mobile app, Traffic Signal Control System (TSCS), Transit Bus
Assumptions:	1- PedPal mobile app is connected to TSCS, and receiving intersection status 2- Pedestrian's mobile device localization services are operational 3- Pedestrian is trained to use PedPal mobile app 4- PedPal mobile app has access to a pre-planned itinerary 5- Pedestrian has previously developed a travel plan (trip route) 6- Transit Bus has an operational DSRC OBU 7- A transit bus stop is nearside of the intersection on the other side of the street that Pedestrian intends to cross
Preconditions:	1- Pedestrian is approaching the intersection where the destination bus stop specified in the travel plan is located
Sequence of Events:	1- In advance of arriving at the intersection, PedPal mobile app consults the stored travel plan, determines that this intersection is the last in the travel plan, 2- PedPal mobile app sends a crossing request that specifies (1) expected arrival time at the intersection, (2) the destination bus stop and (3) the desired bus route number. 3- TSCS consults its current list of approaching buses (each in continuous contact with the intersection via DSRC communication) for one with the desired bus route number. 4- If none are found (implying that no buses with that route are expected to arrive at the adjacent nearside bus stop before the time that the pedestrian is currently expected to arrive at the bus stop. However, if a bus traveling the desired bus route is found, then TSCS will estimate both (1) the time at which Pedestrian is expected to arrive at the bus stop and (2) the time at which the bus is expected to be finished dwelling at the bus stop and ready to move on to the intersection, and then determine if additional crossing time must be allocated to ensure that the bus stays at the bus stop until the pedestrian can get across the street and to the bus stop. The minimum crossing time is set to include the additional time required for the pedestrian to get across and over the bus stop 5- TSCS communicates acceptance and status of the request to PedPal mobile app 6- TSCS adjusts SPaT message broadcasts accordingly
Post Conditions:	1- Pedestrian exercises Use Case 1, 2, 3, 4, 5 or 8 as appropriate

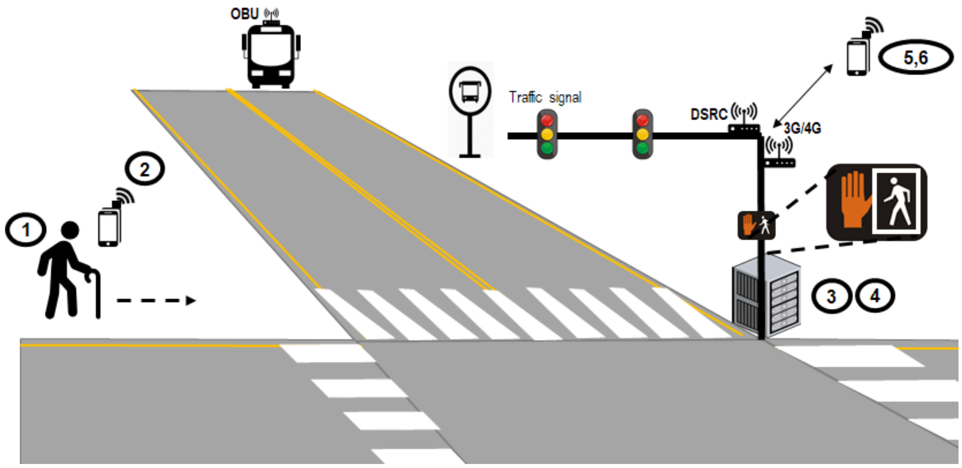
	Use Case 14: Pre-Crossing –Pedestrian Crossing Synchronized with Bus Arrival
Notes/ Comments:	

Table 5-3 below provides a mapping of the User Needs, as defined in Section 3.2 above, to the appropriate Use Cases just defined. The left two columns of each row indicate the number and description of each User Need. The next fourteen columns are used to indicate which of the fourteen defined Use Cases are relevant to and reflect the corresponding User Need. A cell containing an “X” indicates that the User Need specified in the same row is met through exercising the corresponding Use Case (indexed by Use Case number).

Table 5-3: Mapping of Needs to Operational Scenarios

User Need		Operational Scenario / Use Case													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Interacting with the Traffic Signal Control System	X	X	X	X			X	X	X	X	X	X	X	X
2	Obtaining Real-Time Information about the Intersection	X	X	X	X		X	X	X	X	X	X	X	X	X
3	Assisting Crossing the Intersection	X	X	X	X		X	X	X	X	X	X	X	X	X
4	Locating and Recognizing the Intersection	X	X	X	X		X	X	X	X	X	X	X	X	X
5	Positioning and Orienting:	X	X	X	X		X	X	X	X	X	X	X	X	X
6	Confirming	X	X	X	X		X	X	X	X	X	X	X	X	X
7	Customizable Assistance	X	X	X	X		X	X	X	X	X	X	X	X	X
8	Supporting Hands-Free Option						X	X	X				X	X	X
9	Interacting with other PedPal mobile apps												X	X	X
10	Supporting Audio Communication	X	X	X	X		X	X	X	X	X	X	X	X	X
11	Integrating a Pre-planned Itinerary														X
12	Incorporating Transit Bus Arrivals														X

6 Summary of Impacts

6.1 Operational Impacts

It is expected that this system development project will significantly improve the safety of intersection crossings for pedestrians with disabilities, including injured veterans and older adults. The proposed system will affect the following operational activities:

Informing the traffic signal control system at an intersection of intent to cross: Pedestrians equipped with this PedPal mobile app will not have to use pedestrian call buttons located at intersections. Instead, the PedPal mobile app will serve to notify the intersection of the presence and intention of the pedestrian, eliminating the challenge pedestrians with visual disabilities have in locating and accessing pedestrian call buttons.

Locating the start of the crosswalk: Pedestrians with visual disabilities will be provided with information about the current corner (e.g., the presence and positioning of curb cuts) to assist them in locating the target crosswalk, reducing the complexity of that challenge. Like other user interface features, we are expecting this information to be delivered through multiple modalities, including visual presentation of a textual list of relevant features or as a set of audio cues.

Notifying pedestrians to initiate crossing: The PedPal mobile app will inform pedestrians when to cross, eliminating a major challenge for people with visual disabilities, which is currently addressed using approximate techniques based on audio cues from accompanying pedestrians and parallel traffic.

Traversing a crosswalk: The PedPal mobile app will improve navigation of crosswalks for pedestrians with visual disabilities by providing guidance for staying within the lines of the crosswalk and on progressing to its exit point. The PedPal mobile app also will improve safety of all crosswalk traversals by tracking progress through the crosswalk and extending the green time in the crosswalk direction if additional time is needed. The crossing times will be tailored to the user's individual constraints and needs to provide a more customized experience. In the case of an exceptional event during crossing (e.g., a pedestrian stops making progress on a crosswalk), the system will protect the pedestrian by extending the walk until the person is clear.

Streamlining multi-intersection travel: The system will improve the mobility of pedestrians with disabilities in navigating intersections. The ability to anticipate pedestrian arrival times at intersections and to incorporate this information in real-time to generate timing plans will result in more efficient and more reliable estimates of the time required for crossing an intersection or for traveling through a series of intersections. Also, the time for pedestrians with disabilities to make their desired bus connection will be reduced.

6.2 Organizational Impacts

From an organizational perspective, the introduction of this system could have a variety of impacts. These impacts are positive provided consideration is given to them early on before full implementation of the system. The effectiveness of the functionality of the proposed system depends on how the following impacts are managed prior to deployment.

Increased interaction and collaboration among public agencies and private industries: The successful implementation of the proposed system will require close collaboration and interaction among state and federal transportation agencies, representatives of different communities of people with disabilities, the mobile devices industry, the hardware industry building DSRC and signal controller systems, and the application developers.

Streamlined standards and protocols development process: As a result of this system development, modifications may be required for the various messaging protocols, including the SAE J2735 messages, to provide better information for the PedPal mobile app.

Increased inter-agency and inter-jurisdictional data sharing: The successful implementation of this systems may require standardization of data formatting and sharing across different TMCs and signal controllers. Pedestrians should be able to travel across various jurisdictions seamlessly and receive similar data regardless of the jurisdiction.

Revised transportation planning process: Since the system dynamically responds to traffic and pedestrian requests, the planning process will need to update performance measures and maintenance schedules to accommodate the new system. For example, in an event of power failure, how will the TMC's manage these intersections effectively? This question segues to the next topic on new requirements and training.

New requirements, training, and testing for road users: With any new system, existing requirements need to be updated or adapted to the new functionality or new requirements need to be established. For example, training is important for both the users of the system and the managers of the system. Vehicle drivers need to understand why a specific pedestrian cross phase is longer and under what conditions it happens. Educating the drivers is as important as training pedestrians with disabilities on how to use the system. On the management side, police officers assigned to traffic control also need to understand how the system works in order to respond effectively in an event of a power failure at the intersection.

Third-party system and interface certification procedures

Third-party certification of the system and relevant interfaces will be required prior to full deployment. A comprehensive testing and certification process must therefore be developed to ensure that the design objectives are met. These certification procedures will test safety and functionality prior to exposing the PedPal mobile app to the users.

7 Analysis of the Proposed System

This section presents an analysis of the benefits, limitations, advantages, disadvantages, alternatives, and trade-offs considered for the proposed system.

7.1 Summary of Improvements

The proposed system (smartphone application) will develop and demonstrate assistive services that ensure safe passage of injured veterans, older adults, and other persons with blindness, low vision, cognitive, or mobility related disabilities when crossing signalized intersections, and exploit 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 DSRC capability, allowing them (1) access to real-time information from traffic signal infrastructure and nearby vehicles and (2) the ability to actively influence traffic signal control decisions and vehicle movements at the intersection. The smartphone app will provide accessible interfaces that allow pedestrians to communicate personalized intersection crossing constraints (e.g., movement speed, crossing direction) to the signal system and ensure that it allocates sufficient crossing time, to receive geometric and obstacle information (e.g., curb cut locations) about the intersection that will facilitate safe crossing, and to be alerted when a crossing movement indicates safety concerns (e.g., moving outside of the crosswalk).

Real-time monitoring of crossing performance will also be used to automatically extend the green time in real-time when appropriate. The PedPal mobile app will 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.

Moreover, since the real-time traffic signal control system is optimizing all detected traffic flows at a given intersection, the approach will yield compound benefits in areas with large concentrations of disadvantaged pedestrians (e.g., in the vicinity of elder care facilities, retirement homes, schools for persons with disabilities, etc.).

The proposed system will also incorporate technology innovations to include the following features:

Acquisition and incorporation of personalized crossing constraints – Conventional signal timing plans operate with a fixed pedestrian crossing time in any given direction. Our proposed system will instead apply online machine learning techniques to GPS trace data to acquire a pedestrian-specific travel speed for each device user, and will use this speed to dynamically establish a minimum phase time, with a safety margin, in the crossing direction.

Online planning of pedestrian-friendly timing plans – The same travel speed information just mentioned can be used to estimate pedestrian arrival times at the intersection from advance location data that is communicated to the infrastructure, and thus can be directly factored into real-time traffic signal control decisions. The proposed system will include new real-time adaptive signal control procedures that use knowledge of pre-planned pedestrian routes (e.g., as generated with the use of a wayfinding app) to construct timing plans that are coordinated at the network level and expedite pedestrian movement through a series of intersections.

Active monitoring and attention to crossing progress – Current traffic signal control systems, both conventional and adaptive, execute pedestrian minimum crossing times in open loop fashion, extending the green time only if compatible vehicle traffic warrants this action. The proposed system will instead use real-time GPS data to actively track progress and direction of a crossing pedestrian, detect and alert the pedestrian to unsafe trajectories, and dynamically adjust green time as measured progress dictates. Mechanisms for pedestrian signaling of unexpected delays (e.g., a wheelchair stuck in a pothole) or completed crossings will provide a complementary basis for real-time adjustment of green phase durations.

Integration with real-time bus information for more efficient connections – Pedestrians with disabilities currently struggle with making bus connections, including navigating to the bus stop itself, knowing where to stand to attract the bus driver's attention, and being aware of more extreme circumstances like unexpected route detours. Simple conveyance of geometric and location information available to the traffic signal infrastructure about nearby bus stops can solve some of these issues. However, by using real-time bus information (e.g., provided via DSRC) the proposed system can do much more. The proposed system will demonstrate the ability to generate timing plans in real-time that synchronize pedestrian crossing times with projected bus arrival times to promote timely arrival at nearby bus stops.

7.2 Goals, Performance Measures, and Transformative Performance Targets

Table 7-1 below identifies specific goals of this project and the proposed system, the performance measures and the performance targets. It is important to note that these measures will vary across the pedestrians based on the type of disability they have. A closer look at the measures is required to make that distinction across different disability types. However, the performance targets provided below would indicate an average across different pedestrian types.

The threshold value represents the minimum range for the performance targets and the objective represents a maximum value.

Table 7-1: Transformative Performance Measures

#	Goals	Performance Measure	Performance Target Threshold[9]	Performance Target Objectives[10]	Notes
1	Increase in pedestrians' confidence crossing intersections	Perceived Safety	Feeling moderately safe using the PedPal mobile app	Feeling very safe using the PedPal mobile app	This is a qualitative factor that will be measured by conducting surveys
2	Increase in pedestrians' confidence crossing intersections	Number of cycles pedestrians waits to feel safe crossing the intersection	1	0	Pedestrians will wait for the next cycle if he or she is not confident with app directions
3	Increase in pedestrians' confidence crossing intersections	% Increase in number of new intersections pedestrians try to cross	10%	30%	This is a measure of # of new intersection they try to cross because of using (reliance) on the PedPal mobile app.
4	Increase in pedestrians' confidence crossing intersections / Efficiency	% decrease in total duration of the time from start-finish crossing an intersection	5%	15%	The time is calculated from when the pedestrian indicates that he/she is intending to cross till the time he completes the crossing; before and after using the PedPal mobile app.
5	Improve overall intersection crossing time of a single intersection	% pedestrian travel Time Improvement (rush hour, mid-day)	5%	15%	This measure would be different based on the day of the week and time of the day.
6	App accuracy and increased reliability	% of time that the system correctly identifies the intersection that the pedestrian is at	30%	90%	This depends on accuracy of GPS location technology

9 Minimum acceptable value

10 Ideal Value

#	Goals	Performance Measure	Performance Target Threshold[9]	Performance Target Objectives[10]	Notes
7	App accuracy and increased reliability	% of time that the system correctly identifies the intersection corner the pedestrian is at	30%	90%	This depends on accuracy of GPS location technology
8	App accuracy and increased reliability	% of the time that the system identifies that a pedestrian is delayed crossing an intersection	55%	90%	The delay could be due to pedestrian low speed crossing or unexpected delay due to a fall etc. This depends on accuracy of GPS location technology
9	App accuracy and increased reliability	Detection of pedestrians' deviation from the path	50% deviation detection	90% deviation detection	This depends on accuracy of GPS location technology

7.3 Disadvantages and Limitations

There are several technical challenges identified for development of this system which are listed as follows.

Challenge 1: Robustness of GPS tracking

Our approach to monitoring the progress of a pedestrian crossing an intersection, as well as detecting movement outside of the crosswalk, depends on reliable GPS tracking data, which can be subject to problems in dense urban environments. This could be less of an issue given the fact that intersections are mostly at open space. Also, smartphones can use Wi-Fi-assist to improve GPS accuracy. Wi-Fi-assist tends to work well in urban settings since there are typically many Wi-Fi access points within range of the user, with the caveat that it is battery intensive.

Challenge 2: Interoperability with other smart phone apps and external data sources

Several valuable assistive technologies have emerged in recent years for pedestrians with disabilities (e.g., Seeing AI, wayfinding, route planning) and the smart phone has emerged as a common platform for hosting these capabilities. Thus, it is important that the safe intersection crossing app be designed to interoperate seamlessly with complementary capabilities and exploit synergies where possible. One technical challenge is commonality in user experience across apps that might be used in a coupled manner with the safe intersection crossing app. In the context of the current project, route planning is one such application that the proposed system could leverage to enhance pedestrian mobility.

Challenge 3: Uncertainty in bus stop dwell times

The ability to accurately predict bus arrival times at the intersection depends greatly on the uncertainty of dwell times at near side bus stops (if bus stops are far side of the intersection, then much of the uncertainty in dwell times can be squeezed out due to the distance to the next intersection and the fact that PedPal mobile app re-computes intersection signal timing plans every couple of seconds). Our preliminary analysis of bus dwell times (Isukapati, I., H. Rudova, G.J. Barlow and S.F. Smith, “Analysis of Trends in Bus Dwell Time Data for Real-Time Predictive Modeling”, *Journal of the Transportation Research Board*, To Appear, 2017) indicate that dwell times do exhibit seasonal stability but vary considerably by stop, and times also vary considerably within peak periods. This suggests that prediction will be more accurate at some bus stops than at others, and that ultimately our ability to synchronize crossings at some bus stops may be limited.

Challenge 4: acquisition and use of external data sources

A related technical issue concerns acquisition and use of external data sources such as a curb cut data base, bus stop locations, route/schedule information, etc. For purposes of developing and testing the safe intersection crossing prototype, such data can be collected and made available for the specific test site locations. However, in the longer term, identification of and integration with necessary external data sources will present a significant technical challenge, since this information cannot be expected to be standardized across different cities. General resolution of this issue is beyond the scope of this project, but as an initial step, the proposed system will generate relevant information requirements.

7.4 Alternatives and Trade-Offs

Alternatives and trade-offs have been considered for the proposed system in the following key areas:

Robustness of Localization Services

Use Wi-Fi-assist to improve GPS accuracy. Perhaps there is a way to judiciously exploit this capability, by turning on continuous GPS tracking only when close to a DSRC-equipped intersection and relying on cheaper GPS sampling elsewhere. Alternatively, it may be possible to use DSRC communication to overcome GPS problems (e.g., by having the DSRC Road Side Unit track the location of the mobile device and detect when crossing is complete). On the other hand, GPS tracking problems can be mitigated with user-provided estimates of progress or the lack there of (e.g., I’m halfway across) that can be used as a basis for making real-time decisions about the green time.

Interoperability with other smart phone apps and external data sources

The project team has recently engaged with PathVu (another ATTRI awardee whose work scope includes route planning) and plan to discuss possible synergies with respect to user interface development and design commonality as part of our requirements analysis and system architecture design process. To promote broader interoperability and integration with other externally developed apps, the project team will adopt standard development tools (e.g., the IOS SWIFT Library), utilize service-oriented software design principles and provide well specified APIs.

Uncertainty in bus stop dwell times

This problem can perhaps be mitigated somewhat using a probabilistic dwell time prediction model. However, the proposed system can also introduce pedestrian wait time to compensate for bus stops with higher uncertainty, i.e., plan for the pedestrian crossing to ensure that the pedestrian arrives at the bus stop sufficiently ahead of the projected dwell time end. Information about the number of other waiting disabled pedestrians can also help, as this is likely to have a non-trivial impact on dwell time

8 Referenced Documents

This section lists the applicable documents which are inputs to the project (i.e., needed but not produced by the project). Some of the relevant Documents include:

- Real-Time Adaptive Traffic Signal Control for Urban Road Networks: The East Liberty Pilot Test, Stephen F. Smith, Gregory J. Barlow, Xiao-Feng, Zachary B. Rubinstein, Technical Report, July 2013
- Smart Urban Signal Networks: Initial Application of the SURTRAC Adaptive Traffic Signal Control System, Stephen F. Smith, Gregory J. Barlow, Xiao-Feng, Zachary B. Rubinstein, Proceedings 23rd International Conference on Automated Planning and Scheduling, Rome, Italy, June 2013.
- Schrank, D., T. Lomax, and S. Turner. Annual Urban Mobility Report. Texas Transportation Institute, Texas A&M University System, TX, 2011.
- Chin, S. M., O. Franzese, D. L. Greene, H. Hwang, and R. C. Gibson. Temporary Losses of Highway Capacity and Impacts on Performance: Phase 2. ORNL/TM-2004/209, Oak Ridge National Laboratory, 2004.
- Papageorgiou, M., C. Diakaki, V. Dinopoulou, A. Kotsialos, and Y. Wang. Review of road traffic control strategies. Proceedings of the IEEE, Vol. 91, No. 12, 2003, pp. 2043–2067.
- Systems Engineering for Intelligent Transportation Systems, An introduction for Transportation Professionals, January 2007.
- Xie, X.-F., S. F. Smith, L. Lu, and G. J. Barlow. Schedule-driven intersection control. Transportation Research Part C: Emerging Technologies, Vol. 24, 2012, pp. 168–189. [6] Xie,
- X.-F., S. F. Smith, and G. J. Barlow. Schedule-driven coordination for real-time traffic network control. In 22nd International Conference on Automated Planning and Scheduling (ICAPS), Sao Paulo, Brazil, 2012, pp. 323–331.
- Using a Smartphone Application to Support Visually Impaired Pedestrians at Signalized Intersection Crossings, Chen-Fu Laio, *Transportation Research Record*, No. 2393, 2013.
- IEEE 1220-2005 IEEE Standard for Application and Management of the Systems Engineering Process
- IEEE 29148-2011 - ISO/IEC/IEEE International Standard - Systems and software engineering -- Life cycle processes --Requirements engineering
- IEEE 1609.2, IEEE 1609.3 and IEEE 1609.4 Wireless Access in Vehicular Environments (WAVE) standards: describing the upper layer protocols for DSRC (WAVE); Specifically defines WAVE Short Message Protocol (WSMP) and service advertisement protocols
- IEEE 802.11p DSRC Physical layer standard: describing the physical layer and channel access requirements for DSRC
- SAE J2735 standard: defines the Basic Safety Message
- SAE J2945/9: Vulnerable Road User Safety Message Minimum Performance Requirements
- National Transportation Communications for Intelligent Transportation System Protocol (NTCIP)

- User Needs Assessment: Stakeholder Engagement Report, Accessible Transportation Technologies Research Initiative (ATTRI) USDOT, May 2016
- ATTRI Institutional and Policy Issues Assessment Summary Report, USDOT, February 2017

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