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

Concept of Operations (ConOps)

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16. Abstract

This project aims to develop 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 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 app, 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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Chapter 1. Introduction

This project is in support of Accessible Transportation Technology Research Initiative (ATTRI) 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.

The purpose of this project is to build a mobile application that will assist people with disabilities, cross signalized intersections safely, independently and confidently. For example, if there is no safe island zone mid-intersection then signal light duration becomes very important.

The application design should ensure safe intersection crossing assistance for all unique travelers as they interface with existing traffic, signals, all types of vehicles, and assistive devices. This technological solution will be designed for people with blindness, low vision, cognitive and mobility issues. This solution is intended to 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.

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 identified 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 or integrate the safe intersection crossing application.

This ConOps will identify:

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

This document will be updated periodically to reflect the evolving system development in greater detail and document changes in operational scenarios that may occur based on future findings.

Project Scope

Transportation and mobility are crucial for today's society. However, for people with disabilities (mobility, vision, hearing, and cognitive) inadequate transportation can hinder them from living a full life. Accessible Transportation Technology Research Initiative (ATTRI) of the U.S Department of Transportation's (USDOT) Intelligent Transportation Systems Joint Program Office (ITS-JPO) is focused on developing advanced technology applications to support this population travel with independence and confidence.

This project intends to 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 leverage smart traffic signal infrastructure to further provide these persons with significant mobility enhancements.

Chapter 2. 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.
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- Systems Engineering for Intelligent Transportation Systems, An introduction for Transportation Professionals, January 2007.
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- 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.
- IEEE 1220-2005
- IEEE 1028-2008
- 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

Chapter 3. Current State

Background

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. ATTRI, through continued research and application development continues to work toward improving the mobility of travelers with disabilities and provide enhanced capabilities for all travelers to reliably and safely execute independent travel.

Technologies conceived, developed and used by ATTRI 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 key focus areas include the signals, all types of vehicles and assistive devices. It is imperative that technological solutions including design, 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 the following at the very least: pedestrian interface with traffic signals, vehicles, nomadic devices, and automated intersection crossing assistance, beacons or electronic tags to interact with the built and pedestrian environment including support for multiple languages and sharing of real-time information. They should 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.

Users and Other Involved Personnel

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 CMU and herself a blind person.
    c. Aaron Steinfeld, a Research Professor of Robotics at Carnegie Mellon University 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 where older adults, people with mobility disability, and veterans with disabilities, and we intend to follow up with representative individuals and organizations from these communities. Although they were not able to attend our initial stakeholders meeting, we have also been in contact with the following organizations and will solicit their input individually in subsequent meetings:

8. PathVU – PathVU is another recipient of a 2017 ATTRI award, to further develop their wheelchair-based technology. We have had discussions with Eric Sinagra, the project PI, about possible synergies and opportunities for collaboration between our respective projects down the road, and intend to keep this conversation going and additionally discuss user requirements.
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 and put us in touch with others that could help.
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) will be contacted to find one or more representatives from this community to support user requirements analysis. We will reach out to local centers and communities of older adults to invite them to our subsequent stakeholder 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 two 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

Existing Surtrac System

The capabilities for safe and more efficient intersection crossing to be provided by the proposed mobile application will depend on interaction and interoperability with the Surtrac system. Surtrac is a real-time adaptive traffic signal 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.

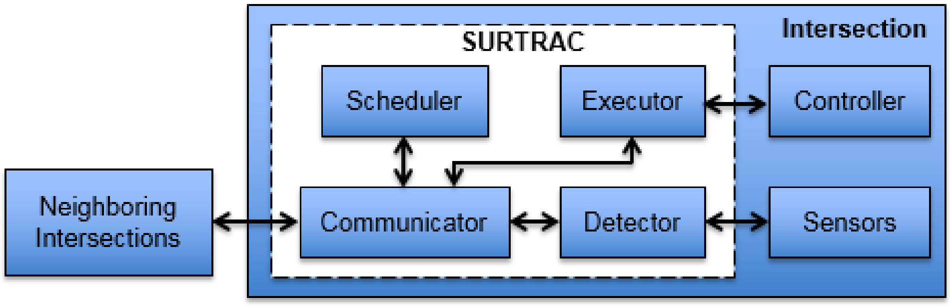


Figure 1: Surtrac High-Level System Architecture
(source: [Smith, Barlow, Xie, 2013])

Figure 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 approaching the intersection along various approaches is pulled from the intersection sensors (e.g., video cameras, radar, DSRC 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 neighbors to provide an expectation of what traffic is coming down the pike (according to the plan) behind 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, 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 mobile application, will be integrated as an additional sensor/effector, providing additional information to the detector and executor subsystems.

Support Environment

This section discusses the major components of the support environment that is required for the system to operate. First and foremost, the proposed mobile app will be designed to interact with the Surtrac adaptive signal system to influence traffic control decisions, and as such the first prerequisite for use at a given signalized intersection is that the Surtrac system is deployed at this 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. In September 2017, Surtrac was deployed at 24 intersections in Atlanta GA as part of the city’s North Avenue Smart Corridor project, and agreements are now in place to deploy in Portland ME, Kane County IL, and Beverly Hills CA in 2018. We expect Surtrac presence in US cities to increase significantly over the next few years, and we expect that the proposed mobile app (if it is subsequently commercialized) will provide further incentive for adoption of Surtrac.

With regard to the proposed effort, the field-test plan will take advantage of the current Pittsburgh Surtrac deployment. Our Year 1 evaluation will take place at the intersections surrounding the Carnegie Library for the blind and physically handicapped (LBPH), which are currently running the Surtrac system (see Figure 1). In year 2, the plan is to extend the Surtrac deployment to include the two additional intersections at Bayard/Craig and Bayard/Bellefield, and conduct the prototype demonstration in close vicinity to the Western Pennsylvania School for Blind Children (WPSBC) facility (see Figure 1). The WPSCB has additionally offered us access to the simulated intersection that they maintain on their grounds, which we intend to use for periodic capability enhancement demonstrations. This simulated intersection, which is used to teach students safe intersection crossing practices, will be upgraded to run the Surtrac system.

Figure 2: Year 1 (left) and Year 2 (right) test site locations
(source: Google maps)

To communicate with the Surtrac adaptive signal control system, the mobile app will also require a Dedicated Short Range Communication (DSRC) Road Side Equipment (RSE) unit installed at the intersection as another necessary component in the support environment. This unit provides the medium by which the prototype mobile app will communicate with Surtrac. Figure 2 shows a DSRC RSE installed at one of the Surtrac controlled intersections in the Pittsburgh deployment – all intersections target for field test experiments also have DSRC RSE units installed. The mobile app will be hosted on an iPhone[1] that is connected to a mobile DSRC device called a LocoMate™ ME sleeve. LocoMate™ ME is a mobile DSRC device for V2X deployment with a full DSRC WAVE software solution and applications for

[1] iPhone was the device preferred by majority of the user community that attended the ConOps stakeholder meeting held in the Carnegie Mellon Campus in early November 2017. The team thus decided to start the development process on the iOS platform and evaluate addition of android in the option year

integration with smartphones to ease the human-user-interface. The LocoMate™ ME device is shown in Figure 3.

Figure 3: An intersection in the Pittsburgh Surtrac deployment that shows an installed DSRC RSE.

Figure 4: The LocoMate™ ME mobile DSRC sleeve
(source: www.aradasystems.com)

To communicate with the intersection from the mobile app, our design goal will be to adhere to the message standards (BSM, Wayfindr, etc.) whenever possible, and only develop new or extend messages when the functionality required has not been anticipated by the standards process. For example, we expect to utilize a variant of the Basic Safety Message (BSM) to notify the traffic control system of pedestrian arrival at the intersection and to communicate user crossing constraints.

A final necessary component of the smartphone that utilized to host the mobile app is GPS tracking. The proposed mobile app will utilize this capability to monitor user progress across the intersection. In the event that GPS localization of the smart phone is not sufficiently accurate, solutions such as those provided by companies like 5D Robotics, which may require installation of additional hardware at the intersection, will be investigated.

Chapter 4. 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.

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 a 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,

[2] https://www.nhtsa.gov/road-safety/pedestrian-safety

special electronic aids, or no additional aid. Crossing the street may include the following actions with focus on blind or low vision pedestrians[3].

1. **Recognize an Intersection** — First, especially for blind pedestrians must be able to 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 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.

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:

[3] http://www.apsguide.org/appendix_d_understanding.cfm

1. They cannot wait through a light 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.

Description of Desired Changes

The desired system will address the issues discussed above incrementally. The following features are envisioned, but some of these features depend on highly accurate GPS data which is currently not available. Our system design will try to take these features into consideration and accommodate them fully when more accurate (and cost effective) GPS technologies become available.

1. **Interacting with the Signal Controller:** Address pedestrians' interface with traffic signals, vehicles, nomadic devices, and automated intersection crossing assistance

2. **Obtaining Real-Time Information about the Intersection:** Provide beacons or electronic tags to interact with the built and pedestrian environment, including support for multiple languages and sharing of real-time information. Information about the intersection, street names, number of streets, road condition, and other data that better help the pedestrian visualize and prepare would be very helpful.

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

4. **Locating and Recognizing the Intersection:** 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)

5. **Positioning and Orienting:** Help pedestrians (especially those with visual disabilities) locate the right position (in preparation for crossing the street) and face the correct direction.

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.

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. Also, allow users to adjust assistance based on road conditions and user capabilities. For example, if a specific intersection is too complicated to cross for a particular user, provide a less complicated alternative if possible. A complicated intersection is subjective and its description could vary from person to person. An intersection could be termed complicated if it has several lanes of traffic in either direction making the crossing path very long, has heavy traffic, allows turn on red and or if it has a pedestrian island between either direction of traffic.

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.

9. **Interacting with other GPS Apps:** it would be very helpful to minimize the number of Apps people with disabilities need to use to get to their final destinations safely. If this intersection crossing app could interact or be integrated with other apps people already use, it would make it easier for them to navigate.

10. **Supporting Audio Communication:** For people with blindness disability, 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.

Priorities Among the Changes

The followings are the highest priority features necessary for an intersection crossing assistance from the user's perspective. However, it is important to note that achieving 100% solution for some of these features rely heavily on highly accurate underlying GPS technologies, and may not be attainable in the short term. However, our team will use any workarounds available to get very close to these desired features.

1. **Locating and Recognizing the Intersection**

2. **Positioning and Orienting**

3. **Interacting with the Signal Controller**

4. **Obtaining Real-Time Information about the Intersection**

5. **Assisting Crossing the Intersection**

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- **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.

3- **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.

4- **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.

5- **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.

Chapter 5. Concepts for the Proposed System

Operational Concept

The purpose of this project is to develop a smart phone application that will ensure safe passage of injured veterans, older adults, and other persons with blindness, low vision, cognitive, or mobility related 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 that are equipped with Dedicated Short Range Communication (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., 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 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.).

Subsystems

This section provides a description of all the subsystems (sub-functions) and an overall plan for their development. These subsystems will be integrated into the final system to achieve the desired outcome

Surtrac Adaptive Traffic Signal Control System

Key to effective operation of the proposed mobile app is inter-operability with the Surtrac traffic signal control system. To provide the desired functionality of the proposed mobile app, several extensions will be made to the Surtrac system. First, extensions will be made to allow a pedestrian’s required crossing time to serve as the system’s minimum crossing time constraint in the pedestrian’s target direction. Second, the system will be extended to allow for dynamic extension of this minimum crossing time constraint if an unexpected delay is detected. Third, extensions will be made to enable acceptance of user travel routes and incorporation of this knowledge when generating signal timing plans to anticipate pedestrian arrivals. Finally, extensions will be made to enable adjustments to generated signal timing plans to ensure synchronized arrival of pedestrians and buses at nearby bus stops.

Mobile app – RSE Connectivity

Interaction between the mobile app and the Surtrac system will be enabled by a Dedicated Short Range Communication (DSRC) radio subsystem. The prototype mobile device will couple a LocoMate™ ME mobile DSRC sleeve with an iPhone, and the former component will communicate with a DSRC Road Side Equipment (RSE) unit that is installed at the intersection. The LocoMate™ ME sleeve will communicate with the mobile app on the iPhone via Bluetooth. Prior work with Surtrac has established basic vehicle-to-infrastructure (V2I) connectivity and the system currently supports receipt of the Basic Safety Message (BSM) and broadcast of both the Signal Phase and Timing (SPAT) and MAP messages to equipped vehicles. We envision use of variants of these messages as well as newly defined messages to effect necessary communication of pedestrian goals and constraints, as well as system generated commands, guidance, and alerts back to the mobile device.

To establish physical connectivity between the mobile app and the Surtrac signal control system, we will develop scripts on the programmable LocoMate™ ME units being used to provide (1) Bluetooth connectivity to the attached smartphone and (2) DSRC connectivity to translate messages communicated from the smart phone app to the unit into DSRC formats.

Mobile App User Interfaces (UI)

A third identifiable subsystem of the proposed mobile app is the app’s User Interface (UI). This subsystem will be developed in stages, each corresponding to a functional capability that the mobile app is intended to provide:

- UI for personalized crossing
- UI for crossing assistance
- UI for use of pre-planned routes
- UI for synchronization of pedestrian and bus arrivals

For purposes below, we consider each of these component interfaces as separate subsystems.

Mobile App UI for Personalized Crossing

The mobile app UI for personalized crossing allows the pedestrian to communicate his/her crossing goals and constraints to the traffic 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 app). In more complex settings the pedestrian may alternatively specify a destination location, and request that the traffic control system suggest the appropriate crossing sequence. Depending on the current state of the intersection, the application 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.

To provide this basic functionality, an initial interface will be developed that supports the above communicative actions, and will be used by the infrastructure to establish and enforce personalized intersection crossing time constraints. Once this interface is in place on the mobile device, our team will work on integrating it with Surtrac to enable the extensions developed to implement this personalized crossing service.

Mobile App UI for Crossing Assistance

The mobile app UI for crossing assistance is responsible for monitoring and supporting the pedestrian's trip across the intersection once the crossing command has been given. The app will periodically monitor the pedestrian's location in the intersection, and take action in different unusual circumstances. If the 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 his/her 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[4]) 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 for safe intersection crossing 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.

Mobile App UI for Use of Pre-Planned Routes

The mobile app UI for use of pre-planned routes is intended to provide the pedestrian with the ability to communicate its planned route to the traffic control system in advance of execution, so that the traffic signal 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 team will develop interfaces to enable a pedestrian to import a travel route that has been pre-planned, either by direct specification (on a map based interface such as Google Maps or the like, through speech or otherwise) or through inter-operability with a mobile, wayfinding app. In either case, the input will be transformed into a route format consistent with emerging open standards, and we will rely on interaction with Wayfindr to support this objective. Interface support will also be developed for conveying progress toward the pedestrian's destination and expected arrival time at the destination. The team will then integrate these user interface extensions with corresponding extensions to Surtrac.

Mobile App UI for Synchronizing with Bus Arrivals

The mobile app UI for synchronizing with bus arrivals is a final UI module that is planned. This module is intended to allow pedestrians to designate destination bus stops and desired bus routes in advance, so that the traffic signal system can try to synchronize bus and pedestrian arrival times at the bus stop. Complementary research at CMU RI (Carnegie Mellon University Robotic Institute) is currently using DSRC communication to obtain real-time bus information and factor this more accurate arrival time

[4] 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.

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 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). The team will then integrate and test the supporting extensions to the Surtrac system.

The details and development plan for this UI component will be addressed more fully in the Year 2 version of the ConOps document.

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 foundational considerations, listed below, should be addressed:

Equipped Intersections and Users: The fundamental requirement for the application to work is that the intersection be equipped with the Surtrac system and that users that have the application installed and the Locomate sleeve that is capable of communicating with the Surtrac system.

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 implementing multiple communication formats (visual, audible, haptic) where possible. Likewise, consideration should be given to incorporate user profiles and documented needs from all stakeholder and ability groups, and creating user experiences with information sharing on any display associated with such applications in built and pedestrian environments including wearable and nomadic devices. The feasibility 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[5] that we will take 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

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

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 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.

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 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 and the pedestrian's nominal traveling speed and current location (at or approaching the intersection). The traffic signal system will in turn use this provided information together with its knowledge of intersection crossing distances to compute a required crossing time, and then adopt this 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 GPS 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 affect 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.

Chapter 6. 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 document 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, we have also put together the following table extracted from personas 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 we connect the uses cases to specific features highlighted in this table.

Table 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

Disability Type	Description of Problem	Desired Design Features
	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
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 below provides a high-level schematic of the general steps that occur when a pedestrian crosses an intersection using the envisioned system:

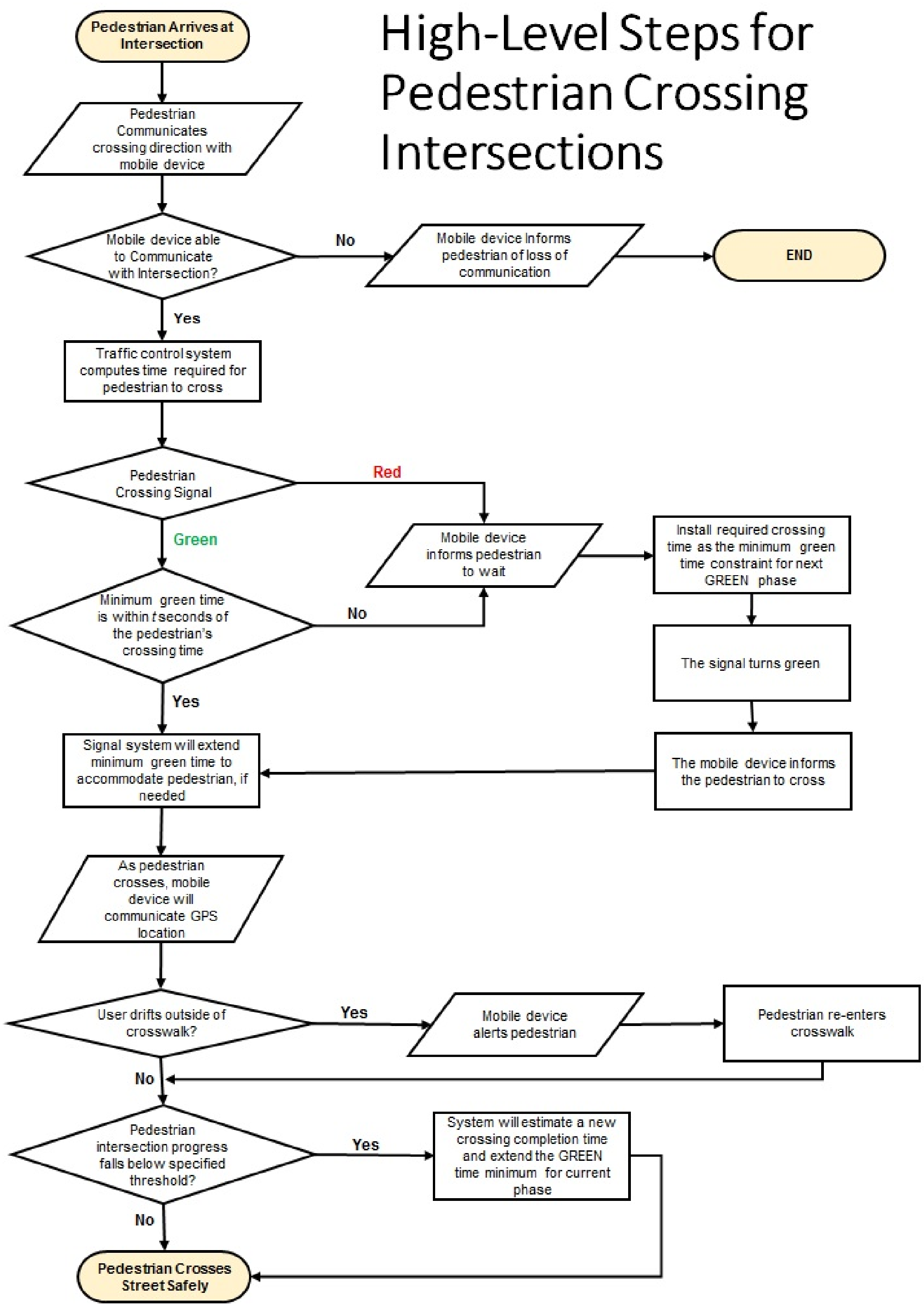


Figure 5: Flowchart diagram of the steps leading a pedestrian to cross an intersection

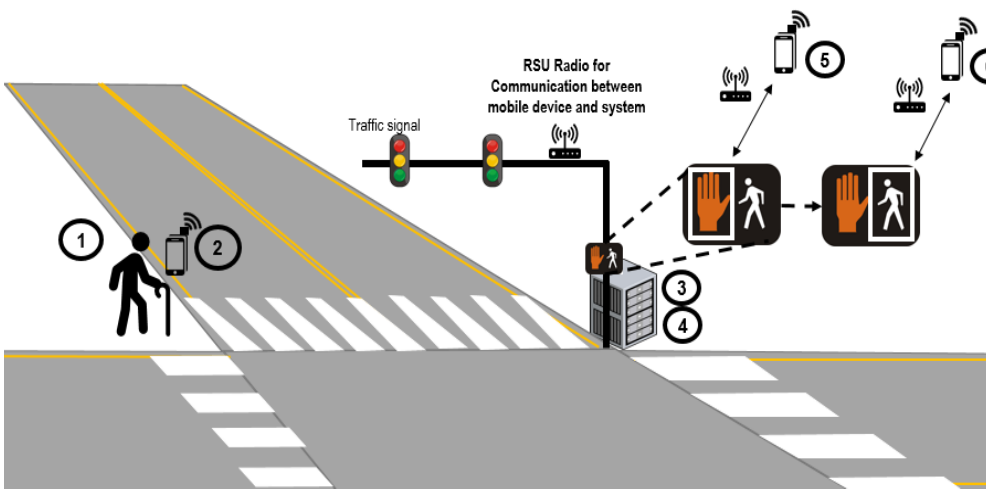
Table below highlights the list of all the use cases that are further described in this section.

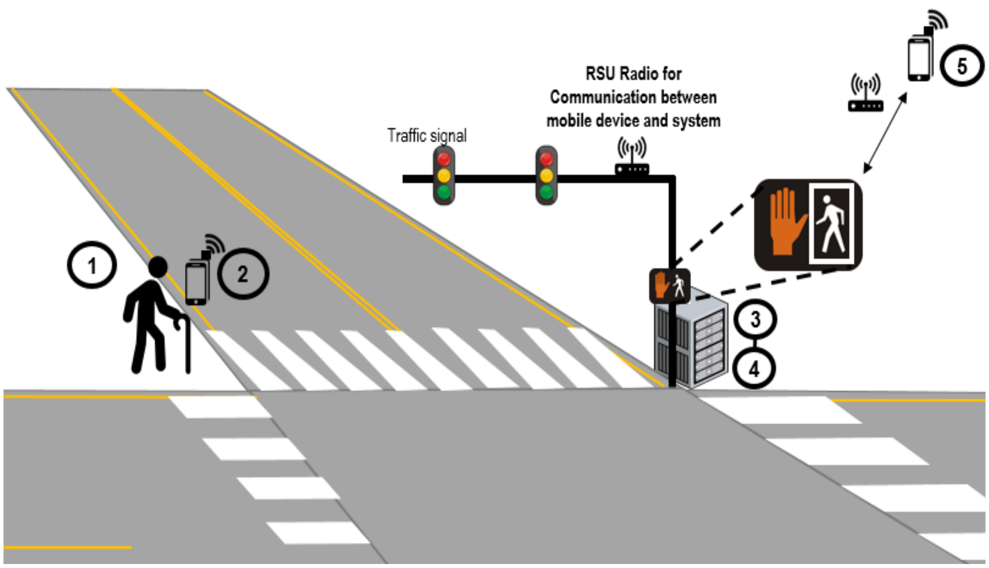
Table 2: List of Use Cases

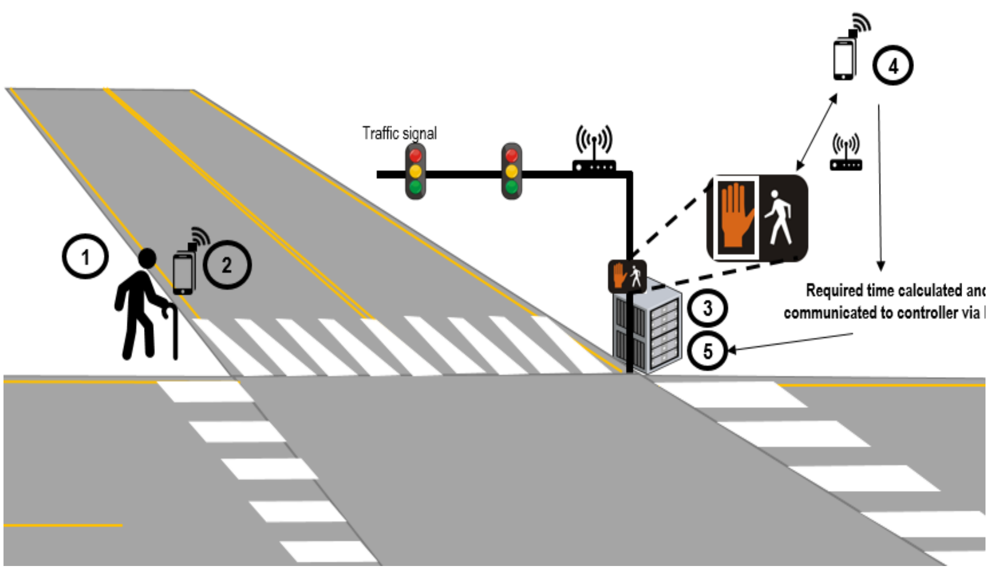
Use Case #	Title
1.	Pedestrian Intersection Crossing – Signal Control is Red
2.	Pedestrian Intersection Crossing – Signal Control is Green (Enough Time)
3.	Pedestrian Intersection Crossing – Signal Control is Green (Not Enough Time)
4.	Multiple pedestrians arriving at an intersection-Signal Control is Green
5.	Pedestrian Intersection Crossing – Roadside Unit Malfunction
6.	Pedestrian Intersection Crossing – Unsafe Trajectory Detected
7.	Pedestrian Intersection Crossing – Unexpected User Delay
8.	Pedestrian Intersection Crossing with an All Pedestrian walk phase (allowing diagonal crossing)
9.	Notifying pedestrian that the upcoming intersection signal is red ahead of time
10.	Helping the pedestrian know which direction to face for crossing
11.	Helping the pedestrian to cross the intersection in adverse condition
12.	Helping the pedestrian maneuver a complicated intersection
13.	Pedestrian miss instruction provided by the mobile app
14.	The pedestrian decides not to cross
15.	Pedestrian Crosses a Street with Traffic Island
16.	Mobile App signals the approach of an emergency vehicle

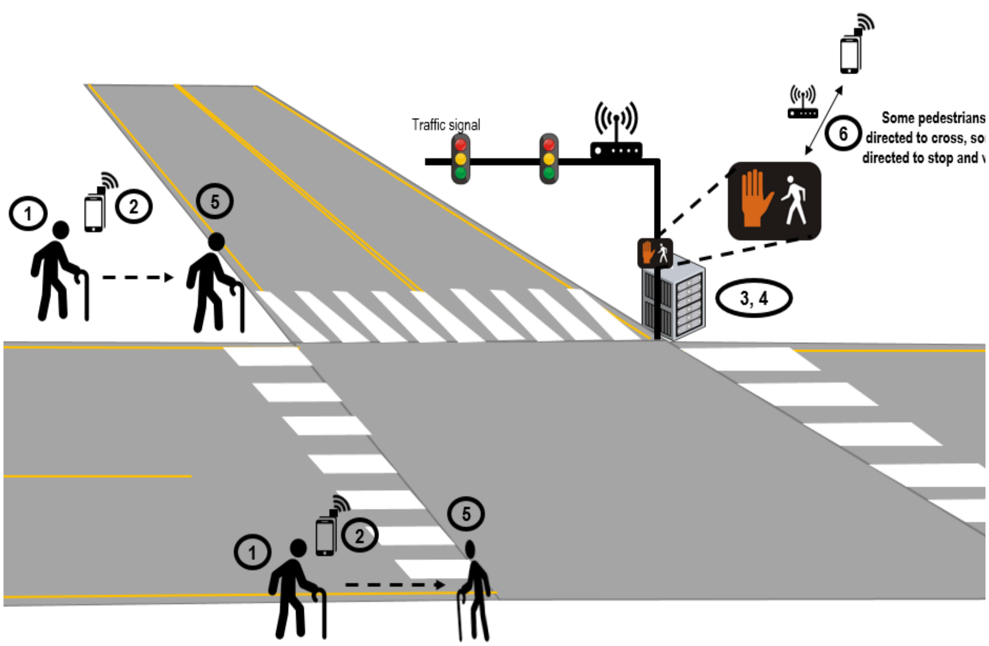
In the tables that follow, a detailed description of each of these use cases are provided, identifying:

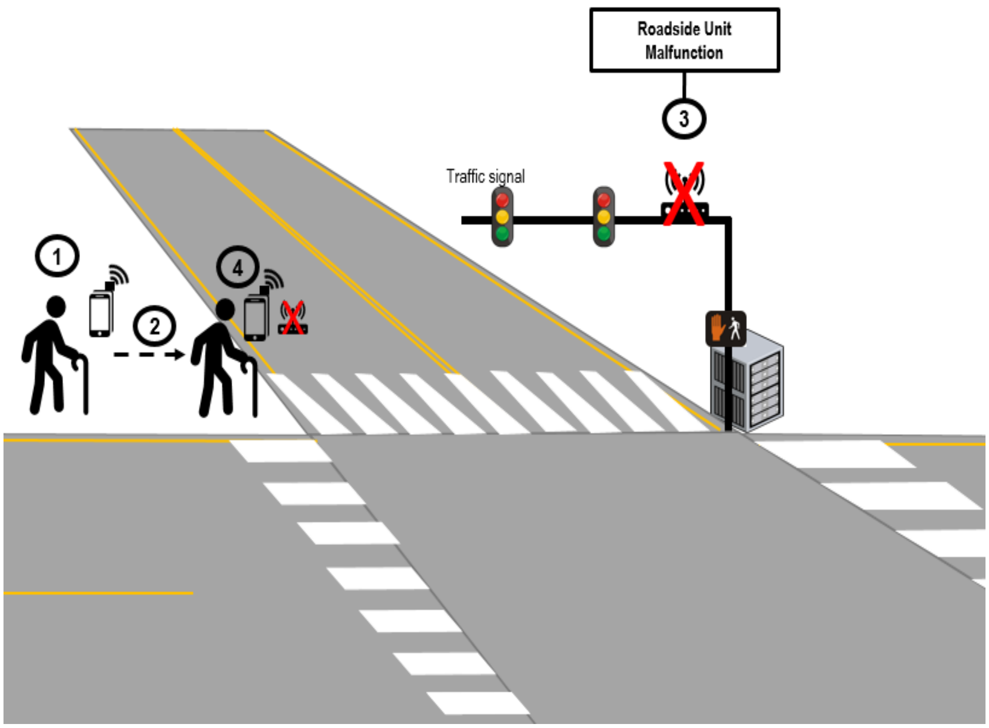
- The system and external elements and actors
- The assumptions necessary for the use case to occur
- The initial state (preconditions)
- The sequence of events in terms of elements in the system diagram (which element does what in what sequence)
- The ending state (post conditions) (i.e., what, if anything,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

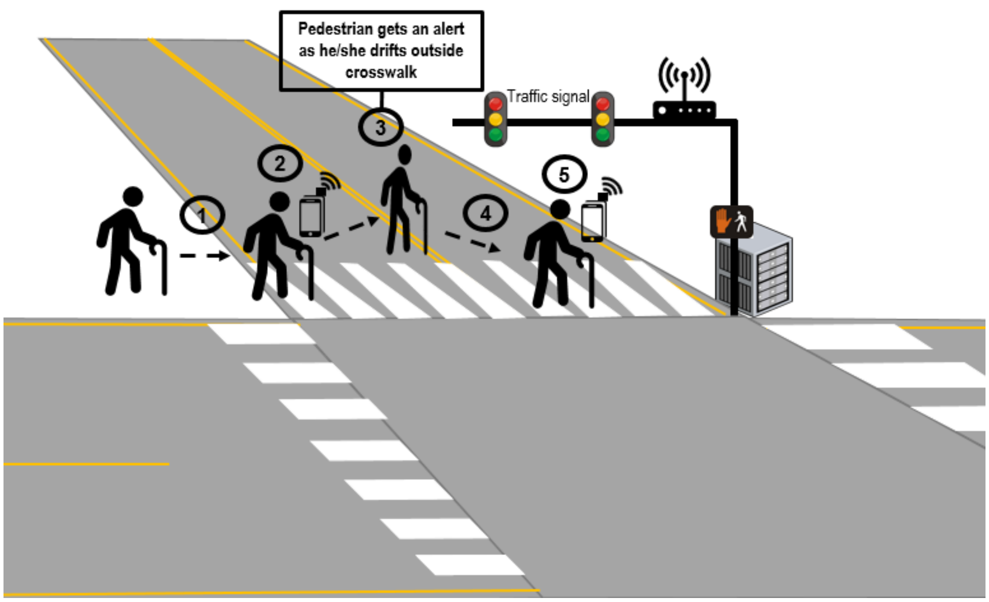
	Use Case 1: Pedestrian Intersection Crossing – Signal Control is Red
Actors/System Elements:	Pedestrian, Mobile App, RSU, Signal Control
Assumptions:	RSU is operational, GPS is connected, the pedestrian is trained to use the mobile app; the signal is red when the pedestrian arrives at the intersection
Preconditions:	Pedestrian is walking towards an intersection that is currently red
Sequence of Events:	1- Pedestrian arrives and stops at intersection and communicates crossing direction to the mobile app 2- Mobile app communicates the crossing direction and the pedestrian's speed to the traffic control system 3- Traffic control system computes time required for the pedestrian to cross 4- The required crossing time is communicated to signal controller for use as the minimum green time constraint for next GREEN phase in the pedestrian's crossing direction 5- The mobile device will inform the pedestrian to continue to wait 6- When the signal subsequently turns GREEN in the pedestrian's crossing direction, the mobile app will signal to the pedestrian that it is time to start crossing.
Post Conditions:	The pedestrian starts crossing the intersection
Notes/Comments:	

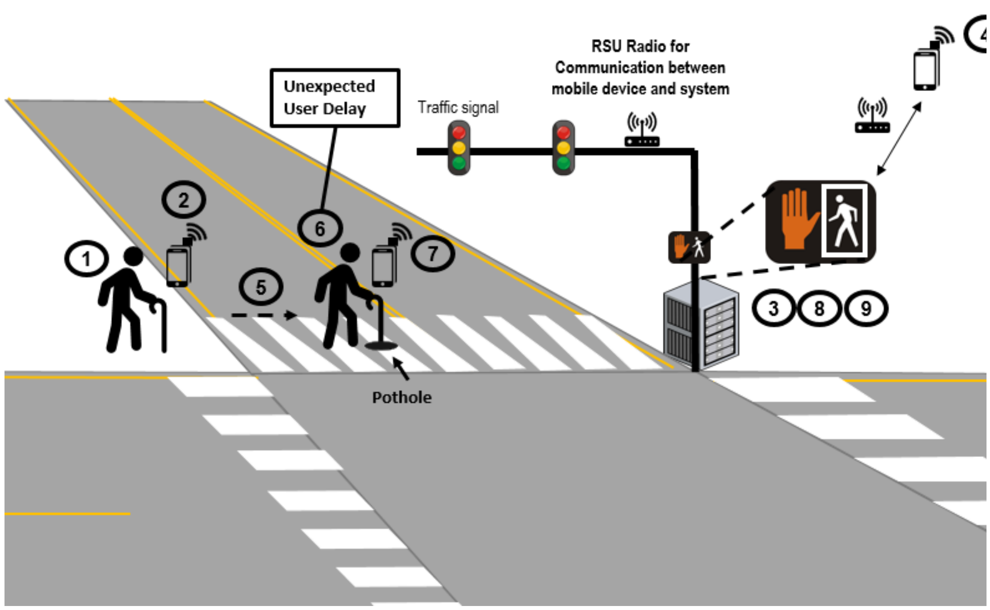
	Use Case 2: Pedestrian Intersection Crossing – Signal Control is Green (Enough Time)
Actors/System Elements:	Pedestrian, Mobile App, RSU, Signal Control
Assumptions:	RSU is operational, GPS is connected, the pedestrian is trained to use the mobile app; the signal is green when the pedestrian arrives at the intersection
Preconditions:	Pedestrian is walking towards an intersection
Sequence of Events:	1- Pedestrian arrives and stops at intersection and communicates crossing direction to the mobile app 2- Mobile app communicates the crossing direction and the pedestrian's speed to the traffic control system 3- Traffic control system computes time required for the pedestrian to cross 4- The remaining minimum green time is within t seconds of the pedestrian's crossing time, so the signal system extends the minimum green time to accommodate the pedestrian 5- The mobile app will inform the pedestrian to start crossing.
Post Conditions:	The pedestrian starts crossing the intersection
Notes/Comments:	

	Use Case 3: Pedestrian Intersection Crossing – Signal Control is Green (Not Enough Time)
Actors/System Elements:	Pedestrian, Mobile App, RSU, Signal Control
Assumptions:	RSU is operational, GPS is connected, the pedestrian is trained to use the mobile app; the signal is green when the pedestrian arrives at the intersection
Preconditions:	Pedestrian is walking towards an intersection
Sequence of Events:	1- Pedestrian arrives and stops at intersection and communicates crossing direction to the mobile app 2- Mobile app communicates the crossing direction and the pedestrian's speed to the traffic control system 3- Traffic control system computes time required for the pedestrian to cross 4- The remaining minimum green time is NOT within t seconds of the pedestrian's crossing time, and the mobile app will inform the pedestrian to wait. 5- The required crossing time is calculated and communicated to signal controller for use as the minimum green time constraint for next GREEN phase in the pedestrian's crossing direction
Post Conditions:	The pedestrian waits for the next signal
Notes/Comments:	

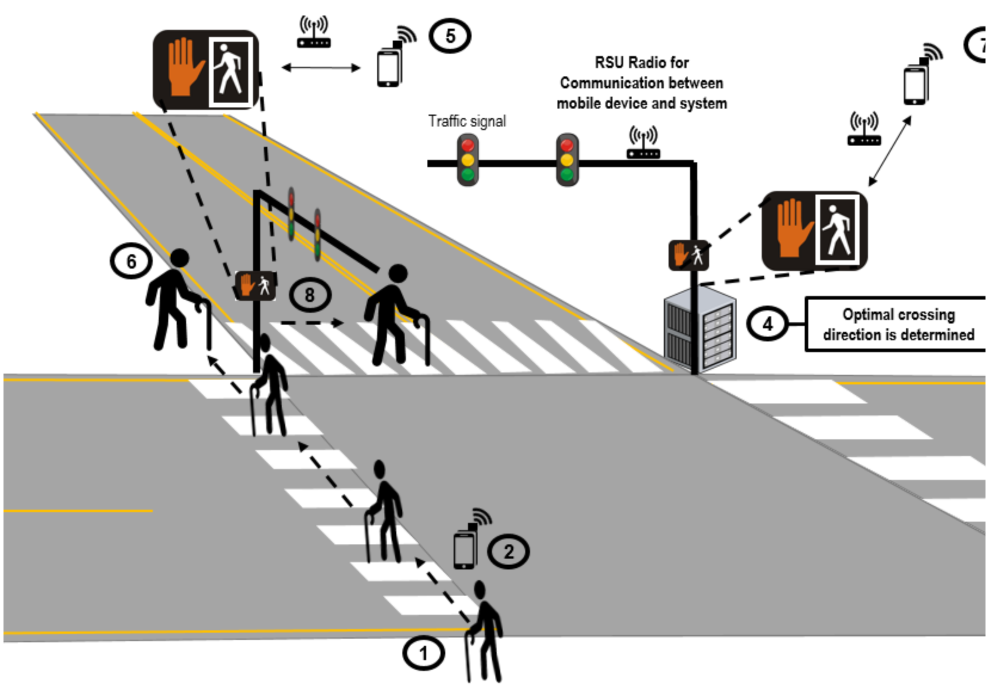
	Use Case 4: Multiple pedestrians arriving at an intersection-Signal Control is Green
Actors/System Elements:	Pedestrian, Mobile App, RSU, Signal Control
Assumptions:	RSU is operational, GPS is connected, the pedestrian is trained to use the mobile app; the signal is green when the pedestrians arrive at the intersection
Preconditions:	Pedestrians are walking towards an intersection
Sequence of Events:	1- Each pedestrian activates the mobile app, and enters his/her intention to cross an intersection 2- Mobile app communicates the crossing direction and the pedestrians' speed to the traffic control system 3- Traffic control system computes time required for the pedestrians to cross 4- The traffic control determines which direction should be green first and for how long 5- Pedestrians arrive at the intersection 6- Based on step 4, some directed to stop and some will be directed to cross
Post Conditions:	Some pedestrians cross the street and some remain at the red signal until it turns green.
Notes/Comments:	Note that the steps after step 5 are similar to the steps in use case 1 and 2 depending on if the signal is red or green 

	Use Case 5: Pedestrian Intersection Crossing – Roadside Unit Malfunction
Actors/System Elements:	Pedestrian, Mobile App, RSU, Signal Control
Assumptions:	RSU is not operational, GPS is connected, the pedestrian is trained to use the mobile app, the mobile app can detect loss of communication with the intersection
Preconditions:	Pedestrian is walking towards an intersection
Sequence of Events:	1- The pedestrian activates the mobile app, and enters their intention to cross an intersection 2- The pedestrian arrives at the intersection and stops 3- Communication between app and RSU does not occur 4- The mobile app notifies the pedestrian that roadside unit is down and to use caution when crossing intersection.
Post Conditions:	Pedestrian stops relying on the mobile app for crossing the intersection.
Notes/Comments:	

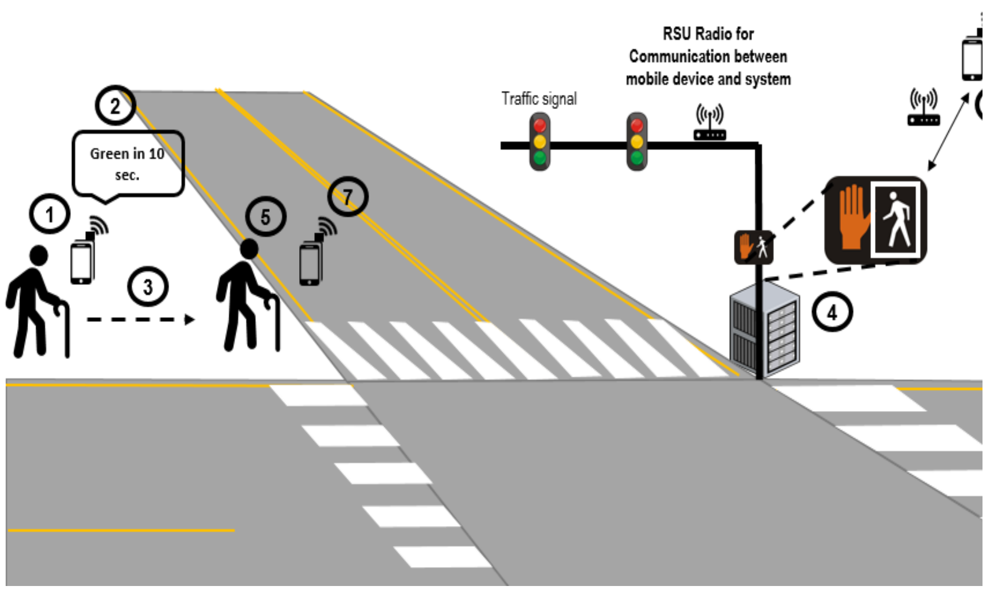
	Use Case 6: Pedestrian Intersection Crossing – Unsafe Trajectory Detected
Actors/System Elements:	Pedestrian, Mobile App, RSU, Signal Control
Assumptions:	RSU is operational, GPS is connected, the pedestrian is trained to use the mobile app, the signal is green
Preconditions:	Pedestrian is crossing an intersection
Sequence of Events:	1- The pedestrian enters the cross walk 2- As the pedestrian begins crossing, the mobile app will periodically communicate GPS location of the pedestrian. 3- If the mobile app detects that the pedestrian has drifted outside of the crosswalk, then it will alert the pedestrian. 4- The pedestrian re-enters crosswalk 5- The mobile app will continuously monitor the pedestrian's progress through the intersection. If progress falls below a specified threshold, the signal system is notified to project a new crossing completion time and extend the GREEN time minimum for the current phase to this time
Post Conditions:	The pedestrian continues crossing the intersection. The mobile app continues monitoring the pedestrian path to detect any deviation.
Notes/Comments:	

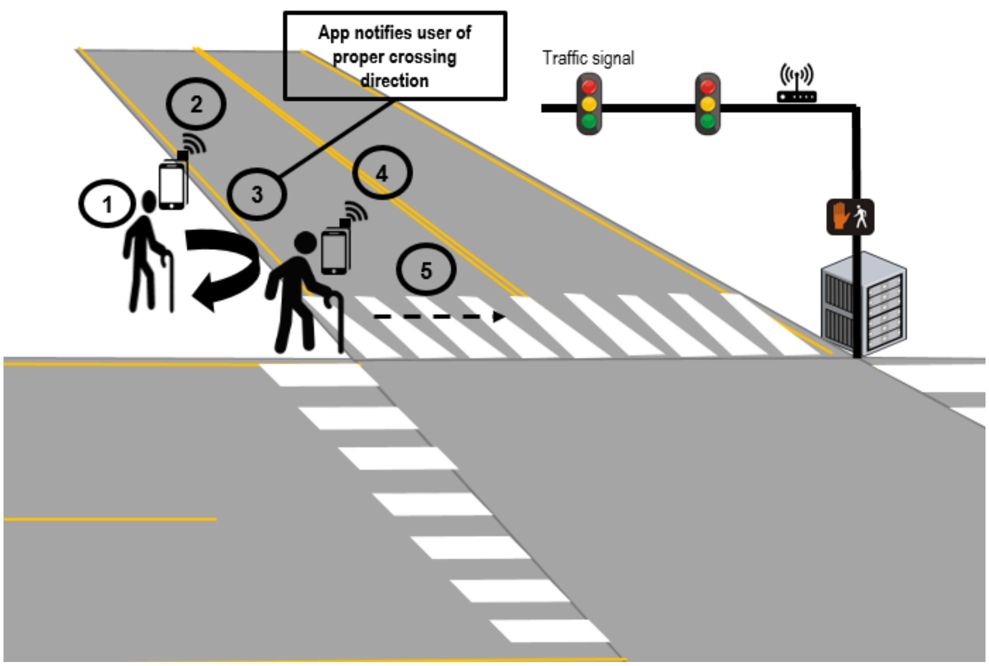
	Use Case 7: Pedestrian Intersection Crossing – Unexpected User Delay
Actors/System Elements:	Pedestrian, Mobile App, RSU, Signal Control
Assumptions:	RSU is operational, GPS is connected, the pedestrian is trained to use the mobile app, the signal is green when the pedestrian arrives at the intersection
Preconditions:	Pedestrian is planning to cross an intersection
Sequence of Events:	1- Pedestrian arrives and stops at intersection and communicates crossing direction to the mobile app 2- Mobile app communicates the crossing direction and the pedestrian's speed to the traffic control system 3- Traffic control system computes time required for the pedestrian to cross 4- The mobile app notifies the pedestrian the light is green and there is enough time for him/her to cross 5- The pedestrian enters the cross walk 6- The pedestrian experiences an unexpected delay (e.g., wheelchair stuck in pothole). 7- The Mobile app detects that user is taking longer to cross intersection than anticipated. 8- The traffic signal system is notified 9- The traffic signal system will also continuously monitor the pedestrian's progress through the intersection, and as such the signal system will project a new crossing completion time and extend the GREEN time minimum for the current phase to this time
Post Conditions:	The pedestrian continues crossing the intersection
Notes/Comments:	

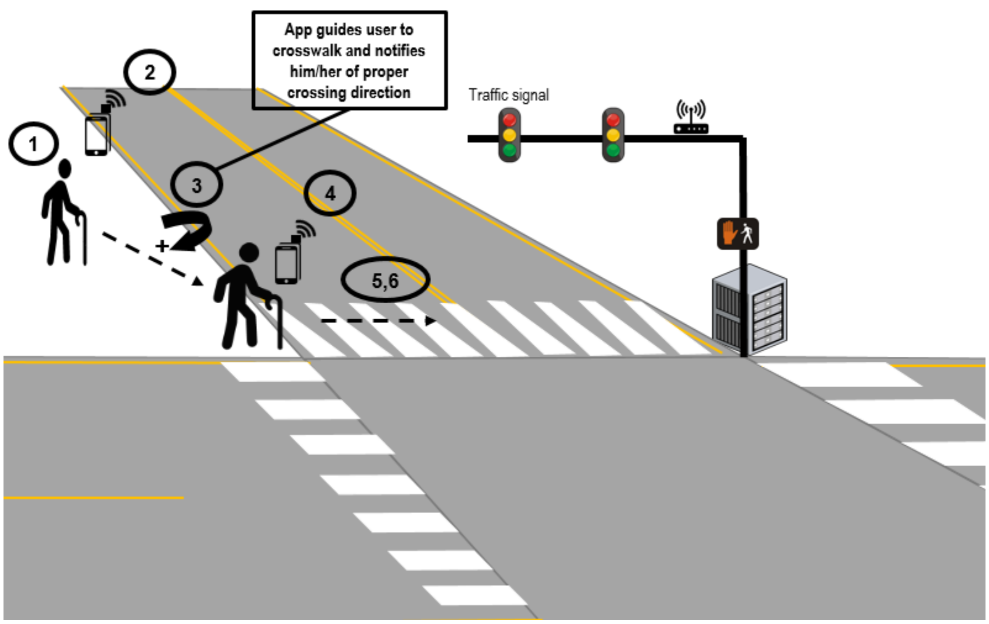
	Use Case 8: Pedestrian Intersection Crossing with an All Pedestrian walk phase
Actors/System Elements:	Pedestrian, Mobile App, RSU, Signal Control
Assumptions:	RSU is operational, GPS is connected, the pedestrian is trained to use the mobile app, the signal is green when the pedestrian arrives at the intersection
Preconditions:	Pedestrian is planning to cross two intersections to get to the diagonal point
Sequence of Events:	1- The pedestrian arrives at the intersection and stops 2- The mobile app is notified that the intersection includes an "all pedestrian crossing phase 3- Mobile app communicates diagonal destination, and the pedestrian's speed to the traffic control system 4- The optimal initial crossing direction is determined and timing is calculated 5- The mobile app informs the pedestrian which intersection to cross first 6- The pedestrian completes the first crossing 7- The Mobile app notifies the pedestrian when it's safe to make the second crossing 8- The pedestrian starts crossing the second intersection
Post Conditions:	The pedestrian continues crossing
Notes/Comments:	As there are two crossings involved in this case, the app should help the pedestrian to know which crossing to make first and which second



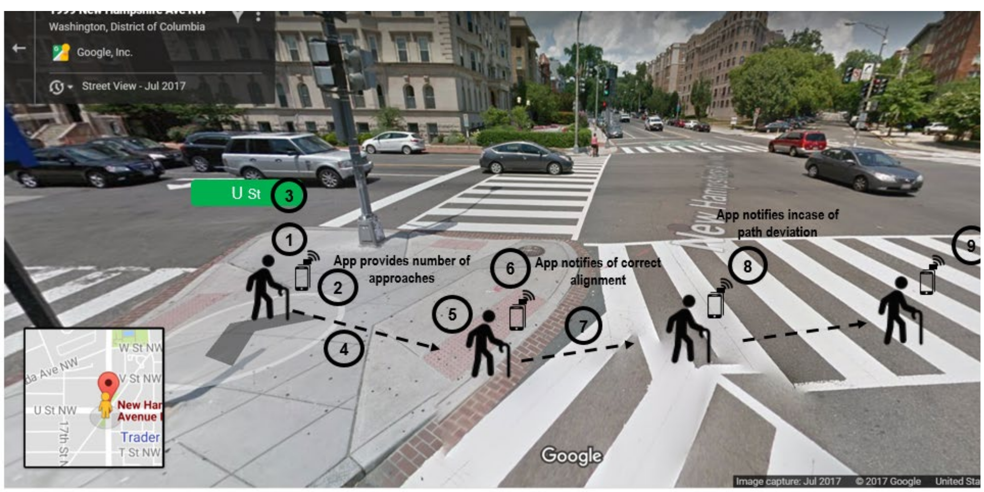
	Use Case 9: Notifying pedestrian that the upcoming intersection signal is red ahead of time
Actors/System Elements:	Pedestrian, Mobile App, RSU, Signal Control
Assumptions:	RSU is operational, GPS is connected, the pedestrian is trained to use the mobile app, the pedestrian signal is red
Preconditions:	Pedestrian is walking towards an intersection
Sequence of Events:	1- The mobile app notifies that the signal at the upcoming intersection is red 2- The mobile app notifies the pedestrian how long is left until the signal turns green (essentially how much time is left for pedestrian to make it to a green signal) 3- The pedestrian could potentially use this information to pace his/her speed accordingly 4- The mobile app notifies the control signal of the pedestrian estimated arrival 5- The pedestrian arrives at the intersection 6- The signal has turned green and there is enough time for pedestrian to cross 7- The mobile app notifies the pedestrian that it's safe to cross
Post Conditions:	The pedestrian starts crossing
Notes/Comments:	This is to notify the pedestrian of the signal controller status so the pedestrian can pace accordingly

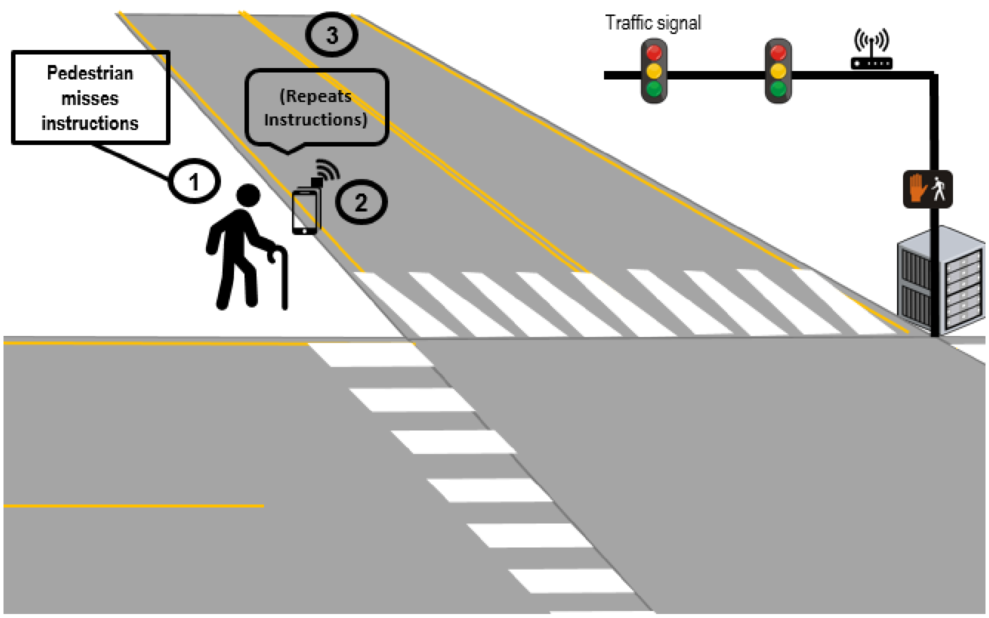


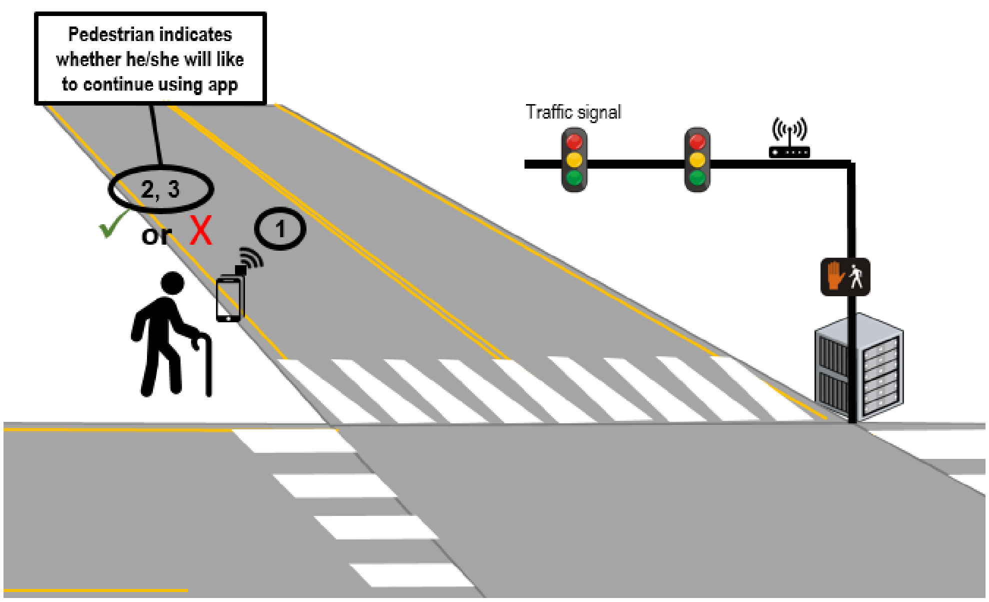
	Use Case 10: Helping the pedestrian know which direction to face for crossing
Actors/System Elements:	Pedestrian with vision disability, Mobile App, RSU, Signal Control
Assumptions:	RSU is operational, GPS is connected, the pedestrian is trained to use the mobile app
Preconditions:	Pedestrian is planning to cross an intersection
Sequence of Events:	1- Pedestrian arrives and stops at intersection and communicates crossing direction to the mobile app 2- Mobile app determines alignment position and whether pedestrian is standing in the crosswalk “corridor” (the rectangular path defined by the crosswalk pattern borders, extended onto the sidewalk it adjoins), to the left of it or the right. 3- If the mobile app detects that the pedestrian is standing in the crosswalk “corridor” but not facing proper crossing direction, it will notify him/her of the clock position of the crossing intersection 4- Once the pedestrian is aligned with the crossing intersection, the mobile app will notify them 5- Refer to Use Case 1,2, or 3 for remainder of steps
Post Conditions:	The pedestrian starts crossing the intersection
Notes/Comments:	Alignment of the individual is likely to be very challenging to ascertain, as the mobile device will not know how the user is aligned with the intersection. We need a better understanding of how we could actually accomplish this. 

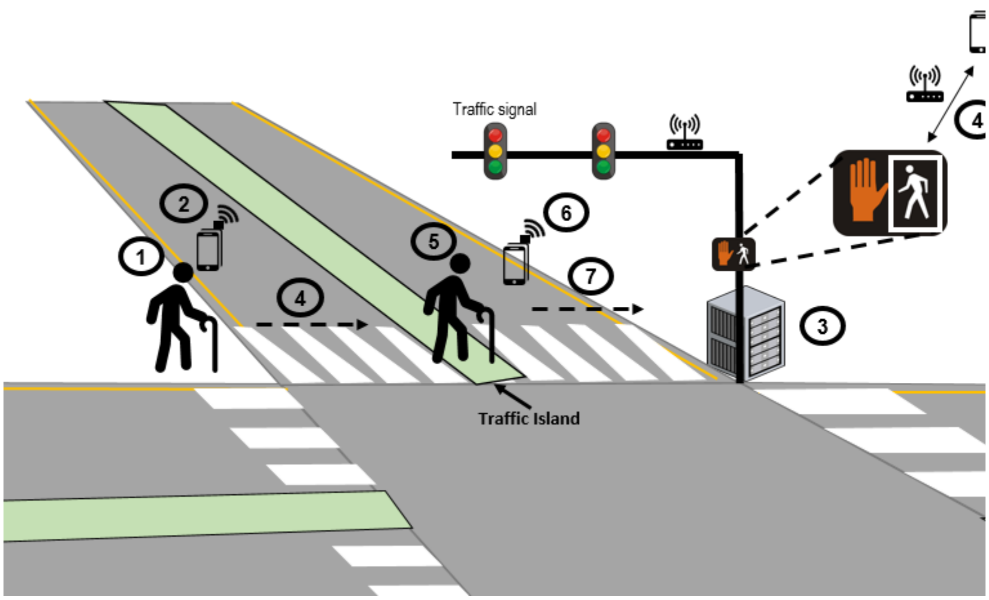
	Use Case 11: Helping the pedestrian to cross the intersection in adverse condition
Actors/System Elements:	Pedestrian with vision disability, Mobile App, RSU, Signal Control
Assumptions:	RSU is operational, GPS is connected, the pedestrian is trained to use the mobile app
Preconditions:	Pedestrian is planning to cross an intersection that has difficulty knowing where the sidewalk ends and crosswalk starts
Sequence of Events:	1- Pedestrian arrives and stops at intersection and communicates crossing direction to the mobile app 2- Mobile app determines alignment position and whether pedestrian is standing in the crosswalk “corridor” (the rectangular path defined by the crosswalk pattern borders, extended onto the sidewalk it adjoins), to the left of it or the right. 3- If the pedestrian is not standing in the crosswalk “corridor” and not facing the proper crossing direction, the app will notify them of the clock position of the crossing intersection and guide him/her to the crosswalk “corridor.” 4- Once the pedestrian is aligned with the crossing intersection, the mobile app will notify them 5- Refer to Use Case 1,2, or 3 for remainder of steps 6- Throughout the steps the mobile app continuously provides notifications if the pedestrian deviates from the path.
Post Conditions:	The pedestrian starts crossing the intersection
Notes/Comments:	Alignment of the individual is likely to be very challenging to ascertain, as the mobile device will not know how the user is aligned with the intersection. We need a better understanding of how we could actually accomplish this. 

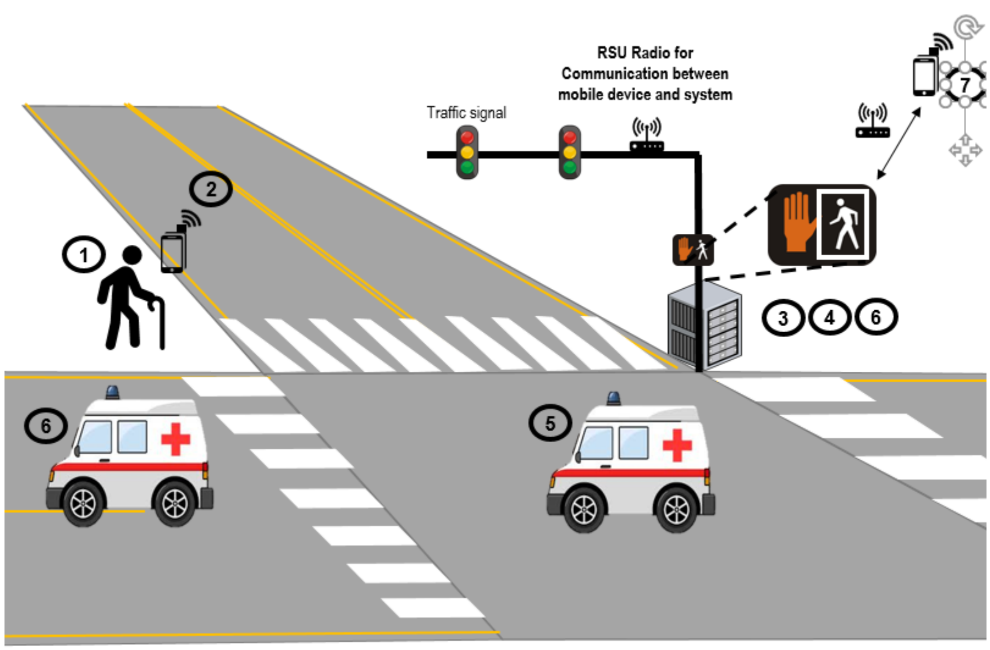
	Use Case 12: Helping the pedestrian maneuver a complex intersection
Actors/System Elements:	Pedestrian with vision disability, Mobile App, RSU, Signal Control
Assumptions:	RSU is operational, GPS is connected, the pedestrian is trained to use the mobile app,
Preconditions:	Pedestrian is walking towards a 5 or 6-way intersection
Sequence of Events:	1- Pedestrian arrives and stops at intersection and communicates crossing direction to the mobile app 2- The pedestrian is notified of the number of separate approaches to the intersection 3- The pedestrian is notified which street he/she is currently standing on 4- Mobile app determines alignment position and whether pedestrian is standing in the crosswalk “corridor” (the rectangular path defined by the crosswalk pattern borders, extended onto the sidewalk it adjoins), to the left of it or the right. 5- If the pedestrian is not standing in the crosswalk “corridor” and not facing the proper crossing direction, the app will notify them of the clock position of the crossing intersection and guide him/her to the crosswalk “corridor.” 6- Once the pedestrian is aligned with the crossing intersection, the mobile app will notify them 7- Refer to Use Case 1,2, or 3 for remainder of steps 8- Throughout the steps the mobile app continuously provides notifications if the pedestrian deviates from the path. 9- The mobile app provides additional notifications to help pedestrian stay the course (for example instructs to deviate a bit to 2:00 o’clock)
Post Conditions:	The user continues crossing
Notes/Comments:	This is a case where the intersection is very complicated (e.g. 5 streets or more, crowded, lots of noise) Same comments about the difficulty of alignment as in Use Case 12



	Use Case 13: Pedestrian miss instruction provided by the mobile app
Actors/System Elements:	Pedestrian with vision disability, Mobile App, RSU, Signal Control
Assumptions:	RSU is operational, GPS is connected, the pedestrian is trained to use the mobile app;
Preconditions:	Pedestrian is using mobile app to complete trip
Sequence of Events:	1- Pedestrian miss instructions provided by mobile app 2- Pedestrian notifies mobile app 3- Mobile app repeats instructions
Post Conditions:	Pedestrian continues listening to instructions and crossing the intersection
Notes/Comments:	

	Use Case 14: The pedestrian decides not to cross
Actors/System Elements:	Pedestrian with vision disability, Mobile App, RSU, Signal Control
Assumptions:	RSU is operational, GPS is connected, the pedestrian is trained to use the mobile app
Preconditions:	Mobile app notifies pedestrian that it is safe to cross but pedestrian does not start crossing intersection
Sequence of Events:	1- The mobile app prompts user to indicate if he/she still intends to cross intersection 2- If pedestrian notifies the app that they are no longer crossing intersection and pausing the mobile app, the mobile app will discontinue its safe crossing intersection guidance until pedestrian resumes app. 3- If the pedestrian notifies the app that he/she would like to continue using the app to cross intersection, refer to Use Case 1 for following steps.
Post Conditions:	Mobile app stays on pause
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 15: Pedestrian Crosses Street with Traffic Island
Actors/System Elements:	Pedestrian with vision disability, Mobile App, RSU, Signal Control
Assumptions:	RSU is operational, GPS is connected, the pedestrian is trained to use the mobile app; the signal is green when the pedestrian arrives at the intersection
Preconditions:	Pedestrian is planning to cross an intersection with a traffic island
Sequence of Events:	1- Pedestrian arrives and stops at intersection and communicates crossing direction to the mobile app 2- Mobile app communicates the crossing direction and the pedestrian's speed to the traffic control system 3- The optimum crossing pattern and timing is calculated 4- The mobile app informs the pedestrian to cross intersection and to utilize traffic island until another green phase is initiated by the signal control 5- The pedestrian completes the first crossing 6- The Mobile app notifies the pedestrian when is safe to make the second crossing 7- The pedestrian starts crossing the second half of the intersection
Post Conditions:	The pedestrian is crossing the street.
Notes/Comments:	

	Use Case 16: Mobile App signals the approach of an emergency vehicle
Actors/System Elements:	Pedestrian with vision disability, Mobile App, RSU, Signal Control
Assumptions:	RSU is operational, GPS is connected, the pedestrian is trained to use the mobile app; the signal is green when the pedestrian arrives at the intersection; intersection has been made aware of an approaching emergency vehicle
Preconditions:	Pedestrian is planning to cross an intersection
Sequence of Events:	1- Pedestrian arrives and stops at intersection and communicates crossing direction to the mobile app 2- Mobile app communicates the crossing direction and the pedestrian's speed to the traffic control system (as usual) 3- Traffic control system computes time required for the pedestrian to cross 4- The required crossing time is communicated to signal controller for use as the minimum green time constraint for next GREEN phase in the pedestrian's crossing direction 5- The mobile device will inform the pedestrian to wait due to approaching emergency vehicle. 6- Once the vehicle has passed, the traffic signal system will assess whether there is enough green time left to allow passage, and if not inform the pedestrian to continue to wait. 7- When the signal subsequently turns GREEN in the pedestrian's crossing direction, the mobile app will signal to the pedestrian that it is time to start crossing.
Post Conditions:	Pedestrian starts crossing
Notes/Comments:	

Chapter 7. Summary of Impacts

Operational Impacts

We expect this system development project to significantly improve the safety of intersection crossing for pedestrians with disabilities, including injured veterans and older adults. The proposed system will affect the following operational activities:

Informing the traffic control system at an intersection of intent to cross: Pedestrians equipped with this app will not have to use pedestrian call buttons located at intersections. Instead, the 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 guided to the starting location of the intended crosswalk, reducing the complexity of that challenge. In addition, the app will provide information on crosswalk entrance points, such as cutouts, grade, and geometry, facilitating entry into the crosswalk for those with mobility disabilities.

Notifying pedestrians to initiate crossing: The 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 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 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 stop making progress on a crosswalk), the system will protect the pedestrian by extending the walk until the person is clear.

Locating the end of the crosswalk: Pedestrians with visual disabilities will be advised on how to exit the crosswalk by providing guidance to the exit point and information about whether there is a curb or a cutout, grade, etc.

In Year 2 of the project, we 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 a pedestrian with disabilities to make a bus connection will be reduced.

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 mobile application.

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 leads us 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, traffic cops 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 application to the users.

Chapter 8. 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.

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 Dedicated Short-Range Communication (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 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 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. We will develop 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 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. We 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) we can do much more. We 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.

Goals, Performance Measures, and Transformative Performance Targets

Table 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 3: Performance Measures

#	Goals	Performance Measure	Transformative Performance Target		Notes
			Threshold [6]	Objectives [7]	
1.	Increase in pedestrians' confidence crossing intersections	Perceived Safety	Feeling moderately safe using the app	Feeling very safe using the 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 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 App.
5.	Increase in pedestrians' confidence crossing intersections / Efficiency	% increase in number of times (or cumulative time) that the Green time is extended by the signal system	20%	10%	Users are likely to cross the intersection slower if he or she is not confident enough
6.	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] Minimum acceptable value

[7] Ideal Value

#	Goals	Performance Measure	Transformative Performance Target		Notes
			Threshold [6]	Objectives [7]	
7.	App accuracy and increased reliability	% of time that the system correctly identifies the intersection pedestrian is at	30%	90%	This depends on accuracy of GPS location technology
8.	App accuracy and increased reliability	% of time that the system correctly identifies the intersection corner pedestrian is at	30%	90%	This depends on accuracy of GPS location technology
9.	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
10.	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

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 app that we would like to take advantage of 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 mobile application 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 a first step, we will define relevant information requirements.

Alternatives and Trade-Offs

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

Robustness of GPS tracking

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 thereof (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

We have 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, we 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, we 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

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