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

System Design Document (SDD)

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16. Abstract

This document presents the system design consisting of a mobile application for use by pedestrians with disabilities to facilitate safe and efficient intersection crossing though specially equipped intersections. The mobile application is designed to allow the pedestrian to communicate directly to the equipped intersection and to actively influence traffic control decisions. Most basically, the mobile application enables the pedestrian to communicate personalized crossing duration requirements to the infrastructure. However, the mobile application is also capable of monitoring pedestrian progress, and by utilizing the SURTRAC real-time adaptive traffic signal control system, it is capable of triggering dynamic extension of the green phase if necessary. Various aspects of the design are specified, including the physical architecture, the DSRC-based pedestrian-to-infrastructure communication framework, the mobile application's user interface, and necessary extensions to the SURTRAC adaptive signal control system.

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1 Introduction

Transportation and mobility are crucial for living today. However, for people with disabilities (mobility, vision, hearing, and cognitive), inadequate transportation can prevent them from living a full life. The Accessible Transportation Technology Research Initiative (ATTRI) of the U.S Department of Transportation's (USDOT) Intelligent Transportation Systems Joint Program Office (ITS-JPO) aims at improving the mobility of travelers with disabilities through research, development, and implementation of transformative technologies, applications, or systems for people of all abilities to effectively plan their personal and independent travel. ATTRI research focuses on the needs of three stakeholder groups: persons with disabilities, older adults, and veterans with disabilities.

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

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

This document is developed as a part of a USDOT sponsored project focused on the Safe Intersection Crossing application area. The project will span two years with each year consisting a systems engineering (SE) cycle containing phases for ConOps development, system requirements specification, system design, development, testing and demonstration. The first year of the project was focused on the basic safe crossing features with the second year incorporating additional, more advanced features. This "Year 2" System Design Description (SDD) encompasses both the Year 1 and Year 2 features. As with other parts of the SE cycle, the system design process is both iterative and recursive, and it is anticipated that the SDD will be a living document. Furthermore, as this project is using an agile approach for developing the *Safe Intersection Crossing* system, this SDD will be updated periodically to reflect the evolving system design and development at subsequent stages of the project.

1.1 Purpose of the System Design Document

This project will develop and demonstrate assistive services that (1) promote safe passage of veterans with disabilities, older adults, and other persons with blindness, low vision, cognitive, or mobility related disabilities when crossing signalized intersections, and (2) 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 either 3G/4G cellular communications capability or 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 PedPal mobile app and its host smartphone will provide accessible interfaces that allow pedestrians to communicate personalized intersection crossing constraints (e.g., required duration, crossing direction) to the signal system to ensure that that the signal system allocates sufficient crossing time, 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.

In Year 2, the PedPal mobile app will also enable users to provide pre-planned pedestrian route and destination information (e.g., walking path and target bus stop and route) 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., near elder care facilities, retirement homes, schools for persons with disabilities, etc.).

The purpose of this System Design Document (SDD) document is to specify the system design of the PedPal mobile app which will, once developed, test and deployed on a smartphone, provide this set of intersection crossing services. Since the development of capabilities for using pedestrian routes and synchronizing with buses is planned for the second year of the project, this Year 1 edition of the System Design Document will focus on the design of basic capabilities for communicating and using personalized crossing constraints to provide sufficient green time for crossing, for monitoring the user's crossing progress and for dynamically extending the green time and/or alerting the user if the situation warrants. In the design phase at the beginning of Year 2, this system design document will be updated to incorporate more advanced mobility enhancement capabilities. In both years, technical design and development will build on the existing real-time adaptive traffic control system developed at the Carnegie Melon University, known as Scalable Urban Traffic Control (SURTRAC).

1.2 Assumptions

The system architecture design specified in this report makes the following assumptions:

1. *Positioning and directional accuracy*: The architecture design specified assumes sufficient positioning and directional accuracy from a smartphone Global Positioning System (GPS) to allow for precise curbside navigation of users. Supplementary technology might be required if the accuracy turns out to be less than ideal during our implementation phase. Please refer to Chapter 3.2.3 for our latest thinking on providing this required localization capability.)
2. *DSRC message sets beyond standardized messages:* It was originally assumed that our system architecture design would require some extension of the standardized Society of Automotive Engineers (SAE) J2735 message sets. However, as the design has developed it has been possible to use the Signal Request Message (SRM) and Signal Status Message (SSM) message types without change to support communication of pedestrian requests to the infrastructure.
3. *Two Sequential Development Cycles:* There will be two yearly system engineering cycles, with each cycle consisting of phases for concept definition, requirements engineering, design, development, test and evaluation. Year 1 prototype system design focused on the safety aspects of safe intersection crossing, while the Year 2 Prototype focuses on mobility features and components such as use of pre-planned pedestrian routes and bus-stop synchronization.
4. *User Interface (UI) design:* This project includes human-machine interactions, which require further evaluation and studies in the domain of human-factors. This is beyond the scope of

this project, and the architecture and interface designs specified in this document are based on principles that have proven to be most effective in previous research (e.g., use of multiple interaction modalities, use of native phone accessibility features, ability to control verbosity, etc.) The Year 1 field test and subsequent evaluation provided valuable feedback into the effectiveness and utility of the PedPal mobile app's UI and functionality and user criticisms and suggestions were factored into the Year 2 prototype system. Please refer to the project's Year 1 Test and Evaluation Report [3] for more information.

1.3 Constraints

Safe navigation of crosswalks can be a key challenge for people who need more time to traverse an intersection. If there is no safe island zone mid-intersection then signal light duration becomes very important, for example. Within this application area, providing safe intersection crossing assistance for all unique travelers as they interface with existing traffic, signals, all types of vehicles and assistive devices is a key focus area. It is therefore imperative that the design of technological solutions focuses on assistive tools for people with blindness, low vision, cognitive and mobility issues. Assistive tools may be in the form of personal nomadic devices, wearable technologies and kiosks on streets corners to allow for ubiquitous access to connected services.

Applications in this area should, for example, provide guidance, notifications and alerts in various communication formats that assist pedestrians and all users of the transportation system as they navigate safely through intersections. They should also focus on providing precise and concise information when it is needed and at the right moment to promote decision-making and actions. These applications should address and could include but are not limited to the following components: the pedestrian's 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 the sharing of real-time information. It should provide contextual information including Geographical Information Systems (GIS) and crowd sourced information on curb cuts, bus stop locations, side walk grade and slope, and any disruption of the built environment (damaged infrastructure, dead ends, potholed) to aid all travelers. Additional examples could include; futuristic and innovate approaches to solving this issue with automated intersection crossing assistance, technical design solutions for people with blindness, low vision, cognitive and mobility issues, or integrated beacons or electronic tags to interact with the built environment.

1.4 Risks

Several assumptions presented in Section 1.3 are also risks associated with this project, and additional risks will be documented as we proceed through design and implementation stages in future deliverables. Some of the identified risks and mitigation strategies based on current design are presented below:

Table 1-1: Risks

No.	Risk	Mitigation Strategy
1	Without positional systems such as differential GPS, the architecture design presented here runs the risk of degraded	The team plans to investigate alternate approaches such as DSRC signal-strength estimation, introduction of external Bluetooth beacons at the intersection, and localization

No.	Risk	Mitigation Strategy
	positional and directional accuracy.	based on multiple GPS devices to improve accuracy of GPS-based location services.
2	The current architecture utilizes SRM and SSM, which are currently only standardized for Transit Signal Priority (TSP) and Emergency Vehicle Preemption (EVP).	Pedestrian calls and traffic signal phases work similar to TSP and EVP, and we expect minimal modifications to SRM and SSM to allow SURTRAC to utilize pedestrian calls to adjust the green time.
3	DSRC message-set latency or errors could cause Signal Phase and Timing (SPaT) information to switch back and forth and confuse users.	The software design will utilize smoothing methods to avoid unknown variations in Time to Red by utilizing an internal timer.
4	DSRC technology might prove unreliable and/or or inconvenient (for the pedestrian) communications equipment.	We have found the mobile DSRC technology to be somewhat unstable and the learning curve for getting it to work to be rather steep. More generally, the documentation is sparse for all DSRC devices, which has further complicated development. At this point we have worked through most issues and have the ability for bi-directional communications. However, this required undesirable workarounds to achieve this. Specifically, it was necessary to upgrade the firmware of the mobile DSRC sleeve to enable communication with the RSU, but which broke the ability to use Bluetooth to communicate with the smartphone. Until this firmware bug is corrected, we are limited to using a wired connection between the smartphone and the sleeve. We investigated the use of (1) a larger plastic case to encapsulate the mobile device and the exposed wiring, or (2) the use of a fanny pack to hold all equipment at the waist and allow the user to handle just the tethered smartphone or use a runner's sleeve to attach it to the user's arm. Our Year 1 mitigation strategy was to use the wired connection between the smartphone and the sleeve which while functional, was not particularly attractive from a usability perspective. However, after appropriate discussion with field test participants during their training, it was determined that the negative impact of the loss of Bluetooth connectivity should be minimal, and that in some ways, it resulted in an easier device package for the user interaction.

No.	Risk	Mitigation Strategy
		In Year 2, this risk will be further mitigated through the addition of cellular (3G/4G) connectivity with the intersection. As an alternative, or backup to the primary DSRC path. The use of cellular connectivity should provide equivalent functionality and similar performance as that of DSRC for prototype system testing. This may not be true, in the longer run, when future iterations of the prototype system consider the introduction of SAE J2735 Personal Safety Messages (PSM).
5	Lear has informed us that it plans to discontinue the Arada Systems Locomate ME sleeve device, and no longer support it.	While we have not yet found another DSRC sleeve device to replace the Locomate, we have selected a compact Codha OBU that is adaptable for use with the PedPal mobile app using a wired connection. Codha has provided us with a sample unit to use as a prototype, and furthermore the device has been recommended to the Port Authority for use onboard its buses. We have introduced cellular based IP communications between the PedPal mobile app and the SURTRAC, as an alternate communications path.

2 System Description

In this chapter, we describe the application view of the Safe Intersection Crossing technology and the prototype system that was developed and tested in Year 1 of the project. Furthermore, we will describe the mobility enhancements that will be added in Year 2 of the project. These enhancements are focused on enabling users to provide pre-planned pedestrian route and destination information to the traffic signal infrastructure, which can be used in conjunction with other real-time transit vehicle information 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.

2.1 Concept

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

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

The smartphone app will provide accessible interfaces that allow pedestrians to communicate personalized intersection crossing constraints (e.g., required time, crossing direction) to the signal system and ensure that it allocates sufficient crossing time, to receive geometric and obstacle information (e.g., curb cut locations) about the intersection that will facilitate safe crossing, and to be alerted when a crossing movement indicates safety concerns (e.g., moving outside of the crosswalk). Real-time monitoring of crossing performance will also be used to automatically extend the green time in real-time when appropriate. The app will also enable users to provide pre-planned pedestrian route and destination information (e.g., walking path and target bus stop) to the traffic signal infrastructure, which can be used in conjunction with other real-time information (e.g., bus locations and routes) to adapt signal phase timings preemptively as the pedestrian approaches the intersection, leading to shorter and more reliable pedestrian travel times, and more efficient travel connections. Moreover, since the real-time traffic signal control system is optimizing all detected traffic flows at a given intersection, the approach will yield compound benefits in areas with large concentrations of disadvantaged pedestrians (e.g., the vicinity of elder care facilities, retirement homes, schools for persons with disabilities, etc.).

2.2 Subsystems

This section provides a summary description of the subsystems and a high-level overview of the subsystem.

2.2.1 Intersection Infrastructure Subsystem

The Intersection Infrastructure Subsystem (IIS) has the following components.

IIS-1 – SURTRAC Adaptive Traffic Signal Control System

As mentioned in the Chapter 1, a “Safe Intersection Crossing” mobile application, titled the “PedPal mobile app”, will be built to work with the existing adaptive traffic signal system developed by Carnegie Mellon University (CMU) and currently marketed by Rapid Flow Technologies, known as SURTRAC (Scalable Urban Traffic Control).

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. The design of the communications between SURTRAC devices is described in [9]. 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.

SURTRAC implements schedule-driven traffic control as part of a flexible signal control system that is modularly designed for integration with any commercially available controller and sensor hardware. True to the schedule-driven traffic control model, SURTRAC is organized as a completely decentralized multi-agent system. Each intersection is controlled by an agent running on an embedded computer located in the traffic cabinet for the intersection. The agent for each intersection manages the control of the traffic signal and all the vehicle detectors located at that intersection.

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

1. The SURTRAC component accepts detector data from cameras, pedestrian call buttons, and other sensors at the intersection.
2. The SURTRAC component generates timing plans, in real time, for moving currently sensed traffic through the intersection efficiently
3. The SURTRAC component issues commands to the Traffic Signal Controller, the device that controls the state of the traffic signal heads
4. The SURTRAC component communicates predicted outflows to downstream intersections.
5. The SURTRAC component uses the current timing plan to generate SAE J2735 defined SPaT messages
6. The SURTRAC component can receive over DSRC and process the contents (as required) from all relevant SAE J2735 defined messages (e.g. Basic Safety Message (BSM), SRM)
7. The SURTRAC component broadcasts the following SAE J2735 defined messages over DSRC at specified intervals.
    a. SPaT
    b. Map Data (MAP)

c. SSM

The SURTRAC component will require the following functional enhancements to support interactions with the PedPal mobile app.

1. Extension to allow a pedestrian's required crossing time to serve as the system's minimum crossing time constraint in the pedestrian's target direction.
2. Extension to allow for dynamic extension of this minimum crossing time constraint if an unexpected delay is detected.
3. Extension to enable acceptance of user travel routes and incorporation of this knowledge when generating signal timing plans to anticipate pedestrian arrivals.
4. Extensions to enable adjustments to generated signal timing plans to ensure synchronized arrival of pedestrians and buses at nearby bus stops.
5. Communications using standards-based variants of SAE J2735 based messages as well as newly defined messages to effect necessary communication of pedestrian goals and constraints, as well as SURTRAC system generated commands, guidance, and alerts back to the mobile device.

IIS-2 — Signal Controller

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

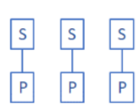
IIS-3 — DSRC Roadside Unit

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

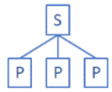
IIS-4 — 3G/4G Wireless Communication Unit

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

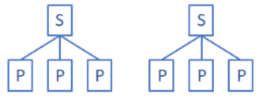
- Concurrent support for single sessions between distinct pairings of a single PedPal mobile app and a single SURTRAC. (Multiple 1:1)



- Concurrent support for single sessions between different PedPal mobile apps and a single SURTRAC. (Single N:1).



- Concurrent support for multiple sessions between different PedPal mobile apps and a single SURTRAC. (Multiple N:1)



IIS-5 — Traditional Intersection Infrastructure

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

IIS-6 — Intersection Localization Infrastructure

As observed earlier, the accuracy of the localization service (e.g. GPS, or augmented GPS) provided by the pedestrian device is key to the effectiveness of the proposed PedPal mobile app's progress tracking capabilities. In the Year 1 field test, the GPS-based localization service provided by the smartphone was found to be marginally satisfactory in supporting these capabilities, and we intend to augment these capabilities in Year 2. Specifically, our infrastructure extension for Year 2 will be to introduce Bluetooth beacons as additional sensors at the intersection. In (Laio13)[1] the use of two or more Bluetooth beacons were used to boost the accuracy of a mobile phone and enable some amount of tracking of pedestrians through the intersection. Under this approach, the known fixed locations of the beacons provide some error correcting capability through triangularization. At the time this work was done, the resulting accuracy obtained was about +/- 1-meter accuracy (basically equivalent to the accuracy of current day smartphones). However, since smartphone localization has improved substantially in recent years, we expect the use of beacons to give us the accuracy we need.

2.2.2 Pedestrian Device Subsystem

The Pedestrian Device Subsystem (PDS) consists of the PedPal mobile app and a computation platform (i.e. a smartphone) for hosting (e.g. installing and operating) the PedPal mobile app. The PDS' computational platform should have accurate localization services, native 3G/4G communication capability, and optionally an extension for DSRC communication capability. Additionally, the PDS'

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

computational platform must support the configurable feedback options (audible, visual or tactile) required for the planned UI.

The proposed PDS consists of the PedPal mobile app hosted on an Apple iPhone[2] which in addition to offering localization services, and 3G/4G communications capability, will optionally be connected to one of two external mobile, DSRC-enabled device types, each of which will provide full DSRC/WAVE capabilities with native applications for integration with smartphones to facilitate the user-interface.

Given that the intersection crossing algorithms and decision-making functions for dynamic intersection signal timing are already integrated into the existing SURTRAC adaptive signal control system, the PedPal mobile app has been designed to work coherently with the SURTRAC architecture and, by extension, the supporting roadway infrastructure.

PDS-1 – Device Localization Services

This component will extend the native smart phone localization capability to triangulate with Bluetooth beacons at the intersection for purposes of achieving sufficient accuracy to recognize corners, and track pedestrian movement across the intersection.

PDS-2 – Cellular (3G/4G) Radio

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

PDS-2 – Mobile DSRC Radio

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

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

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

PDS-4 – PedPal Mobile App

The PedPal mobile app provides basic assistance to the user in crossing the intersection and supports all the native accessibility features of the iPhone, including voice-over, zoom, font enlarging,

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

etc. These features are configured from the iPhone's Settings control. Furthermore, it is customizable to each user and knows the user's personalized crossing constraints. It allows the user to communicate crossing intent (eliminating the need for a pedestrian call button) along with the time that the particular user requires for safe crossing. If the request is made in advance of the green in the crossing direction, then an extension to crossing time will always be granted by the traffic control system. If the request is made when the signal is already green in the crossing direction, the traffic control system will determine whether there is enough time remaining to permit crossing and grant a time extension or if the pedestrian should wait until the next green cycle.

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

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

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

The PedPal mobile app's UI will provide the following functional capabilities:

- *Communication of Personalized Crossing Constraints*

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

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

- *Crossing Assistance*

  The PedPal mobile app UI will also provide crossing assistance to the pedestrian during his/her trip across the intersection (once the command indicating that it is OK to cross has been given). The app will periodically monitor the pedestrian's location in the intersection and take appropriate action in specific circumstances. If the PedPal mobile app detects that the pedestrian has moved outside of the crosswalk, an alert will be issued with an indication of how the pedestrian should adjust her/his heading to get back into the safety zone. If it is detected that the pedestrian is traveling slower than expected, the pedestrian (with certain exceptions[3]) 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 UI will be extended to provide active assistance during crossing, including monitoring and communication of crossing progress, alerting the user if necessary, and conveying real-time extensions to the phase length. In the event of unreliable GPS, it must also be possible for the pedestrian to communicate progress events (e.g., stuck, completely across). The team will work to integrate and refine these interaction capabilities to interoperate with complementary extensions that will be concurrently made to SURTRAC.

- *Use of Pre-Planned Routes*

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

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

- *Synchronizing with Bus Arrivals*

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

3 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.

For this UI component, the team will develop a comprehensive UI 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).

2.3 Operation

2.3.1 Safe Intersection Crossing

The PedPal mobile app is envisioned to be an add-on module (or extension) to the SURTRAC system. The core of the safe-intersection crossing will be a hand-held device, consisting of a cellular smartphone that optionally has been integrated with a DSRC radio. This standalone or coupled mobile device will be either held by or on the person of the pedestrian and will be used by the pedestrian to communicate with the intersection. DSRC-enabled, this device will interact with a DSRC Roadside Equipment (RSE) unit mounted at the intersection, and the DSRC RSE will be connected to the SURTRAC processor residing in the controller cabinet (via an extended Detector module interface). Devices that are not DSRC-enabled, will communicate with the intersection using 3G/4G communications through a dedicated cloud service, while those that are so enabled can use 3G/4G communications as an alternative. Through SURTRAC's normal interaction with the intersection's hardware controller (also resident in the cabinet), both traffic and pedestrian signals are adjusted to fit the pedestrians crossing constraints. Figure 2-1 shows the schematic of different elements of the Safe Intersection Crossing system.[4]

In operation, as the pedestrian approaches the intersection, both MAP and SPaT messages will be detected by the PedPal mobile app. The MAP message content will be used by the PedPal mobile app to present the pedestrian with different crossing options. Based on the content of the SPaT and MAP messages that are being received, the PedPal mobile app will inform the pedestrian which crossing direction is currently green, and how much time remains until the beginning of future crossing phases. When the pedestrian arrives at the intersection and is ready to cross, s/he will use the PedPal mobile app to select a crossing option and trigger a crossing request. This request will indicate the pedestrian's crossing direction and the required crossing duration, which is based on the PedPal mobile app's knowledge of the pedestrian's speed. The user's travel speed is specified to PedPal through the settings screen for the app. For a more detailed discussion of PedPal configuration by the User, refer to Section 3.2.2.1.

If the cross-walk is active (i.e., the corresponding signal phase is green) and the "time remaining" is deemed sufficient, then the pedestrian can begin to cross the street; the PedPal mobile app will

[4] Although many of the application's capabilities rely fundamentally on a real-time, adaptive signal control system such as SURTRAC, it is possible to provide the simple, basic capability to substitute a longer, personalized crossing duration that could be used with a conventional signal timing plan. We intend to design the PedPal mobile app in such a way that this basic capability can be utilized at non-SURTRAC controlled intersections with DSRC communication capability.

monitor progress, generate alerts as necessary, and potentially extend the green time to help the pedestrian safely cross.

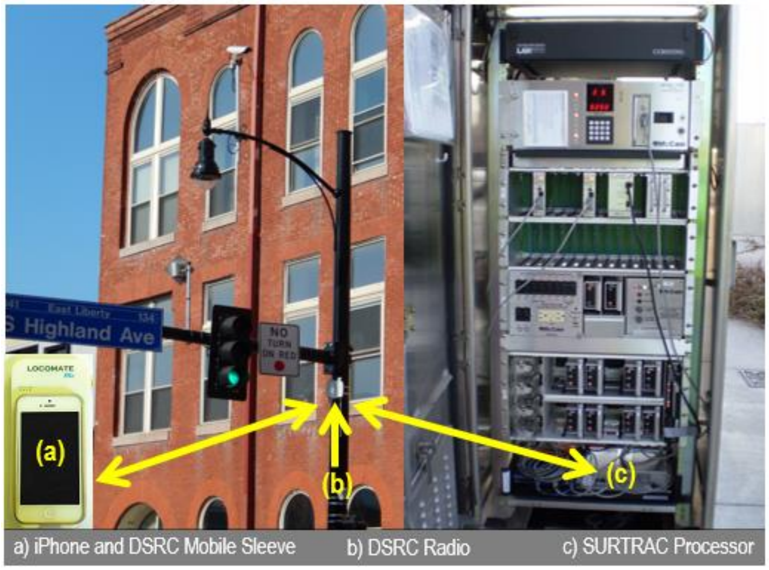


Figure 2-1: Elements of the Safe Intersection Crossing System

If the cross-walk is inactive (i.e., the corresponding signal phase is red), or if the "time remaining" in the current green crossing phase is less than that required for the pedestrian to cross the street, then the pedestrian will be alerted to wait for the next cycle. In this case, the previously communicated crossing duration will be used by the signal control system to ensure that sufficient green time is allocated when the crossing direction does eventually become green. Once the pedestrian signals that s/he is starting to cross, the PedPal mobile app will monitor progress, generate alerts and potentially extend the green time as before.

The PedPal mobile app will be tailored in different ways to the disability of the pedestrian using the application. The UI of the PedPal mobile app will be tailored to the type of disability, so that it can provide visual, audible or haptic feedback. In addition, the pedestrian request will be based on the average moving speed of the pedestrian so that the walk-phase is long enough for his/her safe passage.

2.3.2 More Efficient Intersection Crossing

The PedPal mobile app will also provide three capabilities aimed at enhancing the mobility of pedestrian travel. The first capability is informational, designed to provide the user assistance in finding the appropriate crosswalk (based on the direction of the user's indicated route) upon arrival at the intersection corner. The PedPal mobile app will allow the user to query for relevant characteristics of the intersection corner, including the presence of curb cuts and their location (at the corner or separate for each crosswalk), as well as other characteristics relevant to crossing, such as the presence of a traffic island. These characteristics will be imported from a third-party app, as described in Section 3.2.3.1, when needed in response to each user query.

The second capability will allow the PedPal mobile app to import a pedestrian's route, and to subsequently use it to anticipate the user's arrival at each intersection and inform the SURTRAC system which will use this information to better optimize the signal timing to the user's advantage. It requires that the user first construct the route he/she is planning to travel within a separate third-party navigation mobile app (e.g., Blindsquare) and subsequently export the route into the PedPal mobile app. The PedPal mobile app then communicates the next segment of the predefined route to the intersection that the user is approaching, and the SURTRAC traffic control system incorporates the projected arrival information into its online signal plan generation algorithm to promote more streamlined crossing where the user's wait time at the intersection is minimized.

The third mobility extension will allow the PedPal mobile app to import the user's intention to transfer to a transit bus on a specified bus route at a specified bus stop, again as input through an appropriate (e.g. Transit) third-party mobile app. The PedPal mobile app will forward this information on to the appropriate intersection's SURTRAC system. The SURTRAC system will then integrate the user's expected arrival time at the intersection with independently acquired real-time information on the predicted arrival time of the transit bus at the intersection's bus stop; to help synchronize arrivals (when feasible) and increase the chances of the user catching the bus before it departs.

For both route following and transit synchronization capabilities, the PedPal mobile app will provide an API for importing this information from third-party apps and protocols, described in Sections 3.2.3.1 and 3.2.4.1 for communicating with the SURTRAC system and, by extension, the supporting roadside infrastructure.

3 System Design

In the following subsections we provide the design for each of the subsystems and its components that are part of the overall system shown in Figure 3-1 below. A given subsystem/component can be primarily hardware, primarily software or have both hardware and software components. For subsystems/components where there is a mix of legacy design and new hardware/software to enable the proposed PedPal mobile app, we focus principally on the new elements and reference the legacy design with existing documentation where appropriate.

These systems use a combination of DSRC, cellular/wired/wireless IP-based communication and wired ethernet communication for inter-system and sub-system level communications. More details on the first two of these subsystems, the IIS is provided in the first subsection, with the following subsection covering the PDS, which includes at its core, is the PedPal mobile app.

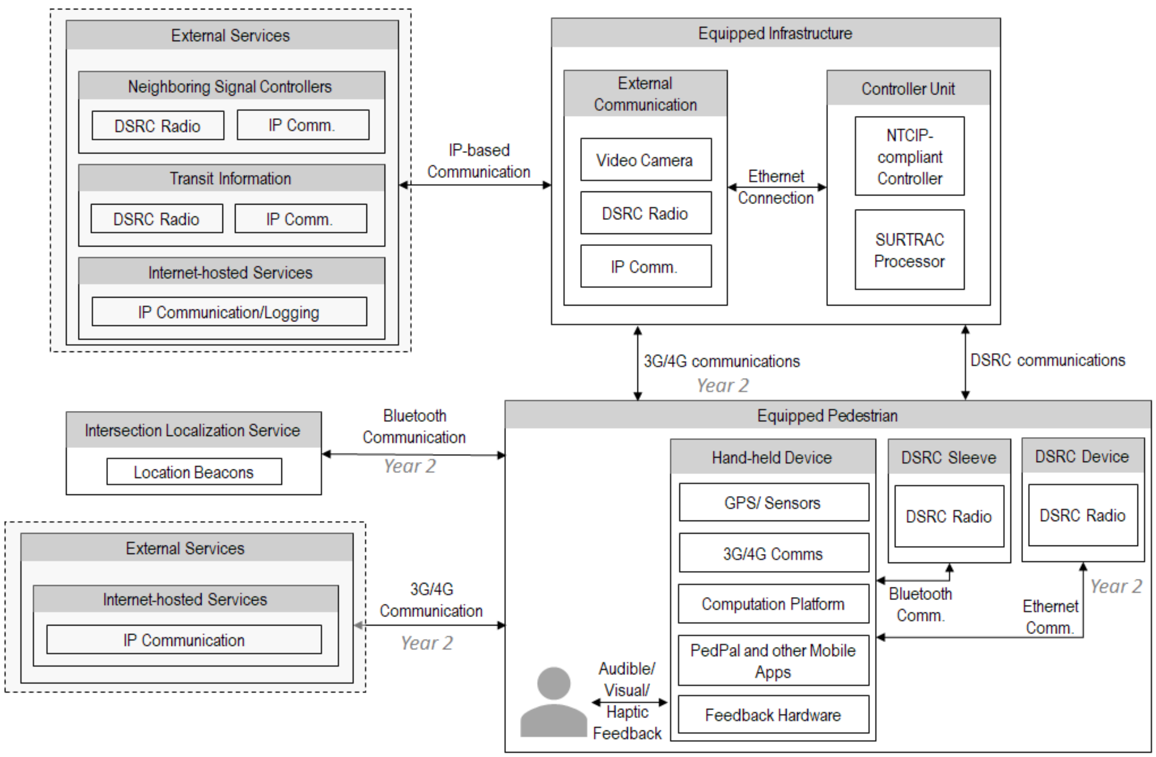


Figure 3-1: Physical Architecture of the Safe Intersection Crossing System

3.1 Intersection Infrastructure Subsystem

3.1.1 IIS Architecture

Figure 3-2 depicts the physical architecture of the IIS.

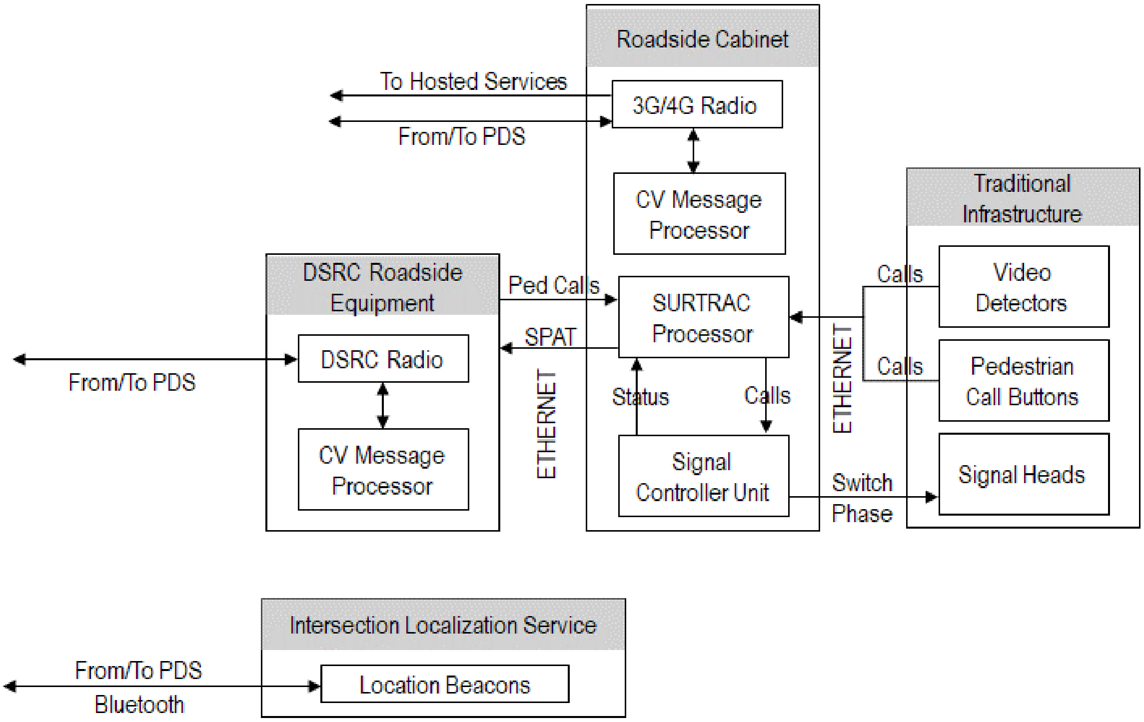


Figure 3-2: Physical Architecture of the IIS

The pedestrian device will communicate to a suite of infrastructure-based components via Dedicated Short-Range Communication or IP-based 3G/4G cellular communications. As shown, the infrastructure components consist of three systems - (a) A DSRC Roadside Equipment (RSE) unit, (b) the Roadside Cabinet containing the SURTRAC processor with a 3G/4G cellular radio and (c) the traditional Infrastructure (hardware controller and traffic signals). Communication between the three systems is based on wired Ethernet.

The DSRC-based RSE has several functions – (a) to receive Basic Safety Messages (BSM) from Connected Vehicles and SRMs from pedestrians for integration into SURTRAC's predictive models of approaching traffic, (b) to broadcast SPaT and MAP messages continuously, and optionally (c) to send an SSM to acknowledge receipt of SRM and whether the request was granted or denied.

IIS-1 – SURTRAC Adaptive Traffic Signal Control 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. Architecturally, the SURTRAC component is organized internally and interacts with intersection infrastructure and neighboring intersections as depicted in **Error! Reference source not found.**. Detector inputs are received by the Communicator module and forwarded to the Scheduler module for construction of the predictive model. The scheduler then generates a timing plan to optimize movement of these predicted traffic flows through the intersection and forwards this plan to the Communication module. The Communication module (1) sends the plan to the Executor module, which begins to issue commands to the traffic controller, and (2) sends the projected traffic outflows implied by the plan to the intersection's downstream neighbors.

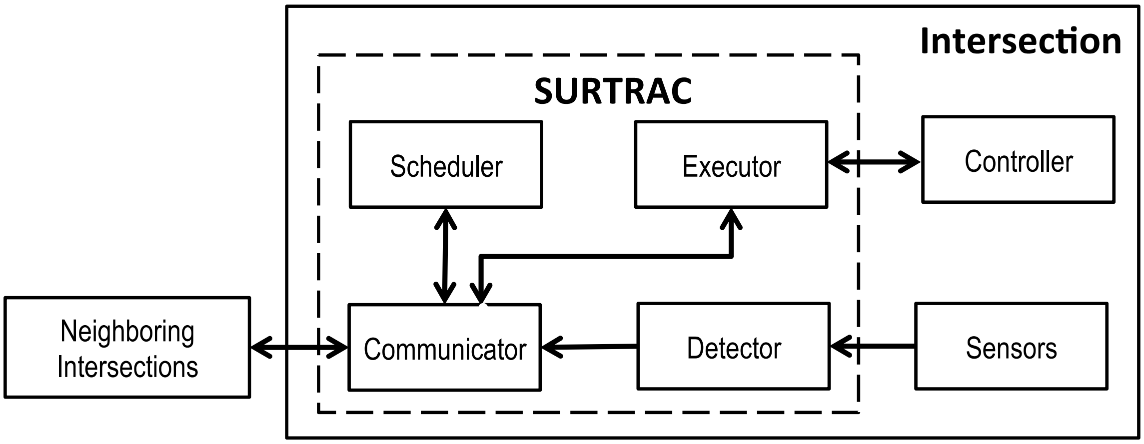


Figure 3-3: SURTRAC Component Architecture (source: Smith 2013 [10])

Further details on the SURTRAC component can be found in Xie 2012-06 [8], Xie 2012-10 [9] and Smith 2013 [10].

Within the Roadside Cabinet, the SURTRAC processor realizes an iterative planning cycle wherein it (1) accepts detector data (from cameras, pedestrian call buttons, and other sensors at the intersection), (2) generates (in real-time) a timing plan for moving currently sensed traffic through the intersection efficiently, (3) issues commands to the Signal Controller (the device that actually drives the signal heads), and (4) communicates predicted outflows to downstream intersections. SURTRAC uses the current timing plan at any point to generate SPaT messages.

The embedded computer running the SURTRAC system interfaces directly with the hardware controller at the intersection, utilizing either the National Transportation Communications for Intelligent Transportation Systems Protocol (NTCIP) 1202 standard for North Electrical Manufacturers Association (NEMA) controllers, or more controller-specific protocols in the case of non-NEMA controllers such as the 170 Controllers used by the City of Pittsburgh. At the beginning of every planning cycle (which is invoked every second), the SURTRAC system accepts standardized traffic detection inputs representing traffic counts, location and heading information that are produced by commercially available vehicle detection technology (e.g., video cameras, radar, induction loops). Using this information, SURTRAC generates a prediction of stop-line arrivals in all directions. This predictive model is then used to generate, in real-time, a timing plan for moving the traffic that has been sensed through the intersection in an optimized fashion (currently minimizing cumulative wait time). Commands (calls) corresponding to the first step of the plan are then communicated to the signal controller for implementation. The SURTRAC intersection scheduler also communicates projected vehicle outflows to its downstream neighbors. The SURTRAC agent resident at each downstream intersection integrates this expected traffic with the traffic it is sensing through its local detectors to generate its own local timing plan, which allows plans to be developed over a longer future horizon.

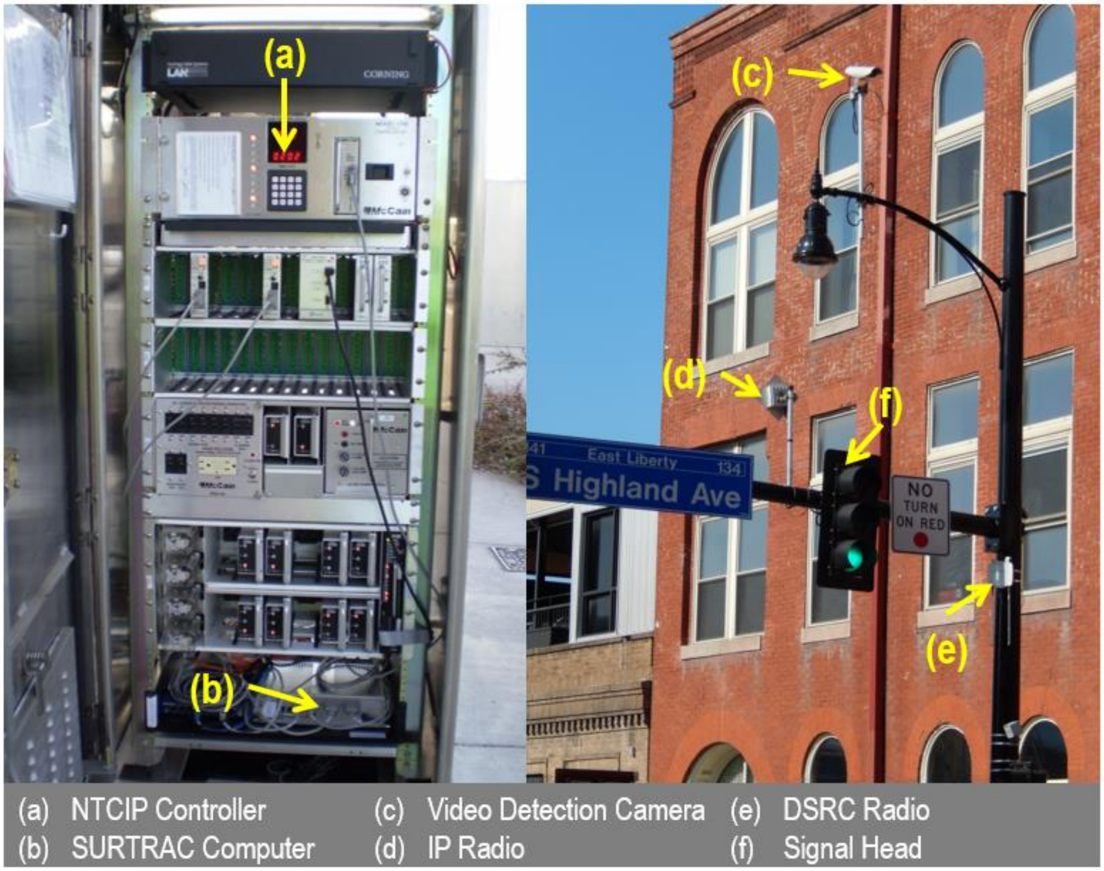


Figure 3-4: Schematic of Physical Hardware at Equipped Intersection

Figure 3-4 shows a schematic of the physical hardware at an equipped intersection. The six components shown are: (a) Traffic Signal Controller, (b) SURTRAC computer, (c) Video Detection Camera, (d) IP Radio for communicating with other signal controllers if fiber optic cable connections do not exist, (e) DSRC RSE radio and (f) Signal Head.

IIS-2 — Signal Controller

This device controls the state of the traffic signal heads, and as it is already integrated with the SURTRAC system, it will require no changes for the proposed system. The design of the traffic signal controller is outside of the scope of this document.

IIS-3 — DSRC Roadside Unit

The SURTRAC components deployed at the selected intersections have been equipped with DSRC radios. These radios have been used to establish basic vehicle-to-infrastructure (V2I) communications with DSRC enabled vehicles, including transit vehicles and emergency vehicles. The proposed system will not require changes to the DSRC Roadside Unit. The design of the DSRC Roadside Unit is outside of the scope of this document.

IIS-4 — 3G/4G Wireless Communication Unit

Data exchange between the pedestrian device's PedPal mobile app and the SURTRAC can also be enabled through IP-based communications. In this case, a cloud-based server will manage the communication between the pedestrian and the appropriate intersection computer running the SURTRAC component.

IIS-5 — Traditional Intersection Infrastructure

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

IIS-6 — Intersection Localization Infrastructure

Two beacons will be installed at each intersection corner (8 total at the intersection) with one pointing in each crossing direction). We will first test accuracy with relatively inexpensive Estimote beacons (https://estimote.com/) If time permits and there are still localization problems with this solution, we will investigate use of a more expensive higher accuracy capability provided by companies like 5D Robotics (now Humantics). Although we believe this approach will be too expensive for general transition of our technology, we also believe that a cheaper alternative is likely to appear on the market in the not too distant future.

3.1.2 IIS - PDS Communications

Communication between the IIS and PDS can be achieved using DSRC radio units or 3G/4G cellular communication as shown in Figure 3-5. Section 3.1.2.1 below provides the design of the baseline DSRC option for communication between the PedPal mobile app and the infrastructure, followed by Section 0 which provides the design of the 3G/4G cellular option for communication with the infrastructure.

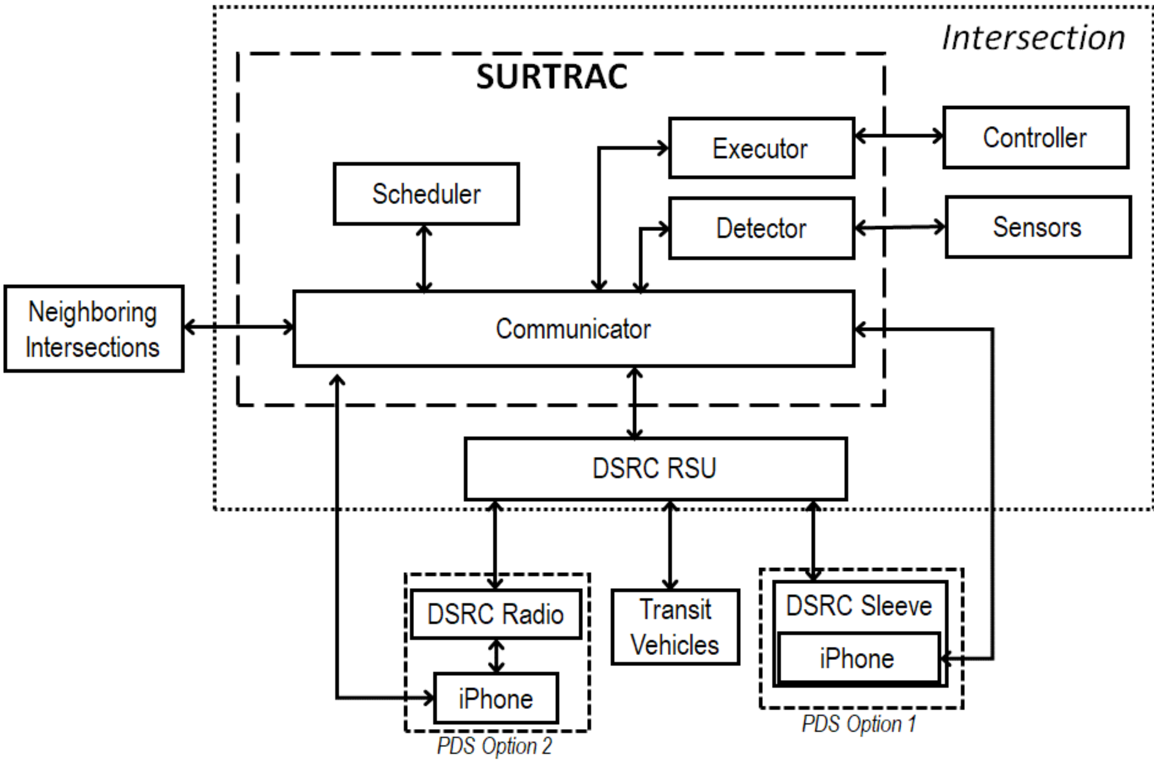


Figure 3-5: Extended SURTRAC Communication Framework

3.1.2.1 DSRC Communications

The primary wireless communications path between the IIS and the PDS uses 5.9 Gigahertz DSRC, as specified by IEEE Wireless Access in Vehicular Environments (WAVE) protocol suite [11], [12] and [13]. Specifically, using the WAVE Short Message Protocol (WSMP) to broadcast WAVE Short Messages (WSM) as defined in IEEE 1609.3 [12] that encapsulate data structures (e.g. MAP, SPaT, SRM and SSM) defined in the SAE J2735 2016 Data Dictionary [14 [5]].

Message encoding and decoding takes place at both endpoints of the transmission (i.e., within the SURTRAC Communication module on the infrastructure side and within the PedPal mobile app on the pedestrian side), and the DSRC devices (RSU and Sleeve). DSRC devices generally serve to

[5] Future releases of PedPal mobile app may be updated to conform to emerging SAE standards In the J2945 suite which will define usage of SPAT, MAP, SRM and SSM messages.

transport encoded messages between these two software processes.[6] The one exception to this communication scheme is the SPaT message. In this case, the Traffic Signal Controller Broadcast Message (TSCBM) is generated by the Executor module within SURTRAC (with input from the hardware controller) and communicated to the DSRC RSE, which in turn transforms the message content into a well formed, encoded SPaT message and forwards to the PDS' DSRC radio unit. This extended communication framework is depicted in Figure 3-5.

Furthermore, it is noted that BSMs are emitted every 0.1s by each DSRC-equipped vehicle to inform other DSRC-equipped vehicles (as well as the DSRC-equipped SURTRAC, and other similarly equipped roadside infrastructure components) about its location, speed, and heading, and other relevant information such as the vehicle mode (e.g., emergency vehicle or transit bus). While not currently used for the prototype system, they are part of the SURTRAC processing, and will be transmitted via DSRC, along with the four message types listed above, during prototype system operations. Furthermore, it is anticipated that in the future, and enhanced version of the prototype system may incorporate the use of the PSM as specified in SAE J2745 and SAE J2945-9. Finally, an enhanced version of the prototype system may also incorporate the exchange of pedestrian route information with the intersection using IP-based DSRC communications.

3.1.2.2 Cellular Communications

This subsection describes the cell-based (3-5G, LTE) communications infrastructure that is an alternative to the DSRC-based one. The advantage of using cell-based communications is that the smartphone does not need to be augmented with a DSRC radio and, therefore, makes PedPal less cumbersome to use and available to more users. At an implementation level, the most significant difference in this model is that, unlike in the DSRC-based model where information is pushed to PedPal from the radio, PedPal is responsible for pulling the information from a cloud-based service.

[6] Intuitively, it would seem that encoding//decoding would be performed on the DSRC devices themselves. However, after considerable effort, the project team was unable to find a way to accomplish this on either DSRC device (RSE or Sleeve), When the team was finally pointed to open source C code to do the encoding /decoding by Chris Stanley of Leidos , a design decision was made to adapt this code for both the iPhone and Linux programming environments and to put this functionality at the message transmission end points. This open source code is available at (ASN1C: https://github.com/vlm/asn1c).

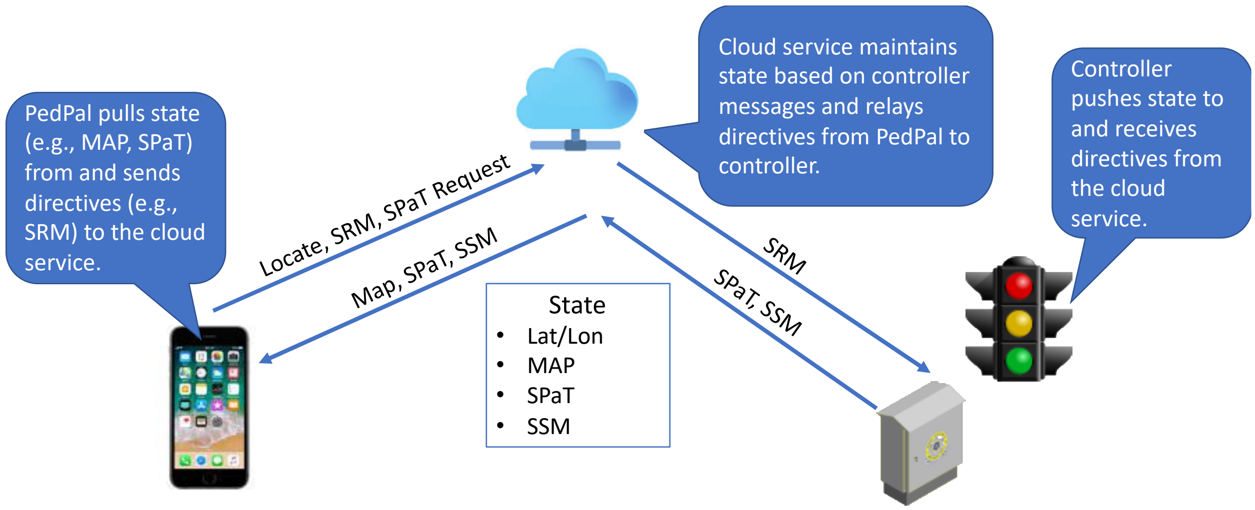


Figure 3-6: Cellular Communications Model

Figure 3-6 shows a high-level architecture for the cell-based communications model. In this model, a cloud service serves as the intermediary between PedPal and the signal controller (e.g., SURTRAC) at each intersection. The TCP/IP-based service runs on a publicly accessible cloud instance that is also connected to the intersection network through a VPN connection. The messaging standard remains the J2735 DSRC Messages Set and, in particular, the MAP, SPaT, SRM, and SSM messages described in more detail in Section 3.1.3. One additional message, Locate, has been added to allow for PedPal to query for MAP messages that are proximal to the user. In this message, the latitude and longitude of the user is sent to the service and the MAP message of the nearest intersection is returned. The Locate message also provides for specifying a list of intersection IDs to ignore as an additional argument to allow for filtering out intersections a user may have recently crossed. The cloud service also provides for directly querying for a MAP message by intersection ID and for a SPaT message, also by intersection ID.

To respond to the Locate and SPaT messages, the cloud service must maintain state about an intersection. In the case of Locate, the relevant state is the MAP message, which is static and simply stored in the cloud service. In the case of SPaT, where the state must be updated dynamically, the signal controller is responsible for pushing new SPaT messages to the cloud service. Finally, to support SRM/SSM messages, the cloud service relays SRMs sent from PedPal to the traffic controllers at the appropriate intersections and stores, as part of its state, the corresponding SSMs sent back from the traffic controllers, where PedPal can then retrieve (pull) them.

3.1.3 IIS - PDS Communications Messages

As indicated above, this communication involves the use of four standard message types below. (Requirements[7] SR-029, SR-030, SR-031, SR-032, SR-033)

1. MAP message - The MAP message provides a physical description of the intersection including the number of approach lanes in each direction, the number of left and right turning lanes, the pedestrian sidewalk and crosswalk locations, and their geometric attributes. The MAP message is broadcast once every second and is used in conjunction with the SPaT Data.
2. SPaT – The SPaT message communicates the current active green phase at the intersection, the time remaining in this active phase and the upcoming next active phase. This message is broadcasted every 0.1s.
3. SRM – The SRM is sent by an equipped pedestrian's device to request a right-of-way access through the intersection. In the case of this project, the message will specify the pedestrian's desired crossing direction (or directions if the intent is to get to the diagonal side of the intersection) and the requested crossing duration (which is computed as the pedestrian's travel speed x the width of the road being crossed).
4. SSM – The SSM is emitted by the intersection to acknowledge the receipt of an SRM and indicate whether the request was granted or denied. In the case that the request has been granted, the SSM also specifies the actual duration that was allocated, given that the signal system may not be able to grant the full requested duration.
5. Locate – the Locate message contains the latitude and longitude of the user is sent to the cloud service and the MAP message of the nearest intersection is returned. The Locate message also provides for specifying a list of intersection IDs to ignore as an additional argument to allow for filtering out intersections a user may have recently crossed.

In the following sections, we provide more detailed specification of many of these message types.

3.1.3.1 MAP Message

The MAP message is used to provide intersection and roadway lane geometry data for one or more locations (e.g. intersections and fragments of maps). Almost all roadway geometry information as well as roadway attributes (such as where a do not block region exists, or what maneuvers are legally allowed at a given point) are contained in the "generic lane" details of this message. MAP messages are used in intersections to number and describe lane level details of each lane. Figure 3-7 summarizes the overall structure and content of the MAP message schema.

[7] Throughout this document, system requirements are presented using the requirement's identifier as defined in the project's System Requirements Specification (SyRS) [2]. This identifier follows the format of "SR-NNN" where "NNN" is the sequential number of the requirement. Each list of one or more requirements will be shown in parentheses and will be preceded by the label "Requirement" or "Requirements" which will serve as a forward reference to the complete list of requirements presented in Section 6.

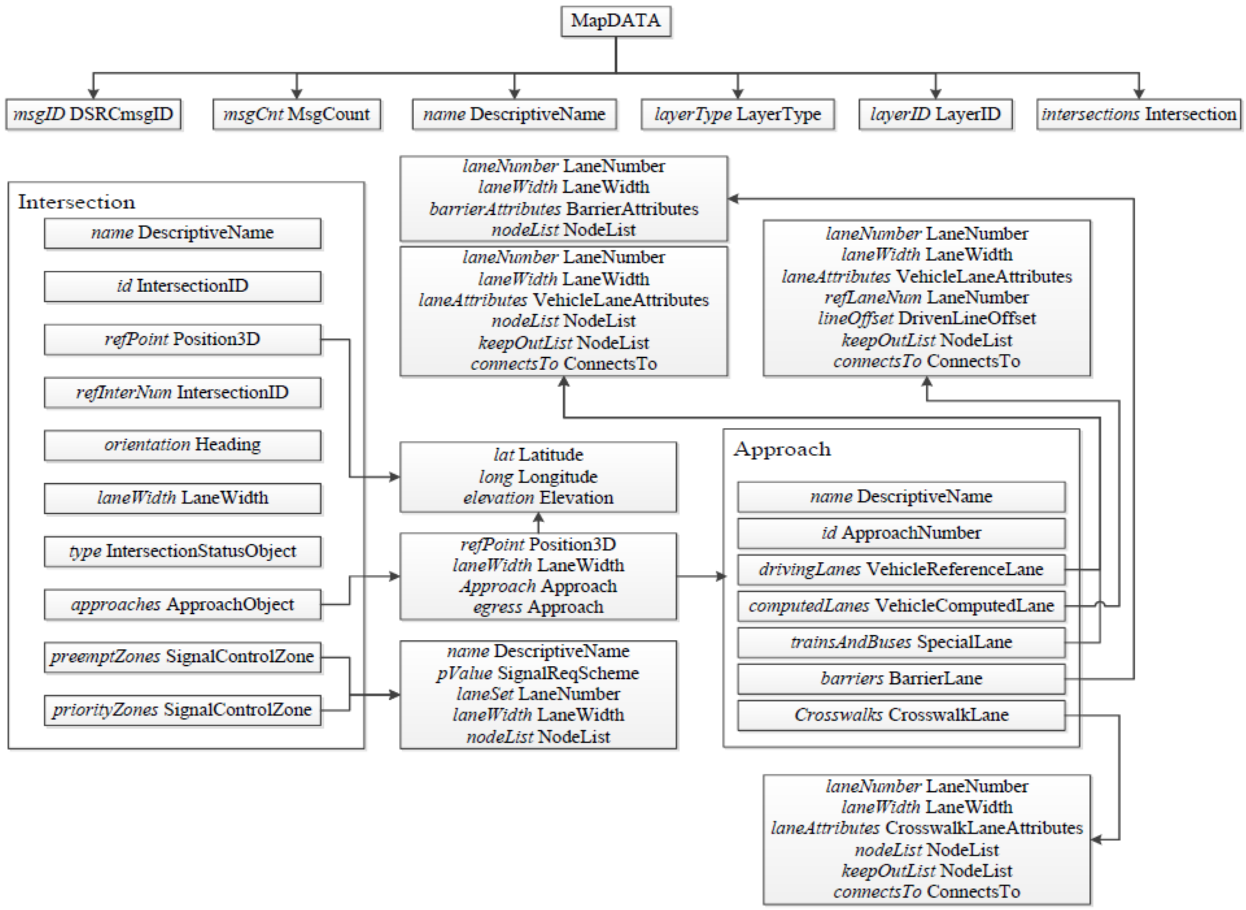


Figure 3-7: Schema of MAP Message

For the PedPal mobile app, the MAP message provides the following specific types of information:

- Lane width information for different intersection approaches to enable computation of requested crossing duration in a given direction (see Section 3.1.3.3 below)
- Street information to enable identification of intersection corners for assistance in orienting the user at the intersection
- Street information to enable user selection of crossing direction
- Signal group IDs for mapping crossing direction to relevant timing information in the SPaT message (see Section 3.1.3.2 below)

To discuss this information in more detail, consider the example MAP message depicted in Figure 3-8, which gives visual and xml representations of a MAP message that describes the intersection of Melwood Avenue and Centre Avenue in the Pittsburgh East End. A designated reference point (shown as the blue pin at the NE corner) is used to ground the message; all other locations in this MAP messages are aligned to this known <lat, long> location and specified as offsets. Three types of lanes (shown in orange) are specified in the message: vehicle (e.g., 2,3), crosswalk (e.g. 11), and sidewalk (which are labeled in yellow). Sidewalk lanes, as one might expect, designate the pedestrian approaches to the intersection.


```
<MessageFrame>
 <messageId>18</messageId>
 <value>
  <MapData>
   <msgIssueRevision>1</msgIssueRevision>
   <layerType><intersectionData/></layerType>
   <layerID>1</layerID>
   <intersections>
    <IntersectionGeometry>
     <name>Centre Ave.|Melwood Ave.</name>
     <id>
      <id>2812</id>
     </id>
     <revision>1</revision>
     <refPoint>
      <lat>404522524</lat>
      <long>-799508479</long>
      <elevation>2460</elevation>
     </refPoint>
     <laneWidth>366</laneWidth>
     <laneSet>

        ...A list of lanes, each described as a <GenericLane>

     </laneSet>
    </IntersectionGeometry>
   </intersections>
  </MapData>
 </value>
</MessageFrame>
```


Figure 3-8: Visual and XML Representations of the Center & Melwood MAP Message[8]

In the context of use by connected or autonomous vehicles, the names given to various approaches to the intersections are of no particular significance. <lat, long> information and other encoded geometric information are all that is needed to navigate. However, in the PedPal mobile app, understandable street names are essential for communication with the user and determination of crossing intentions, and hence must be extractable in meaningful form from the MAP message. For this purpose, we adopt the following naming conventions for lanes of type sidewalk:

- A sidewalk's name is a string that consists of sequential components:
  1. the name of the street to the left or right of the sidewalk (the primary name)
  2. vertical bar ("|")
  3. the name of the preceding (or next) cross street (the secondary name). For example, the western sidewalk approaches to Melwood Avenue from Craig Street on Centre Avenue are given the name "Centre Ave.| Craig St".

[8] Visualization produced using Leidos ISD Message Creator software: https://webapp2.connectedvcs.com

- The 2 sidewalks that form a given corner of the intersection have start nodes with the same <lat, long>

Using these conventions, the four corners of the intersection can be identified via the following simple 3-step procedure:

1. Collect all lanes of type "sidewalk"
2. Identify sidewalk pairs with the same starting location.
3. Extract the primary names of each sidewalk pair to get the street names for each of these corners

For example, if this procedure is applied to find the lower left intersection corner in the MAP message of Figure 3-8, the following two descriptions can be generated to assist in orienting the user:

- "Centre Ave. is in front, Melwood Ave. is on the right, and Bayard St. is behind"
- "Melwood Ave. is in front, Centre Ave. is on the left, and Craig St. is behind"

From the selected corner, the primary street component of the constituent sidewalk lane names identifies the desired crossing direction, e.g., Centre Ave. and Melwood Ave. respectively in the two choices just given). Once the crossing direction is known, the associated Signal Group ID needed to obtain relevant data from the SPaT message can be found via the algorithm specified in Figure 3-9.

To determine the signal group ID:

1. Find the <GenericLane> description for the sidewalk lane whose primary street designates the crossing direction (e.g., "Centre Ave.|Craig St." for crossing along Centre Ave.)
2. The <connectsTo> subfield will contain a single Connection, which has both the connecting lane ID (e.g., 19) and the Signal Group ID (e.g., 8)


```
<IntersectionGeometry>
  <name>Centre Ave. |Melwood Ave.</name>
  ...
  <laneSet>
  <GenericLane>
    <laneID>12</laneID>
    <name>Centre Ave. |Craig St.</name>
    <ingressApproach>8</ingressApproach>
    <laneAttributes>
     <directionalUse>1</directionalUse>
     <sharedWith/>
     <laneType>
       <sidewalk/>
     </laneType>
    </laneAttributes>
    <nodeList>
     <nodes>
       ... list of <nodes> whose coordinates delineate the center line of the lane
   </nodes>
    </nodeList>
    <connectsTo>
     <Connection>
      <connectingLane>
       <lane>19</lane>
      </connectingLane>
      <signalGroup>8</signalGroup>
 </Connection>
    </connectsTo>
   </GenericLane>
   ...
```


Figure 3-9: Finding the Signal Group ID for A Given Crossing Direction

3.1.3.2 Signal Phase and Timing Message

The SPaT message is used to provide the current SPaT data (i.e., times at which the signal phases are expected to change) for one or more signalized intersections, as well as other time of day status details. All SPaT messages link to MAP messages to convey the roadway details and to link the signal controller phases to the correct set of lanes. The SPaT message schema is provided below in Figure 3-10.

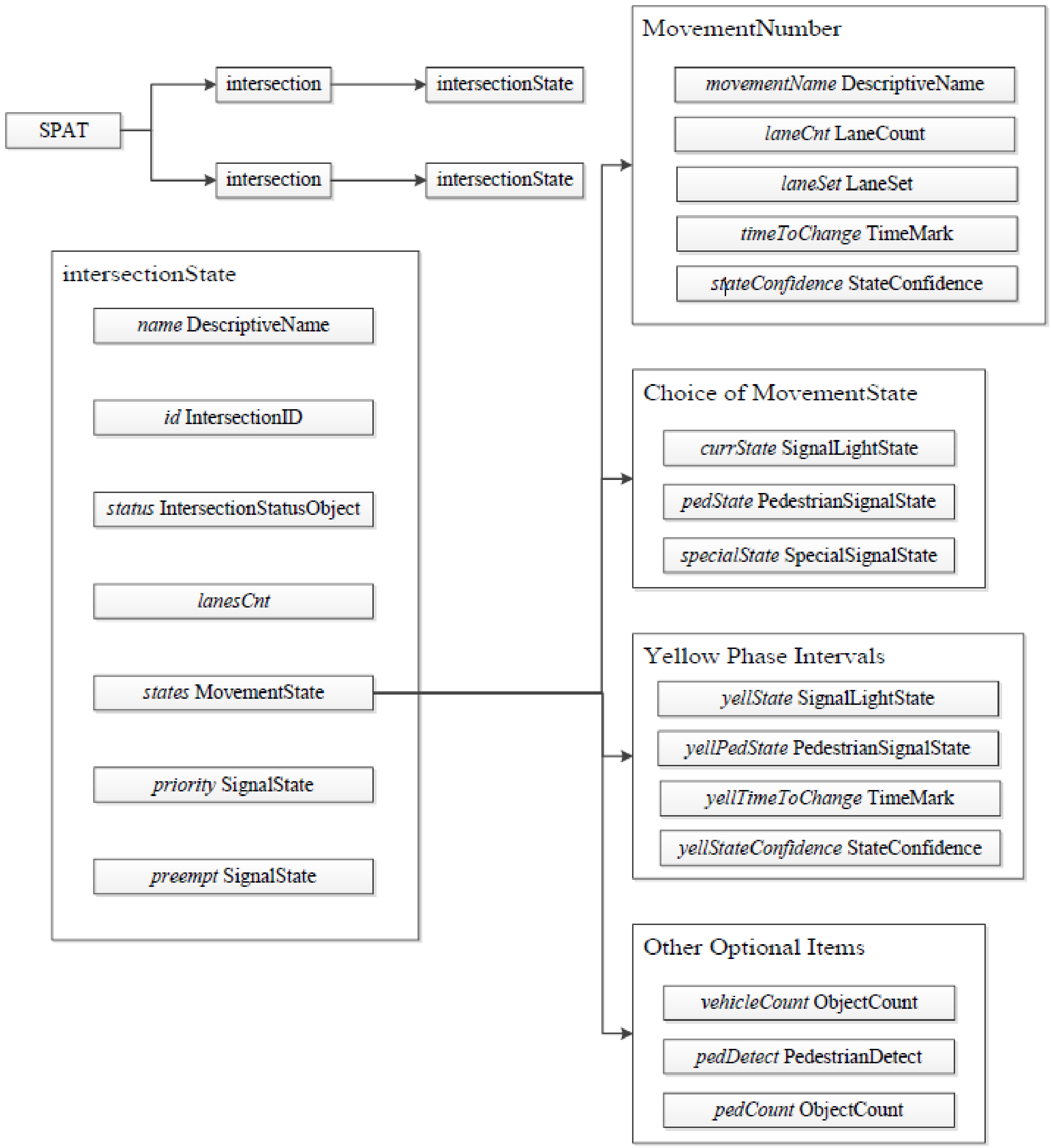


Figure 3-10: Schema of SPaT Message Dataset

For purposes of the PedPal mobile app, we are interested in conveying the time remaining for the crossing direction that is currently green. Continuing to use the example started during the MAP message discussion, the procedure for extracting time remaining from the SPaT message is given in Figure 3-11.

To find the countdown on the SPaT message:

1. In the <states> section of the message, find the <MovementState> entry whose signal group matches the requested signal group ID (e.g., 8)
2. Check that the value of the <eventState> of the entry is permissive-Movement-Allowed (i.e., green)
3. The countdown is the value of the <minEndTime> of the entry (e.g., 15000 msecs)


```
<SPAT>
 <intersections>
  <IntersectionState>
   <id>
    <id>0</id>
   </id>
   <revision>1</revision>
   <status/>
   <states>
    <MovementState>
     <signalGroup>8</signalGroup>
     <state-time-speed>
      <MovementEvent>
       <eventState><permissive-Movement-Allowed/></eventState>
       <timing>
        <minEndTime>15000</minEndTime>
       </timing>
      </MovementEvent>
     </state-time-speed>
    </MovementState>
    ...
   </states>
  </IntersectionState>
 </intersections>
</SPAT>
```


Figure 3-11: Retrieving Countdown Information from the SPaT Message

3.1.3.3 Signal Request Message

The SRM is used by authorized parties (e.g., emergency vehicles) to request services from an intersection signal controller. Vehicles approaching an intersection use this message to affect the signal operation. This is how traditional preemption and priority requests are handled for intersection safety in DSRC. For our PedPal mobile app, the SRM will be used to request a personalized crossing duration in the specified crossing direction.

To illustrate the relevant information, Figure 3-12 provides an example of an SRM in xml format. The request is issued by the PedPal mobile app (the “requestor”) to the intersection (the “id”), and it specifies both a crossing phase (encoded as a Signal Group ID in the “connection” field of the “in-bound-lane”) and a requested crossing duration in milliseconds (the “duration”). To compute the duration, geometric information from the MAP message is used to determine the crossing distance, and then this is multiplied by personalized rate of speed specified by the PedPal mobile app.

```
<MessageFrame>
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 <value>
  <SignalRequestMessage>
   <timeStamp>146256</timeStamp>
   <second>24909</second>
   <requests>
    <SignalRequestPackage>
     <request>
      <id>
       <id>5119</id>
      </id>
      <requestID>90</requestID>
      <requestType><priorityRequest/></requestType>
      <inBoundLane>
       <connection>8</connection>
      </inBoundLane>
     </request>
     <duration>25000</duration>
    </SignalRequestPackage>
   </requests>
   <requestor>
    <id>
     <stationID>45</stationID>
    </id>
   </requestor>
  </SignalRequestMessage>
 </value>
</MessageFrame>
```


(a) SRM Message


```
<MessageFrame>
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 <value>
  <SignalStatusMessage>
   <timeStamp>153459</timeStamp>
   <second>17876</second>
   <status>
    <SignalStatus>
     <sequenceNumber>0</sequenceNumber>
     <id>
      <id>5119</id>
     </id>
     <sigStatus>
      <SignalStatusPackage>
       <requester>
        <id>
         <stationID>45</stationID>
        </id>
        <request>90</request>
        <sequenceNumber>0</sequenceNumber>
       </requester>
       <inboundOn>
        <connection>9</connection>
       </inboundOn>
       <status><granted/></status>
      </SignalStatusPackage>
     </sigStatus>
    </SignalStatus>
   </status>
  </SignalStatusMessage>
 </value>
</MessageFrame>
```


(b) SSM Message

Figure 3-12: Schema for SRM and SSM Message Types

3.1.3.4 Signal Status Message

An SSM sent by the SURTRAC system is used to reflect the outcome of prior requests for service sent within the SRM. This message therefore serves to acknowledge signal requests. Figure 3-12 shows the basic structure of the message. The “status” field indicates the outcome of the associated SRM and can take on one of two possible values: granted or rejected. If an SRM is received too late in the current green phase, or the requested extension would violate intersection maximum time constraints, then it may be necessary for the intersection to reject the request.

3.2 Pedestrian Device Subsystem

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

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

The physical architecture of this device is presented in Figure 3-13 and example hardware units are shown in Figure 3-14 and Figure 3-15. The physical hardware consists of a smartphone and an optional DSRC device connected via Bluetooth. At a high-level, the PDS works as follows:

1. Equipped pedestrian configures the device with the type of feedback (audible, visual or tactile) and the average crossing speed at intersections. Speed is adjustable, by the pedestrian in the device settings, to fit current conditions (e.g., high heels versus running shoes, inclement weather), and in the future, the PedPal mobile app could include learning processes that refine crossing speed through accumulated crossing experience.
2. Pedestrian device consists of a computation platform (i.e., a smartphone) for hosting and running the PedPal mobile app and optionally either an attached DSRC device, or a sleeve with a DSRC radio to which the smartphone attaches (for communication to the infrastructure). Devices that are not DSRC-enabled, will communicate with the intersection using 3G/4G communications through a dedicated cloud service, while those that are so enabled can use 3G/4G communications as an alternative. A software toggle will be provided and initially used to facilitate prototype testing, and which will allow for configuration in deployments that support either, but not both, DSRC and 3G/4G cellular communications.
3. As the pedestrian approaches the intersection, the PedPal mobile app receives both MAP and SPaT messages that are being broadcast by the infrastructure.
4. This information is used by the PedPal mobile app to provide the pedestrian with street crossing options.
5. Upon selection of a street to cross by the pedestrian, the PedPal mobile app issues an SRM to the infrastructure, requesting a crossing duration that is consistent with the pedestrian's speed.
6. The PedPal mobile app will use incoming SPaT messages to convey remaining crossing time to the pedestrian.

Readers are encouraged to refer to the project's Year 2 Concept of Operations [1] document for detailed steps on the 14 use-cases identified for this system.

3.2.1 PDS Architecture

Figure 3-13 below depicts the subsystem architecture of the PDS. If DSRC is used, then the MAP and SPaT, and SSM messages are both received by the DSRC radio or the 3G/4G cellular radio, and then communicated to the smartphone via Bluetooth (sleeved radio) or Ethernet (cabled radio). SRMs are sent from the PedPal mobile app to the connected DSRC radio via Bluetooth or Ethernet, and then communicated via DSRC radio to the intersection. Alternatively, 3G/4G cellular communications can be used in lieu of DSRC communications, for both SPaT/MAP/SSM message reception and SRM message transmission.

The smartphone's GPS sensors and the DSRC device's GPS sensor, used in combination with landmark beacons installed at the intersection if necessary, will provide a basis for tracking the progress of the user during crossing, and for issuing a request to dynamically extend the green time if the user has encountered some difficulty and is moving slower than expected.

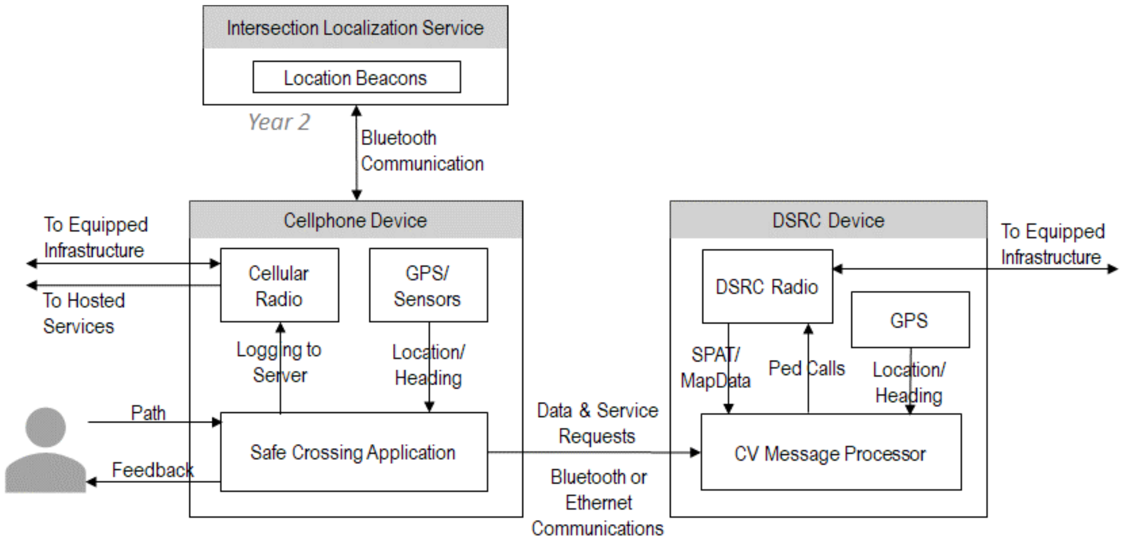


Figure 3-13: Physical Architecture of the Pedestrian Device Subsystem

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

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

Figure 3-14 shows an example of a smartphone that can be used as the computation platform when coupled with a DSRC-enabled sleeve to allow the device to send SRMs and receive SPaT, MAP and SSM messages. For the purpose of this project and prototype demonstration, an iPhone running the iPhone Operating System (iOS) will be utilized. The DSRC device will be a Leer Locomate ME sleeve, which will communicate with the smartphone via a Bluetooth server.

Figure 3-14: Proposed PDS Type 1
(source: www.aradasystems.com)

PDS Device Type 2: Figure 3-15 depicts the second prototype mobile device type, which will couple an iPhone to a small portable Cohda DSRC on board unit (OBU), Connectivity will be made using a Bluetooth (or Wifi) dongle connection to enable end-to-end connectivity between the PedPal mobile app and the SURTRAC signal control system. Scripts will be developed to enable the portable DSRC unit to translate messages between the PedPal mobile app and the DSRC radio.

Figure 3-15: Proposed PDS Type 2

3.2.2 PDS User Interface – Year 1

Fundamental to the viability of the PedPal mobile app is an effective UI. The UI must make it easy for the pedestrian to utilize the handheld device to orient herself/himself at the intersection, to communicate the crossing direction without having to manually push the traditional infrastructure pedestrian call button, and to know when it is safe and appropriate to cross. The interface will be developed according to the guidance provided in Section 4E.11 of the Manual of Uniform Traffic Control Devices (2009) and the Institute of Transportation Engineer's (ITE) Electronic Toolbox for Making Intersections More Accessible for Pedestrians Who are Blind or Visually Impaired, as well as Web Content Accessibility Guidelines (WCAG) and BBC standards and guidelines for mobile accessibility (Requirements SR-002 and SR-003) The PedPal mobile app, which is the core interface between the pedestrian and the signal control system, will follow universal design principles and be designed for different types of disabilities (Requirement SR-001).[9] It will provide multiple modalities for communicating information, specifically incorporating three types of interfaces: (a) a Visual Interface, (b) an Audible Interface and (c) a Tactile/Haptic Interface. The design of each of these interfaces is defined below.

3.2.2.1 Visual Interface

For pedestrians without a visual disability, a visual interface provides the most straightforward basis for utilizing the PedPal mobile app, and the design specified in this section reflects this basic requirement. This interface will be organized into two components:

1. *On-boarding:* This component of the PedPal mobile app will be used to gather initial information about the user and to set initial configurations for the PedPal mobile app accordingly.
2. *(Main):* This component will comprise the interface required to use the pedestrian crossing capabilities that the PedPal mobile app provides. It will provide a basic process for crossing to the user, encompassing steps of orienting and specifying the crossing direction, and indicating when it is time to cross, and also issuing visual alerts and notifications when exceptional conditions such as moving too slow or moving outside of the crosswalk occur. (Requirement SR-008)

In both components, the visual interface will facilitate use in visually difficult lighting situations. (Requirement SR-012).

<u>On-Boarding Interface</u>

The on-boarding interface will let the user input his/her information and preferences regarding types of alerts to issue, types of feedback to provide, and other application settings. In addition, the user will be asked to choose options to designate their crossing speed based on their disabilities. For example, the user can specify the traveler/pedestrian type (e.g. cane traveler, guide dog traveler, wheelchair user, walker user, etc.), which associates a default travel speed, as well as further tune the travel

[9] For the current project we intend to de-emphasize cognitive disabilities, since they are particularly unique and challenging. However, our goal is to eventually extend the design to address this segment of individuals.

speed that is set in the app. The on-boarding interface will also request user approval of services to be utilized by the app, such as Bluetooth, GPS, RSSI etc.

User Configuration/Settings Interface

The PedPal mobile app provides a number of user configuration options designed to personalize the application to the pedestrian user. Figure 3-16 displays the app's current "Settings" screen, which illustrates a number of customization options:

- Travel speed – As a baseline, the PedPal mobile app allows you (as the user) to adopt one of several personas (e.g., walk with cane, guide dog, wheelchair (motorized or not), deaf, etc.). Each of these personas has an associated nominal speed that can be combined with the crossing distance obtained from the MAP message to compute a requested duration. This baseline can be further tuned to fit current circumstances (e.g., weather, type of shoes, etc.) by adjusting the "crossing speed". (Requirement SR-101)
- Diagonal Crossing – For intersections that exhibit an "all-ped" phase, there is an option of whether the user would like to consider diagonal crossings or have those options filtered out. A second related option specifies whether the user would like options resorted upon completion of a cross to push the option in the direction of an original diagonal crossing to the top (and making it easier for a user with visual impairment.
- Device orientation – Some users will prefer the orientation of the display to adjust (from vertical to horizontal and vice versa) as the mobile device is manipulated, whereas others will prefer that the orientation be fixed.
- Voiceover (VO) – Through the iPhone's native "settings" interface, the user can enable voiceover and set the voice speed to match their preference (Requirements SR-005, SR-007)
- Font sizing – The iPhones native "settings" interface can also be used to adjust the font sizes used within the PedPal mobile app.
- Verbosity – Although not shown in the version of the settings screen in Figure 3-16, the frequency at which the countdown of the time remaining within the "Cross Street" screen is announced if VO is enabled can be adjusted. By default, the count is announced in VO mode every 5 seconds, to be compatible with slow speed VO settings (Requirements SR-006, SR-014, SR-019). The system will also have the ability to vary the amount of information provided based on the user's familiarity with the area (Requirement SR-020).

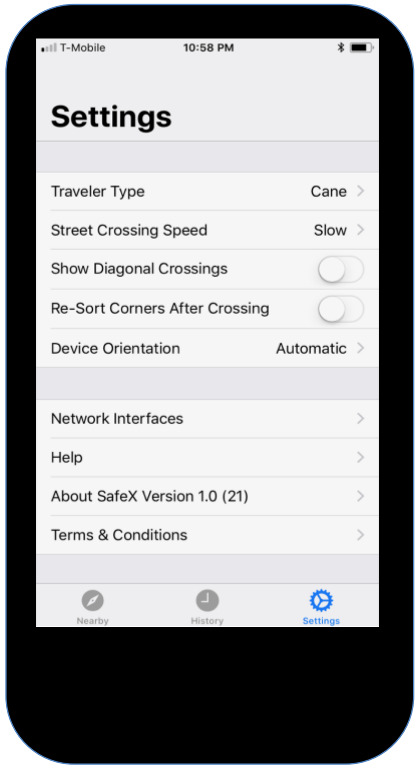


Figure 3-16: PedPal Mobile App User Settings Screen

Primary UI

The Primary UI, shown in Figure 3-17 will provide the capabilities necessary to successfully navigate across intersections while promoting safety. This UI design consists of a base display with four tabs: (a) Home Tab, (b) Nearby Crossings, (c) Settings and (d) Crossing Times Log, as shown in the Mock-Up display in Figure 3-17. The capabilities provided by each of these tabs (and consequently what visual content appears in the blank space on the mock screen in Figure 3-17) are described in more detail below.

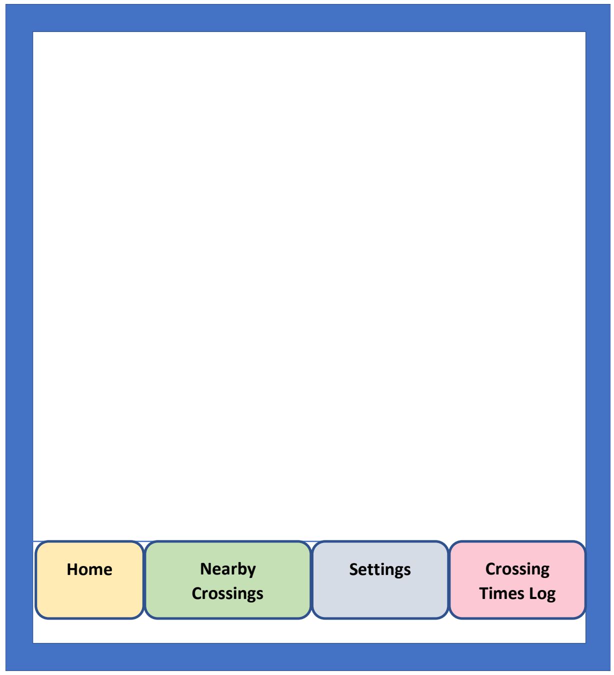


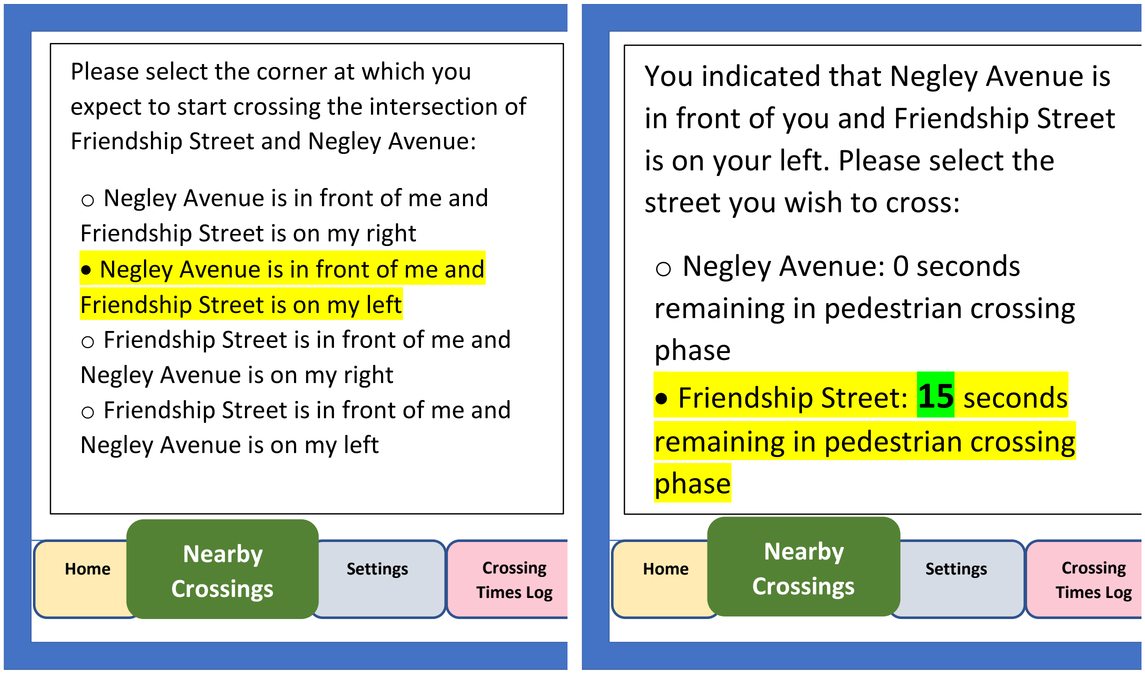
Figure 3-17: PedPal Mobile App Primary UI (Illustration)

1. Home Tab

This tab will have basic information about the PedPal mobile app and any priority information (e.g. liability, Institutional Review Board (IRB), etc.) that we need to provide to the user each time they use the app. We may also provide a list of instrumented intersections here.

2. Nearby Crossings

This tab will provide an enumerated list of corners in the nearest intersection being approached by the user. Each corner will be labeled relative to the user. The user will be prompted to choose one of the corners as illustrated below in Figure 3-18. Once the user chooses a corner, we prompt the user to choose a street to cross. The choices for the streets to cross will be labeled with both the street name and an updating timer indicating time remaining in the green phase to cross that street Figure 3-18.



(a) **Listing of all Nearby Intersection**

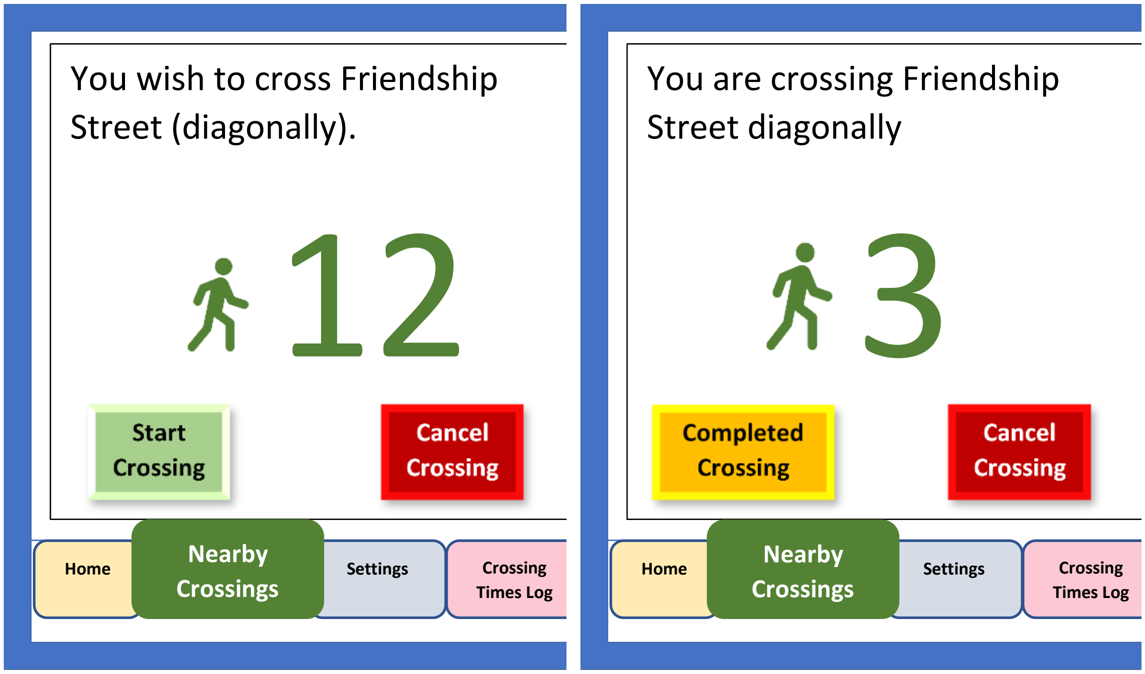
(b) Active Pedestrian Phase of Selected Intersection

Figure 3-18: PedPal Mobile App UI for Selection of Intersection (Illustration)

Once the user has selected the corner of the intersection (Figure 3-18a), the PedPal mobile app will then determine if the geometry and traffic signal phases allow for a crossing (either straight ahead, or diagonally) and will provide the user a further option to choose the direction to cross (Figure 3-18b). The diagonal option can be suppressed by the user in the settings based on preference since most blind travelers will not cross an intersection diagonally. Once the user has chosen the corner, street, and direction of crossing, the relevant green phase countdown will be expressed both visually and aurally via the PedPal mobile app as shown in Figure 3-19. The user will also be presented with two buttons to indicate if they want to start crossing or to cancel that crossing.

Once the user indicates that he/she has begun crossing, the interface presents two buttons for the user to indicate that they either completed that crossing or that they wish to cancel that crossing for whatever reason, as shown in Figure 3-19.

Once the user indicates that the crossing is complete, the list of corners will once again be displayed, but will be re-sorted to move previous corner (just crossed) down to the bottom. It also bubbles up the 3 or fewer remaining corners, with the corner that the user is known to be at, as the first on the list.



(a) Pre-crossing Indicator **(b) Post-Crossing Indicator**

Figure 3-19: PedPal Mobile App UI for Pedestrian Crossing Count-down (Illustration)

3. Settings Tab:

This tab will provide users with options to change settings relevant to the app. At least three setting options would be provided to users:

1. Re-sort corners list upon successful completion of crossing, on/off (People with some cognitive challenges will prefer to keep the list in a fixed order)
2. Pedestrian speed: low, medium, high, - an initial baseline approach to specifying crossing speed until dynamic tracking (and learning based on this data) is available.
3. Display diagonal crossings, on/off

These options are defined in Section 3.2.2.1 above.

4. Crossing Times Log:

This tab will provide users to see a log of crossings that are done using the app, along with an option to send CSV file of crossings to the project's application development team.

3.2.2.2 Audible Interface

For pedestrians who are blind or visually impaired, the PedPal mobile app will also feature an audible interface. To avoid any ambiguity and confusion, the audible interface will be designed based on relevant standards pertaining to pedestrians with disabilities (Requirements SR-002, SR-003, and SR-004). Table 3-1 shows the different speech and tones that the PedPal mobile app will produce to interface with the user based on the Manual on Uniform Traffic Control Devices (MUTCD) standards.

As shown in the table, audible speech is utilized when there are multiple crosswalks in the vicinity to avoid ambiguity around which crosswalk sign is on active and inactive sessions.

Table 3-1: Defined Audible Functions of the PedPal Mobile App

	WHEN TO USE?	IT IS UNSAFE TO CROSS THE INTERSECTION	IT IS SAFE TO CROSS THE INTERSECTION
SPEECH	When the crosswalk is less than 10 feet from another crosswalk.	"Wait to cross <*street name*>"	"<*Street Name*>. Walk sign is on to cross <*Street Name*>"
TONES	When the crosswalk is more than 10 feet from another cross-walk	"Tick-tones at 1/second interval"	"Rapid tick tones with a very brief burst of high-frequency sound at the beginning of walk indication that rapidly decays to 8-10 ticks/second.

Note: Volume should automatically adjust to ambient volume; 5 dBA louder than ambient volume, up to 100 dBA (dBA= A-weighted decibels)

The project team is also considering other open standards such as WayFindr Open Standards etc., to tailor the PedPal mobile app's response.

3.2.2.3 Haptic Interface

For pedestrians who are blind and deaf as well as for other disabled pedestrians under noisy situations, haptic feedback is a good way to indicate "walk" and "non-walk" signs. The handheld device vibration motors are used for such vibrotactile Walk/Don't Walk indication. The vibration-based alerts will also be coded into the PedPal mobile app interface to replicate the audible tone functionality for such purposes. Hence, the rapid tick-tones and slow tick-tones will indicate walk and don't-walk signs, respectively. (Requirement SR-009)

3.2.3 PDS User Interface – Year 2

Several enhancements were made to the Year 1 PedPal UI to enable additional features and address feedback from users in Year 1 of this project.

3.2.3.1 UI Changes

A list of the major changes are as follows:

1. Elimination of start/end crossing button
2. Elimination of history tab
3. Addition of option to get more information about a specific intersection
4. Handling complex intersections
5. Addition of an interface to bus information app
6. Addition of interface to routing app
7. Localization and tracking

These changes are described in greater detail in the following sections. The design of capabilities to anticipate pedestrian arrival at intersections using route information (Requirements SR-053, SR-056, SR-057, SR-061, SR-065, SR-091), to synchronize getting pedestrians to desired bus routes with real-time bus arrival information, and to support navigation of the user to and through the crosswalk at an intersection based on information about the built environment (Requirements SR-043, SR-044, SR-045, SR-046, SR-051, SR-079), are addressed in this section. The design of additional advanced user interface capabilities is also addressed at this time. (Requirements SR-020, SR-023, SR-024, SR-025).

Start/End Crossing Button

The Start/End Crossing button was intended to be a temporary measure in year 1 of this project. Therefore, this button is removed from the Year 2 version of the PedPal UI. This reduces the number of screen taps the user is required to make when using PedPal. Localization efforts on the project provide us with the necessary information to track the pedestrian's progress when crossing.

History Tab

Given the short duration of this project and the fact that the history tab does not provide a necessary element of the project and that users did not indicate a strong interest in this information during Year 1 testing, the history tab is eliminated in the Year 2 version of the PedPal UI.

Corner Information

Several users will benefit from extra information about specific corners and intersections. In the interest of providing verbosity control to users, instead of forcing this information on all users, PedPal provides an option for users to obtain this information if they find it useful. This is information such as the direction of the curb cutting, the geographical shape of the intersection, whether or not an island will be encountered during the crossing, whether there is a dedicated pedestrian phase to the crossing, whether there is a dedicated left turn signal, etc. If the user presses the button, the information will be shown in a drop-down text box and a second tap will collapse the box back into its button format. This information is available to the user once a specific crossing is selected. Only the information specific to the chosen crossing will be available. This button is located in the same location previously occupied by the start/end crossing button (which is eliminated in this version of the PedPal UI).

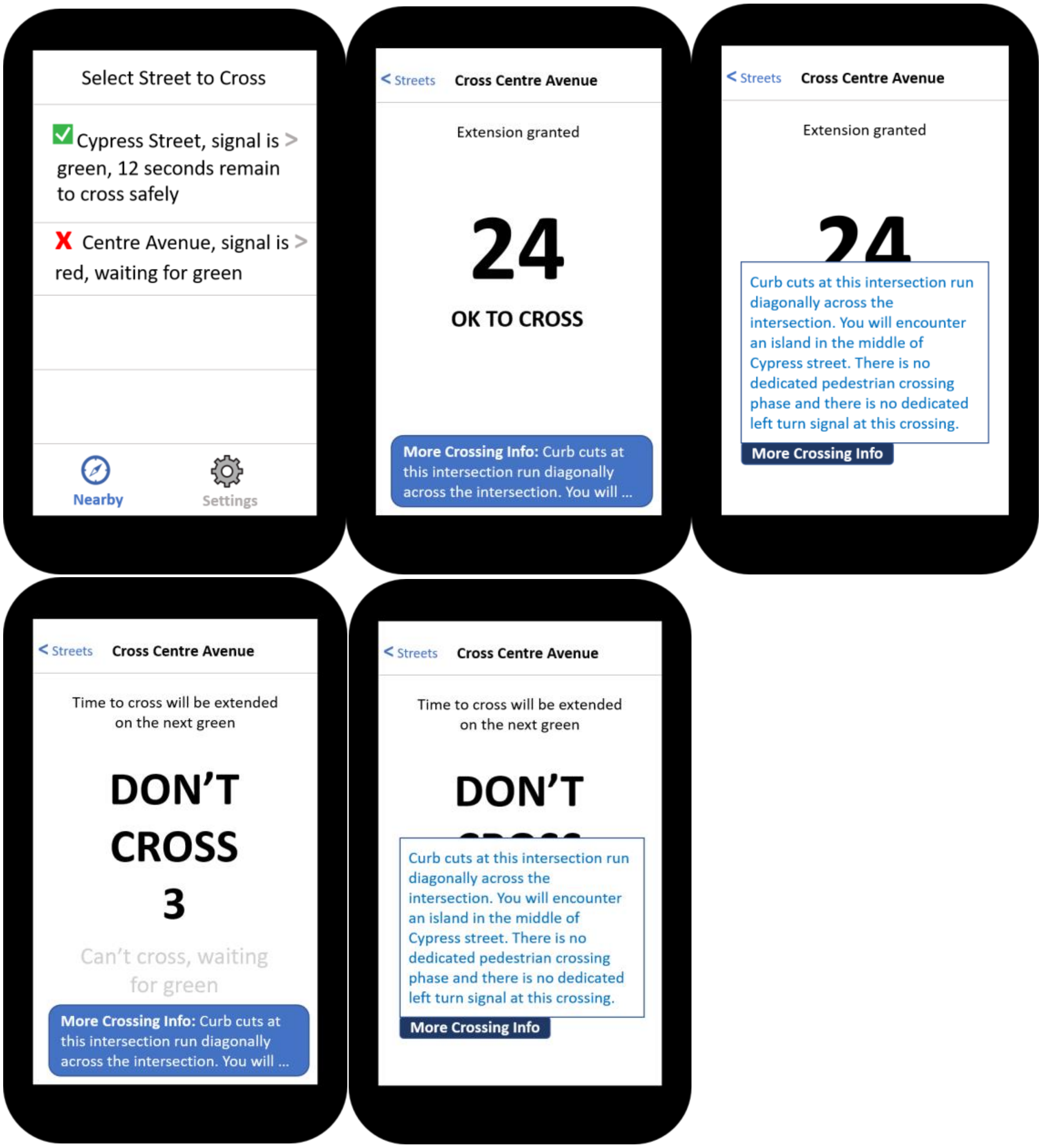


Figure 3-20: PedPal Mobile App UI Screens – Year 2

Complex Intersections

Given the scope of this project, we will not be handling extremely complex intersections such as roundabouts. Therefore, we will accommodate complex intersections simply by including relevant information about the intersection complexities in the additional information that can be accessed via the button mentioned in the previous subsection. The geometry of the intersection is also taken into account when determining the necessary duration for a green light for a specific pedestrian to cross an intersection.

Localization and Tracking

Using relevant localization techniques discussed earlier, the PedPal mobile app will be able to identify the corner where the pedestrian is standing, monitor crossing progress, and detect veering out of the safe crossing zone. These scenarios required adding short messages to be communicated to the pedestrian to keep them in the loop. Tactile vibrations are also a part of the interface to indicate situations such as veering out of the safe zone.

The final two new features of the PedPal mobile app are related in several ways. The PedPal mobile app will handle receiving bus or route informed via information imports from relevant external mobile apps. We will not however currently be interfacing with any existing external mobile apps for either of these features. Instead, we will create a relevant data format and simulate the transfer of that data in the relevant format to the PedPal mobile app for demonstration purposes. Users will be alerted when such information is received, and the user will be required to acknowledge these alerts. Localization and tracking features are further discussed in Section 3.2.4.3.

3.2.3.2 Route Information

A pedestrian might choose to inform the PedPal mobile app of a pre-planned route that he/she wishes to follow. Doing so enables SURTRAC to anticipate the user's arrival at each intersection along the route, and to take this information into account when generating the traffic signal's upcoming phase schedule. The route itself will not be directly planned by the PedPal mobile app since it is not a wayfinding or navigation app. Instead, a third-party app (e.g., Blindsquare) would be used to plan the route and the user would then export this route information into the PedPal mobile app. The route will be imported as a sequence of latitude/longitude "waypoints", with each successive pair of waypoints corresponding to the start corner and the end corner of the next SURTRAC -equipped intersection along the route.

When the PedPal mobile app receives such a route, it will alert the user that a route has been received and that the PedPal mobile app will be transitioning into "route following" mode. The user will then have an option to acknowledge/dismiss this alert. Once the alert is acknowledged, the user will only have access to a button to cancel the route and exit from the route following mode, and the button to learn more details about the specific corner as described in the relevant subsection above. While in route following mode, the PedPal mobile app will handle generation and communication of all crossing requests and selections in the background. At the appropriate mid-block distance to the upcoming intersection, an SRM will be generated, along with an expected arrival time at the start corner. PedPal will use its knowledge of the user's speed to compute expected arrival time. Upon receipt of the SRM, SURTRAC will update its predictive model of approaching traffic to include the user (with appropriate weight relative to vehicle traffic) and then use this updated model generate subsequent signal timing plans (or phase schedules). At the UI level, PedPal will simply alert the user about upcoming crossings and present the usual countdown information needed to cross the intersections safely.

The user will also be alerted any time that route following mode is exited and will also be informed as to whether the route was canceled or completed when this happens. This alert will need to be acknowledged/dismissed by the user.

For purposes of demonstration in Year 2 field tests, we will read a route (sequence of waypoints) from a file, such as would be generated by the export capability of Blindsquare.

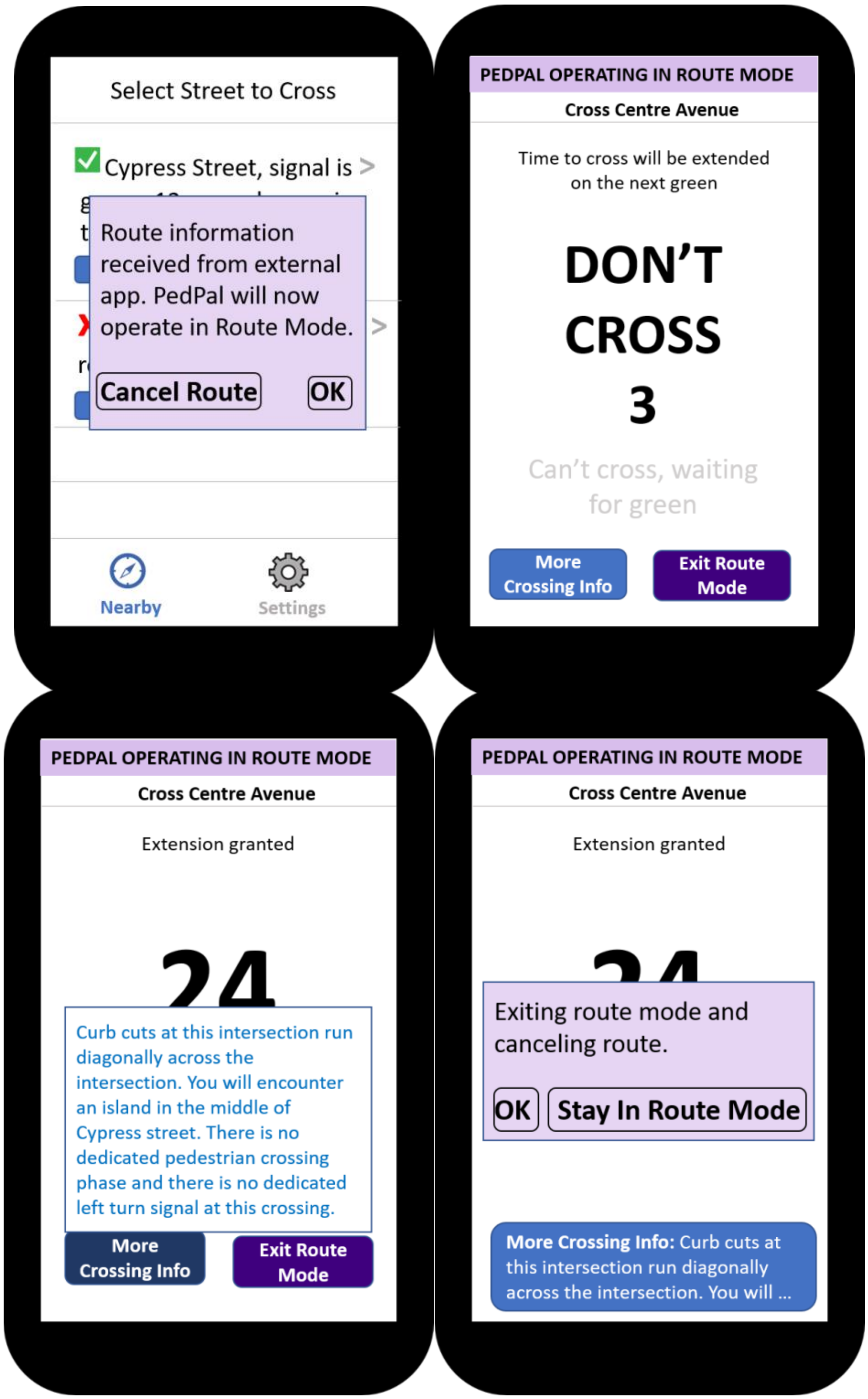


Figure 3-21: PedPal Mobile App UI Screens Supporting Route Following

3.2.3.3 Bus Information

The final feature to be introduced into the Year 2 version of the PedPal mobile app is the ability for users to inform the PedPal mobile app that he/she wishes to catch a specific bus at an intersection where PedPal is operational. The concept is to give SURTRAC the opportunity to combine this information with other real-time information being received independently from approaching buses, and if possible to align the signal phases so as to maximize the user's changes of catching the bus (e.g., by holding it at the light for some extra time to allow the user to get across the street and over to it for boarding).

As with the route following capability, we assume that the user will specify bus route (number) and bus stop via a third-party mobile app (e.g., Transit), and this app will export the information into PedPal. Once this information has been received by PedPal, it will be incorporated into each subsequent intersection crossing request that is sent by the app. When the user selects the street to cross at a given intersection, an SRM that includes this additional information will be sent to the intersection. In response, SURTRAC will first determine if the target bus stop is at this intersection, and if so, will determine the predicted arrival time of the next bus that is running the desired bus route. If the predicted arrival time is sufficiently close relative to SURTRAC's current prediction of when the user will complete the crossing and arrive at the bus stop, then SURTRAC will adjust the current timing plan to extend the relevant phase and hold the bus for an additional fixed amount of time. The only UI change this feature will manifest is that the PedPal mobile app will pop up an alert when bus information is received, and this alert will need to be acknowledged/dismissed by the user. The rest of the use-case for the PedPal mobile app will remain unchanged in this scenario. For demonstration purposes in the Year 2 field test, we will assume that target bus stop and bus route information will be read from a pre-configured file rather than generated by a third-party app.

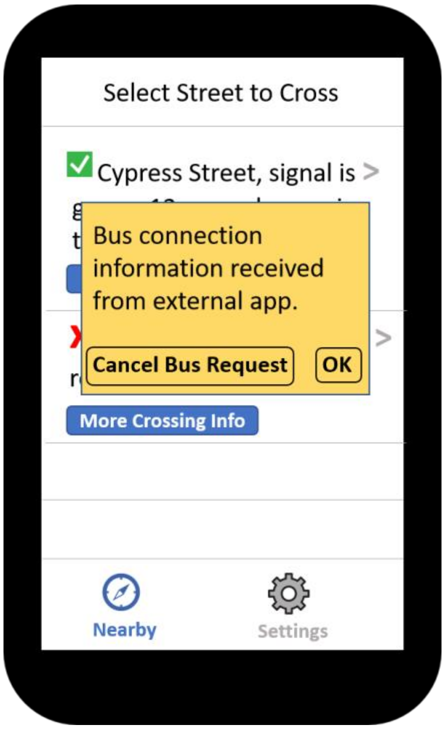


Figure 3-22: PedPal Mobile App UI Screen for Transit Bus Connection

3.2.4 PDS Functionality – Year 1

3.2.4.1 Interfacing with SURTRAC

On the intersection side, the PedPal mobile app also requires extension to the SURTRAC traffic signal control system. The most important consideration is how to handle generation of SPaT messages. Since SURTRAC is a real-time adaptive traffic signal system, it acts to extend or terminate the current green phase on a second by second basis, based on continual re-generation of timing plans that reflect current sensed traffic. Hence, unlike the case of a conventional traffic signal control system, the definition of remaining time in the current green phase (for inclusion in SPaT messages) is generally not well-defined and must instead be estimated (or predicted).

In general, this is a hard problem, but in the current context we can take advantage of the fact that the pedestrian is requesting a minimum crossing time to simplify the solution. In particular, the SPaT message requires specification of minimum and maximum phase ending times, and we can use the fact that the crossing duration requested by the pedestrian is to be treated as a new phase minimum constraint to ensure that the remaining time will never be less than required. It is of course possible that the actual phase end will be greater than this minimum. Consequently, the countdown of remaining time conveyed by SPaT messages over time can increase (as SURTRAC determines that due to the current sensed traffic it should further extend the current phase), but it will never decrease.

Currently, to better synchronize with the Pedestrian walk signals, SURTRAC uses its generated plans to predict when the phase is likely to end. Specifically, when the generated timing plan during any planning cycle predicts a phase change that is sooner than the fixed time required for the “flashing don’t walk” signal, SURTRAC will trigger the “flashing don’t walk” on assumption that the phase end is near.

A second complication with regard to the extensions required to the SURTRAC system stem from the fact that the City of Pittsburgh (our field test site) is currently standardized on McCain 170 controllers, which do not follow NTCIP protocols and have a non-standard interface. Whereas SURTRAC interfaces with NTCIP controllers and issues SPaT messages via the standard Traffic Signal Controller Broadcast Message (TSCBM) provided by the controller, this approach must be implemented in a customized manner in the case of the 170s. We are taking this approach and extending the Executor module of the SURTRAC system to provide the necessary interface to the Wapiti firmware that is used by the McCain170 Controllers currently in service.

Finally, it is necessary to define the semantics for responding to a given SRM. If the request is for a future phase, then the minimum green time for that phase needs to be overridden with the request on the next green cycle. If the request is for the current green phase the situation is more complex. In this case SURTRAC must determine whether enough green time exists to reasonably extend this cycle, or whether the pedestrian should be asked to wait until the next green cycle. The behavior to be implemented in the Year 1 prototype is specified in Figure 3-24.

In Figure 3-24, we make the following assumptions:

- *cutoff* represents some rule for deciding when it is too late in the phase to grant an accept. It could be the beginning of the flashing don’t walk period, or the time at which SURTRAC s prediction of end of phase kicks in and starts the transition to the next phase.
- SRM priority indicates whether the user has already started crossing (high) or has not yet started (low)

- We assume that the user is not alerted if the duration granted < requested duration; the user will see the change in the SPaT countdown.
- PhaseMin(p,t) is reset to the system default at the end of each green phase *p*
- *t* is used to index the current cycle - future phases are designated as occurring on cycle *t+1*; when a phase turns green the cycle = *t*

3.2.4.2 Crossing Selection

An initial safe intersection crossing UI-Prototype, which refines the visual mock-up designs summarized in Section 3.2.2 and incorporates standard IOS voice-over libraries to convey information audibly (Requirement SR-004), is shown in Figure 3-19 The "Nearby" tab is visible in these screenshots and the figure conveys the basic intersection crossing process. In brief:

1. As the pedestrian approaches the intersection, the PedPal mobile app is suspended, waiting for data. This state generally indicates that the device is currently "off-line" (Requirements SR-206, and SR-027)
2. When MAP and SPaT messages broadcast from the intersection are first received by the PedPal mobile app, it uses this information to convey crossing choices to the user (in this case, the PedPal mobile app takes advantage of the fact that the pedestrian has approached a simple 2-phase intersection, and hence it is not necessary to go through an orienting and corner identification step as in the mock-up presented in Figure 3-19, the PedPal mobile app knows this from information contained in the MAP message). The display of crossing options also indicates the current green phase and the time remaining before phase change. (Requirements SR-017, SR-018, SR-030, SR-034, SR-035, SR-041, SR-042, SR-055, SR-058, SR-059, SR-060, SR-062, SR-082, SR-095, SR-096)
3. When the pedestrian selects crossing direction, the PedPal mobile app automatically issues an SRM to the intersection and begins to display time remaining in the crossing direction. If the request were for a future phase, then the PedPal mobile app displays and /or announces "DON'T CROSS" indicating that the pedestrian should wait. When the crossing direction eventually gets the green, the PedPal mobile app alerts the user that it is "OK TO CROSS". (Requirements SR-052, SR-059, SR-054, SR-055, SR-062, SR-066)

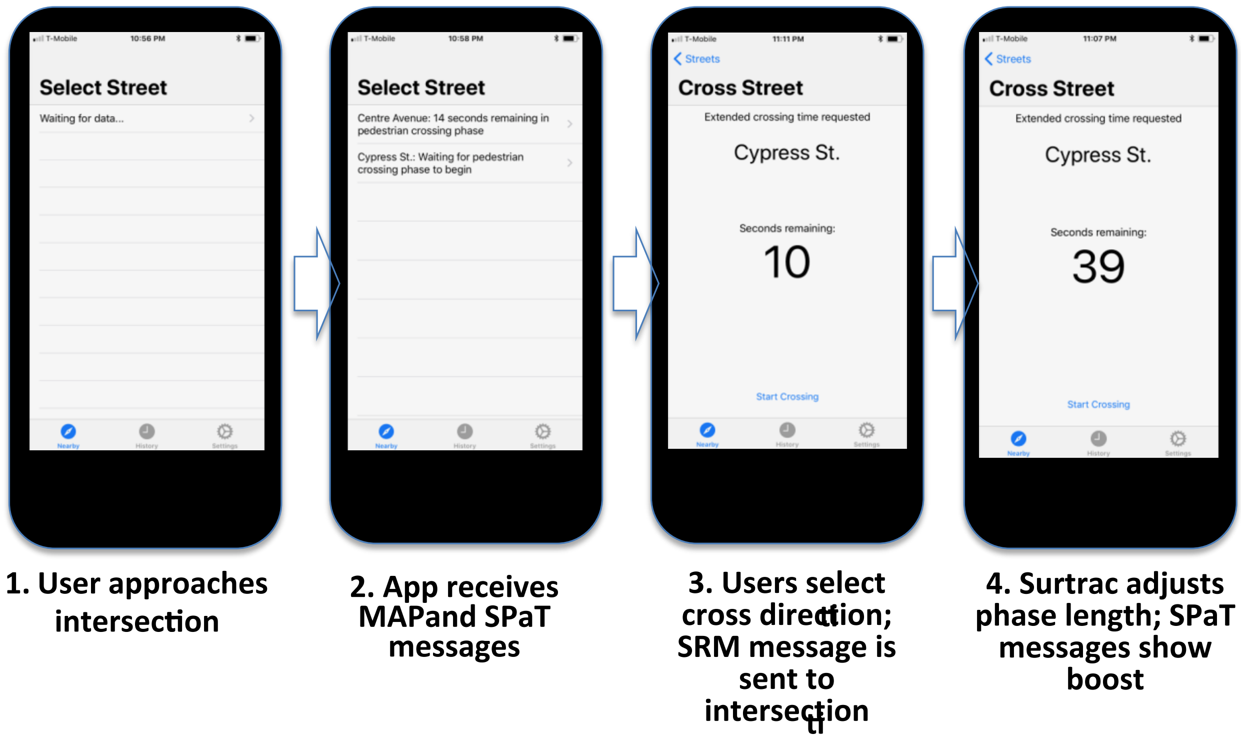


Figure 3-23: PedPal Mobile App UI Screen for User Crossing Process

4. After SURTRAC processes the request and adjusts the phase length, this boost in crossing time is reflected in subsequent SPaT messages and the time remaining is increased. (Requirements SR-063, SR-064)

5. When ready, the pedestrian clicks “Start Crossing” and begins to cross. When the pedestrian is across, “Crossing Completed” is clicked and the history is updated.[10] (Requirement SR-028)

The full intersection-crossing process implemented in the PedPal mobile app follows the design specified in the state transition graph depicted in Figure 3-24. One option specified in this transition graph is to navigate back to the “Select Street to Cross” screen, effectively canceling the prior request (Requirement SR-021), and of course it is possible to turn the PedPal mobile app completely off (Requirement SR-022).

[10] Once we incorporate the ability to dynamically detect location information, and the capability for sufficient location accuracy has been achieved, we anticipate that there will no longer be a need for the user to input “Start Crossing” and “Crossing Completed” information and that these buttons will be removed from the interface. The topics of localization and tracking are discussed in Section 3.2.4.2.

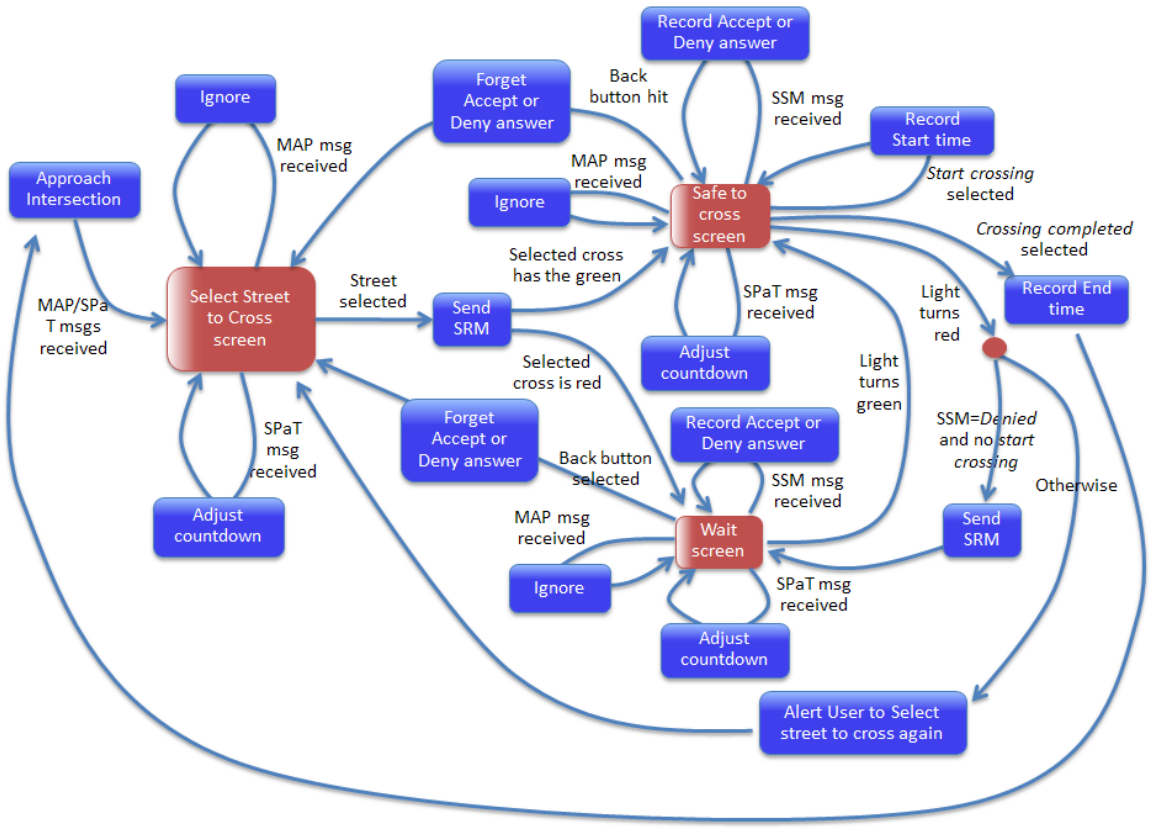


Figure 3-24: PedPal Mobile App State Transition Graph

3.2.4.3 Monitoring Crossing Progress

The second basic capability proposed for year one of the project involves monitoring of the user's progress as s/he moves across the intersection. Given knowledge of the requested crossing duration of the user and some ability to determine the location of the device, the PedPal mobile app should be able to infer whether the user has encountered an unexpected obstacle or otherwise is crossing at a pace slower than expected. If the PedPal mobile app detects this situation, then the desired reaction is to send an SRM requesting that the intersection dynamically extend the green for some period to allow the user to safely complete the crossing. Secondarily, the PedPal mobile app should be capable of alerting the user if s/he moves out side of the crosswalk.

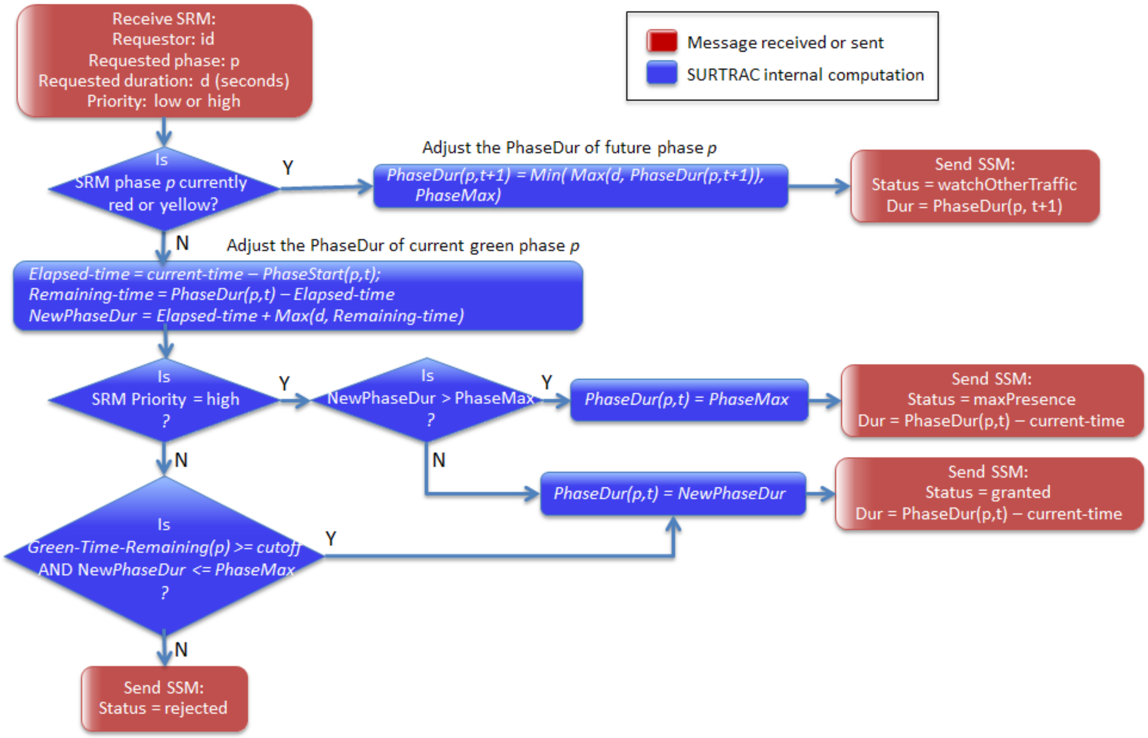


Figure 3-25: Algorithm for SURTRAC response to an SRM – General case of multiple simultaneous requests

The principal challenge to providing this capability is localization accuracy. Whereas both the iPhone8 and the Arada Locomate ME sleeve have independent GPS-based localization capabilities, it is well known that GPS accuracy can be less that satisfactory and is generally rated at no better than +/- 1-meter accuracy. Although initial tests of the iPhone8 localization accuracy at the intersection currently planned for the Year 1 evaluation have actually yielded satisfactory results, a better solution is required to make the PedPal mobile app generally applicable in practice.

To boost localization accuracy of the smartphone, we have considered the following possibilities:

- Use of Bluetooth beacons – In [Laio 2013], the use of two or more Bluetooth beacons were used to boost the accuracy of a smartphone and enable some amount of tracking of pedestrians through the intersection. Under this approach, the known fixed locations of the beacons provide some error correcting capability. However, although the results were effective at the time the work was done, it turns out that the resulting accuracy obtained was about +/- 1-meter accuracy, which is basically equivalent to the accuracy of current day smartphones. Hence, it is not clear how much additional improvement will be possible through addition of beacons. As a second more general argument against this approach, Bluetooth technology is nearing the end of its lifetime and it perhaps it makes sense to find a more forward-looking approach.
- DSRC-based correction – A second possible approach is provided by the RTCM Corrections DSRC message, which is designed to take an OBU GPS reading that has been communicated to the RSU and provide location correction information back to the OBU based on the RSU connectivity to an absolute satellite location. There is a grouping network

of access points nationwide, and several in the Pittsburgh area. Although the approach has been rejected by some urban areas (e.g., New York City) it is still under consideration in other areas of the country (e.g., California). Unfortunately for our purposes here, this approach requires the PDS to utilize a particular, large antenna, which does not fit well with the profile of the user-friendly mobile device.

- Utilization of multiple GPS readings – A third recent branch of research (e.g., [Hedgecock et. al 2013, Schrader et. al 2012]) has considered the potential of combining multiple independent GPS readings to improve location accuracy. This approach seems particularly relevant given that both the DSRC sleeve and the iPhone have GPS sensors and hence two simultaneous independent readings should be easily obtainable. In [Hedgecock et. al 2013] it is demonstrated (using raw GPS readings) that integration of two sensors can yield cm-level accuracy, although the conditions under which these results were obtained are not exactly the same as the current context. Nonetheless, this option is currently deemed as the best possibility and is the approach that we are currently pursuing.

- Given the above considerations, we have decided to proceed with the use of Bluetooth beacons as our approach to achieving more accurate localization in Year 2. Two Bluetooth beacons will be installed at each corner, and one will be pointed toward each crossing direction from the corner. These additions to the intersection infrastructure will be used to triangulate with the phones native localization readings to improve accuracy. This enhanced capability will be used (1) to identify which corner of the intersection the user is currently standing at, (2) to detect when the user begins to cross the street, (3) to track the user's progress and recognize when the user is moving too slow and a dynamic extension of the crossing time is required, and (4) to detect when the user has completed the crossing. Requirement (4) may be the most difficult to achieve, and our fallback plan here will be to re-introduce the crossing-completed button and rely on user input.

Incorporation of pedestrian progress monitoring also requires extension to the PedPal mobile app design. Suppose that a sufficiently accurate localization capability has been established and validated (using one of the approaches outlined above). This capability will then be incorporated into the PedPal mobile app to enable the following:

- Start and stop times of pedestrian crossings – Most basically, localization will be used to detect when a pedestrian starts to cross and completes a crossing, eliminating the need for the user to tap this information into the PedPal mobile app as in the initial prototype. These "Start Crossing" and "Crossing Completed" times, together with the pedestrian's specified speed and the width of the crossing, provides the basic information required for monitoring. These times will be obtained by automatically detecting start and complete times in Year 2. (Requirements SR-037, SR-042, SR-080, SR-081, SR-083)

- Detecting slow progress – Given the pedestrian's expected speed, the width of the crossing and crossing start time, the PedPal mobile app can determine whether the pedestrian is moving faster or slower than expected at any intermediate location. Accordingly, the PedPal mobile app will periodically query the pedestrian's current location, and if the progress being made falls below a specified threshold, an SRM will be issued to dynamically extend the green for an additional amount of time equivalent to the time that would be required to cross if the pedestrian continues at his/her current crossing speed. (Requirements SR-013, SR-067, SR-068, SR-069, SR-070, SR-072, SR-074, SR-075, SR-084)

- Detecting movement outside of the crosswalk – A third capability that is made possible by a sufficiently accurate localization capability is that of detecting movement outside of the crosswalk. To provide this capability, it will be necessary to augment the intersection MAP message to include crosswalk width information. Once this is done, localization can be used to detect this condition. If detected, the PedPal mobile app will issue an alert to the user (both visually and audibly) that indicates the appropriate recovery action. (Requirements SR-038, SR-039, SR-048, SR-049, SR-057, SR-071, SR-076, SR-077, SR-085)

3.2.5 PDS Functionality – Year 2

Two advanced capabilities will be added in Year 2 to the PedPal mobile aimed at enhancing the mobility of pedestrian travel. For both additional capabilities, the PedPal mobile app design will provide an API for importing this information and a protocol for communicating with the infrastructure and SURTRAC system.

3.2.5.1 Using Pedestrian Routes

The first of these capabilities will allow the PedPal mobile app to import a pedestrian's route, and to subsequently use it to anticipate the user's arrival at each intersection and inform the SURTRAC traffic control system which will use this information to better optimize the signal timing to the user's advantage. It requires that the user first construct the expected travel route within a separate third-party navigation mobile app (e.g., Blindsquare) and subsequently to export the planned route into the PedPal mobile app. Typically this is done by the user before commencing their travel. Once imported, this route information will be used by the PedPal mobile app to anticipate the user's arrival at each intersection and streamline any wait time. As the user approaches the next intersection in the route, the PedPal mobile app communicates the next segment of the predefined route to the intersection being approaching. Specifically, the PedPal mobile app will communicate (1) the crossing direction at that intersection and (2) the user's expected arrival time to the SURTRAC process controlling the intersection's signal timing plan. The intersection's SURTRAC traffic control system will insert this additional pedestrian traffic into its current predictive model (i.e., merging the pedestrian's direction and arrival time with those of other currently sensed vehicles and pedestrians). As the pedestrian is incorporated into SURTRAC's model of current traffic flows, this adds additional bias (or priority) to the crossing direction that favors the user. (SR-053, SR-065, SR-066)

Also, internal to the PedPal mobile app, crossing information that can be inferred from the route will be used to eliminate the need for the user to explicitly select a crossing direction at each intersection.

3.2.5.2 Real-Time Bus Arrival Times

The second of these mobility capabilities will allow the PedPal mobile app to import the user's intention to catch a transit bus on a specified bus route at a specified bus stop, again as entered and imported from an appropriate third-party app (e.g., Transit). The PedPal mobile app will forward this information on to the appropriate intersection's SURTRAC traffic control system, which would then determine (using DSRC based messaging) if the transit route of an arriving transit bus matches the pedestrian's desired route. The SURTRAC traffic control system will integrate the user's expected arrival time at the intersection with independently acquired real-time information on the bus predicted arrival time of the transit bus at the intersection's bus stop; to help synchronize arrivals when feasible. If the connection window is tight, the SURTRAC traffic control system will look for opportunities, adjust the signal phase length(s) to extend the intersection crossing time to increase the pedestrian's likeliness of boarding the arriving transit bus before it departs. If a user specifies a target bus route and a target bus stop, the PedPal mobile app will similarly try to use this information to the user's advantage, in this case to help synchronize the user's crossing of the intersection to maximize the user's chances of catching the bus. (Requirements SR-102, SR-103, SR-104, SR-105, SR-106, SR-107, SR-108)

4 Acronyms

Acronym	Description
ATTRI	Accessible Transportation Technology Research Initiative
BSM	Basic Safety Message
CMU	Carnegie Melon University
ConOps	Concept of Operations
CSV	Comma Separated Values
CV	Connected Vehicles
dBA	A-weighted decibels
DSRC	Dedicated Short Range Communication
EVP	Emergency Vehicle Preemption
GIS	Geospatial Information System
GPS	Global Positioning Systems)
iOS	iPhone Operating System
IRB	Institutional Review Board
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
ITS-JPO	ITS Joint Program Office
JSON	JavaScript Object Notation
MAP	Map Data
MUTCD	Manual of Uniform Traffic Control Devices
NEMA	North Electrical Manufacturers Association
NTCIP	National Transportation Communications for ITS Protocol
PSM	Personal Safety Message
RSE	Road-Side Equipment
RSSI	Relative Signal Strength Indicator
RSU	Roadside Unit
SAE	Society of Automotive Engineers
SPaT	Signal Phase and Timing
SRM	Signal Request Message
SSM	Signal Status Message

Acronym	Description
SURTRAC	Scalable Urban Traffic Control
TSCBM	Traffic Signal Controller Broadcast Message
TSP	Transit Signal Priority
UI	User Interface
USDOT	United States Department of Transportation
WAS	WAVE Service Announcement
WAVE	Wireless Access in Vehicular Environments

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6 Requirements Matrix

Table 6-1 provides the list of the system requirements. For each requirement the following information is provided.

- **Requirement ID**: The numerical identifier of the requirements prepended by the label "SR-".
- **Requirement Description**: the textual description of the requirement.
- **Requirement Status**: consisting of one of the following values.
  - Satisfied: requirement was met by the Year 1 prototype system.
  - Partially Satisfied: requirement was partially met by the Year 1 prototype system and will fully met as part of the Year 2 prototype system.
  - Not Done: requirement will be met by the Year 2 prototype system.
  - Deferred: requirement was not met by the Year 1 prototype system, nor will it be met by the Year 2 prototype system. It will be considered for a future version of the prototype system.
  - Removed: requirement has been removed for the reason noted.
- **Notes**: Notes concerning the disposition or status of the requirement.
- **Requirements Type**: consisting of one of the following values.
  - Data: for requirements which describe the ingesting, storing and accessing of relevant data or information within the System. Please note that these requirements, listed below, are focused on system data. For information on data management of project activities, please refer the Data Management Plan, listed in Section 5 above.
  - Functional: for requirements which describe functions, behaviors or tasks to be performed by the System.
  - Interface: for requirements which specify external interfaces to the System, including the interface with the user.
  - Performance: for requirements which specify quantifiable characteristics of the System's operations.
- **Verification Method**: For each requirement, one of the following methods of verification will be listed, consisting of one of the following values.

- Analysis: This method will be used for requirements that are met indirectly through a logical conclusion or mathematical analysis of a result. Analysis method usually includes the use of analytical data, or simulations under defined conditions to show theoretical compliance. Analysis method is used where testing to realistic conditions cannot be achieved or is not cost-effective.
- Demonstration: This method will be used for requirements that the system can be demonstrated without external test equipment. Demonstration method describes a qualitative exhibition of functional performance, usually accomplished with no or minimal instrumentation. Demonstration (a set of test activities with system stimuli selected by the system developer) may be used to show that system or subsystem response to stimuli is suitable. Demonstration may be appropriate when requirements or specifications are given in statistical terms (e.g., mean time to repair, average power consumption, etc.).
- Formal Test: This method will be used for requirements that require some external piece of test equipment or real-world testing. Formal Test describes an action by which the operability, supportability, or performance capability of an item is verified when subjected to controlled conditions that are real or simulated. This verification method often uses special test equipment or instrumentation to obtain very accurate quantitative data for analysis.
- Inspection: This method is verification through a visual comparison. Inspection method describes an examination of the item against applicable documentation to confirm compliance with requirements. Inspection is used to verify properties best determined by examination and observation (e.g., - paint color, weight, etc.).

- **Subsystem**: consisting of one of the following values.
  - PDS (Pedestrian Device Subsystem) which includes the PedPal mobile app and DSRC extension attached to the smartphone that the pedestrian will hold and utilize for assistance. That is the subsystem with which that the user directly interfaces.
  - IIS (Intersection Infrastructure Subsystem) which includes all the hardware and software, most significantly the SURTRAC, that interacts with the intersection's traffic signal system and it will be installed at or near the traffic signal system at the intersection. That is the subsystem that interacts with both the intersection signal system, transit vehicles and the PDS. The SURTRAC component of the IIS Subsystem will be a revised version of the SURTRAC system that CMU previously developed.

Table 6-1: Requirements Matrix

#	Requirement	Req. Status	Notes	Req. Type	Verification Method	Sub-System
SR-001	The system shall ensure that provided information (alerts, navigation, etc.) follows universal design standards to allow accessibility for different types of disabilities.	Satisfied		Interface	Demonstration	PDS
SR-002	The system shall provide accessible interfaces and content that follows Web Content Accessibility Guidelines (WCAG)	Satisfied	The WCAG information can be found at https://www.w3.org/WAI/intro/wcag	Interface	Demonstration	PDS
SR-003	The system shall provide accessible interfaces and content that follows BBC Standards and Guidelines for Mobile Accessibility.	Satisfied	The BBC Guideline can be found at http://www.bbc.co.uk/guidelines/futuremedia/accessibility/mobile	Interface	Demonstration	PDS
SR-004	The system should follow Apple's recommended advice on accessible applications.	Satisfied	iPhone's native accessibility features are incorporated into PedPal. They consist of voice-over, font resizing, and screen zoom capability.	Interface	Demonstration	PDS
SR-005	The system shall have audio components to provide audible notifications and alerts.	Satisfied	Voiceover capability is integrated into the app.	Interface	Inspection	PDS
SR-006	The system shall have the option of slowly delivering aural (ear or hearing) information.	Satisfied	This is accomplished through the iPhone's native speed control functionality within the voiceover capability.	Interface	Inspection	PDS
SR-007	The system shall be capable of providing mono aural information.	Satisfied	This requirement is to accommodate people with hearing loss when there is a big tonal range situation.	Interface	Demonstration	PDS

#	Requirement	Req. Status	Notes	Req. Type	Verification Method	Sub-System
SR-008	The system shall be capable of providing visual alerts and notifications.	Satisfied		Interface	Demonstration	PDS
SR-009	The system shall be capable of providing vibratory alerts and notifications.	Partially Satisfied	A vibration alert is currently given as feedback when the user successfully hits the "start crossing" button. Depending on the accuracy of the localization mechanism that is adopted in Year 2, this button may be retained to provide a baseline for measuring pedestrian progress through the intersection. We also expect to introduce vibratory alerts in the case where a pedestrian veers outside of the crosswalk	Interface	Demonstration	PDS
SR-010	The system shall have the option of delivering visual information slowly.	Satisfied	The native iPhone voiceover capability can be used to vary the speed at which various information that is displayed visually will be delivered to the user.	Interface	Inspection	PDS
SR-011	The system shall have the option of repeating visual information when needed (i.e. requested by user).	Satisfied	This same voice over capability provides the ability to repeat visually-displayed information any time that the user swipes over it. Additionally, information about characteristics of the current corner (e.g., presence/location of curb cuts) can be repeatedly queried by the user.	Interface	Inspection	PDS
SR-012	The system shall facilitate visual interface (reading of the instructions, etc.) in visually difficult situations (e.g. bright light, dark, etc.)	Satisfied		Interface	Inspection	PDS

#	Requirement	Req. Status	Notes	Req. Type	Verification Method	Sub-System
SR-013	The system should be capable of providing the user with confirmation throughout tasks.	Partially Satisfied	This confirmation includes information such as: halfway through and crossing completed. The system currently provides confirmation of whatever actions are taken through the mobile app user interface. Once a localization mechanism is put in place, the app will take responsibility for recording the start and end times of crossing.	Interface	Demonstration	PDS
SR-014	The system shall provide the option to the user for adjusting (i.e. reducing or increasing) the number of notifications user receives.	Partially Satisfied	The ability to vary frequency of the countdown is already done. The ability to toggle information about diagonal crossing options on and off will be added and provide another way of adjusting the number of notifications that the user will receive.	Interface	Demonstration	PDS
SR-015	The system shall be able to receive commands from a user through text input.	Removed	This requirement has been removed as the PDS interface does not emphasize textual input. Any textual inputs (e.g. new destination) would be done via a third-party application.	Interface	Demonstration	PDS
SR-016	The system shall be able to receive commands from the user through voice communication	Satisfied		Interface	Demonstration	PDS
SR-017	The system shall be capable of announcing upcoming task or step.	Satisfied		Interface	Demonstration	PDS
SR-018	The system should be capable of displaying upcoming task or step with text descriptions.	Satisfied		Interface	Demonstration	PDS

#	Requirement	Req. Status	Notes	Req. Type	Verification Method	Sub-System
SR-019	The system shall be able to adjust level of assistance based on user profile (e.g., disability type).	Satisfied		Interface	Demonstration	PDS
SR-020	The system shall have the option of varying the level of assistance (e.g., verbosity).	Partially Satisfied	The frequency at which countdown information is presented can be varied in the PedPal mobile app's settings. In Year 2 we will add the ability to toggle whether the user is presented with diagonal crossing options on and off in the settings.	Interface	Demonstration	PDS
SR-021	The system shall provide the user with an option to cancel receiving directions and alerts.	Satisfied	This is accomplished by hitting the "back" button (which is actually labeled "streets")	Functional	Demonstration	PDS
SR-022	The system shall have the option to be completely turned off.	Satisfied		Functional	Demonstration	PDS
SR-023	The system shall have the option of providing direction using clock position.	Deferred	Deferred due to the challenge of acquiring sufficiently precise user location	Interface	Demonstration	PDS
SR-024	The system shall have the option of providing cardinal directions (e.g. East, Northwest).	Deferred	Deferred due to the challenge of acquiring sufficiently precise user location.	Interface	Demonstration	PDS
SR-025	The system should have the option of providing relative directions (e.g. left, right, behind, in front of).	Deferred	Deferred due to the challenge of acquiring sufficiently precise user location	Interface	Demonstration	PDS
SR-026	The system shall be capable of recognizing when there is no connectivity with the intersection (e.g., traffic signal system).	Satisfied	The PedPal mobile app infers that it is not connected to an intersection at any point in time based on the fact that no MAP or SPaT messages are being received.	Functional	Formal Test	IIS

#	Requirement	Req. Status	Notes	Req. Type	Verification Method	Sub-System
SR-027	The system shall be capable of communicating "no connectivity with the intersection" to the user.	Satisfied	Currently the PedPal mobile app shows "No nearby intersection detected" when it is not connected to the intersection	Functional	Formal Test	PDS
SR-028	The system shall have an option for the user to communicate her/his progress in case of unreliable or unavailable GPS.	Removed	This requirement has been removed due to fact that we do not want the user to be concentrating on interacting with the device during crossing, and instead want the user to concentrate on crossing.	Functional	Demonstration	PDS
SR-029	The system shall be capable of communicating with a traffic signal system.	Satisfied	This requirement is referring to DSRC radio equipped traffic signal systems enabling V2I communications. In Year 2 we are also adding a cellular P2I communication option.	Interface	Formal Test	IIS
SR-030	The system shall be able to collect the signal phase and timing data from the traffic signal system.	Satisfied		Interface	Formal Test	PDS
SR-031	The system shall be able to interact with the traffic signal system to influence signal timing and duration.	Satisfied		Interface	Formal Test	IIS
SR-032	The system shall be capable of communicating with a Smart Phone device.	Satisfied	Currently, this requires the smart phone to communicate via a connected DSRC radio subsystem. In Year 2, the smart phone's native cellular communication capability will also be used.	Interface	Formal Test	PDS
SR-033	The system should be able to adjust the signal timing plan based on the user's speed.	Satisfied		Functional	Formal Test	IIS

#	Requirement	Req. Status	Notes	Req. Type	Verification Method	Sub-System
SR-034	The system should be capable of providing the user with information about the upcoming intersection (cross/don't cross signaling, how many streets crossing and crossing options, etc.)	Satisfied		Interface	Formal Test	PDS
SR-035	The system shall be able to recognize the intersection (e.g., intersection of Maine and 3rd).	Satisfied		Functional	Formal Test	PDS
SR-036	The system should be able to locate the corner of the intersection at which the user is positioned (e.g., southwest corner of Maine and 3rd).	Partially Satisfied	This is difficult due to the challenge of acquiring sufficiently precise user location. In Year 1, the capability was provided for simple 2-phase intersections. In Year 2, the capability should be provided for more complex types of intersections based on more precise user location. The team plans to investigate alternate approaches such as DSRC signal-strength estimation, introduction of external Bluetooth beacons at the intersection, and localization based on multiple GPS devices to improve accuracy of GPS-based location services.	Functional	Formal Test	PDS
SR-037	The system should be able to identify where the user is standing (side walk or street).	Deferred	Deferred due to the challenge of acquiring sufficiently precise user location. More detailed information on the intersection geometry will be provided to the pedestrian. Will rely on the pedestrian to find the appropriate crossing position.	Functional	Formal Test	PDS

#	Requirement	Req. Status	Notes	Req. Type	Verification Method	Sub-System
SR-038	The system should be able to determine location of crosswalk corridor, which is the rectangular path defined by the crosswalk pattern borders, extended onto the sidewalk it adjoins.	Deferred	Deferred due to the challenge of acquiring sufficiently precise user location. More detailed information on the intersection geometry will be provided to the pedestrian. The system will rely on the pedestrian to find the appropriate crossing position.	Functional	Formal Test	PDS
SR-039	The system should be able to determine location of crosswalk corridor relative to the user.	Deferred	Deferred due to the challenge of acquiring sufficiently precise user location. More detailed information on the intersection geometry will be provided to the pedestrian. Will rely on the pedestrian to find the appropriate crossing position.	Functional	Formal Test	PDS
SR-040	The system shall be able to collect personalized intersection crossing constraints from the user.	Satisfied		Interface	Formal Test	PDS
SR-041	The system should be able to communicate to the user on which intersection the user is located.	Satisfied		Interface	Demonstration	PDS

#	Requirement	Req. Status	Notes	Req. Type	Verification Method	Sub-System
SR-042	The system should be able to communicate with the user the exact corner of the intersection at which (s)he is standing.	Partially Satisfied	This is difficult due to the challenge of acquiring sufficiently precise user location. In Year 1, the capability was to be provided for simple 2 phase intersections. In Year 2, the capability should be provided for more complex types of intersections based on more precise user location. The team plans to investigate alternate approaches such as DSRC signal-strength estimation, introduction of external Bluetooth beacons at the intersection, and localization based on multiple GPS devices to improve accuracy of GPS-based location services.	Interface	Demonstration	PDS
SR-043	The system should be able to communicate to the user contextual information on the built environment around an intersection.	Not Done	This capability could involve a third-part app similar to PathVu and could lead to a synergistic ATTRI demo at some point in the future. In Year 2, we will simulate interaction with such a 3rd party service to provide relevant information about the corner to the user (e.g., single curb cut, multiple curb cuts at crosswalk, etc.)	Functional	Demonstration	PDS
SR-044	The system should be able to provide guidance to the user in locating the crosswalk corridor (the rectangular path defined by the crosswalk pattern borders, extended onto the sidewalk it adjoins).	Deferred	Deferred due to the challenge of acquiring sufficiently precise user location. More detailed information on the intersection geometry will be provided to the pedestrian. Will rely on the pedestrian to find the appropriate crossing position.	Functional	Demonstration	PDS

#	Requirement	Req. Status	Notes	Req. Type	Verification Method	Sub-System
SR-045	The system should be able to provide a notification when the user locates the crosswalk corridor.	Deferred	Deferred due to the challenge of acquiring sufficiently precise user location. More detailed information on the intersection geometry will be provided to the pedestrian. Will rely on the pedestrian to find the appropriate crossing position.	Functional	Demonstration	PDS
SR-046	The system should have the capability of providing information about the corner (e.g., presence and type of curb cuts) to users with visual impairments to help him/her orient an navigate to the crosswalk	Not Done	This will be provided in lieu of SR-037, SR-038, SR-039, SR-044 and SR-045	Functional	Formal Test	PDS
SR-047	The system should have the capability to guide the user to the starting location of the crosswalk.	Removed	This requirement has been removed as it is redundant with SR-044	Functional	Formal Test	PDS
SR-048	The system should be able to provide an alert when the user is not inside of crosswalk corridor.	Not Done	This is difficult due to the challenge of acquiring sufficiently precise user location. The team plans to investigate alternate approaches such as DSRC signal-strength estimation, introduction of external Bluetooth beacons at the intersection, and localization based on multiple GPS devices to improve accuracy of GPS-based location services.	Functional	Formal Test	PDS

#	Requirement	Req. Status	Notes	Req. Type	Verification Method	Sub-System
SR-049	The system should be able to provide confirmation when the user is inside of crosswalk corridor.	Not Done	This is difficult due to the challenge of acquiring sufficiently precise user location. Once SR-048 is satisfied, then SR-049 will be satisfied by default - i.e., unless the system raises an alarm the pedestrian can assume he/she are still within the crosswalk.	Functional	Formal Test	PDS
SR-050	The system should inform users with intersection geometric information (e.g., curb cut locations).	Removed	This requirement has been removed as it is redundant with SR-046	Interface	Formal Test	PDS
SR-051	The system should inform users with obstacle information (e.g., work zone) about the intersection	Not Done	This information might be available from a J2735 message either broadcast over DSRC, or sent via cellular connectivity. In any event, this requirement will be considered low priority - in principle, this information would be provided by a third-party service, and would be treated in the same manner as curb cut database information. It is considered non-essential for Year 2 field test experiments	Interface	Formal Test	PDS
SR-052	The system shall be capable of alerting the user to wait when the signal indicates No Walk.	Satisfied		Interface	Formal Test	PDS
SR-053	The system should provide the ability to use pre-planned route and destination information (e.g., walking path)	Not Done	It is anticipated that the pedestrian will ultimately use a third-party app for navigation. For Year 2, we will define an API and simulate interoperability by loaded pre-planned route and destination information from a file.	Interface	Formal Test	PDS

#	Requirement	Req. Status	Notes	Req. Type	Verification Method	Sub-System
SR-054	The system shall be capable of alerting the user to wait when the signal indicates "Walk", but there is not enough time remaining for the user to cross.	Not Done	Notification will be via audio signal (if voice-over is enabled) and visual signal	Interface	Formal Test	PDS
SR-055	The system shall be capable of notifying the user of how much time is remained of a specific signal phase (walk or no-walk)	Satisfied	Notification will be via audio signal (if voice-over is enabled) and visual signal	Interface	Formal Test	PDS
SR-056	The system shall communicate with the user whether an intersection has a traffic island.	Not Done	Information on the presence of a traffic island will be communicated with other information about the corner (see SR-046). Notification will be via audio signal (if voice-over is enabled) and visual signal.	Interface	Formal Test	PDS
SR-057	The system shall be able to provide guidance, notifications, and alerts in order to assist the users in crossing the intersection.	Partially Satisfied	Countdown information together with don't cross/OK to cross information is provided as guidance. Alerting the user when movement outside of the crosswalk is detected will be added in Year 2.	Functional	Demonstration	PDS
SR-058	The system shall allow users to enter their crossing direction.	Satisfied		Interface	Demonstration	PDS
SR-059	The system shall allow users to indicate their intent to cross in the mobile application.	Satisfied		Interface	Demonstration	PDS

#	Requirement	Req. Status	Notes	Req. Type	Verification Method	Sub-System
SR-060	The system should be able to determine direction of the user relative to crossing direction.	Partially Satisfied	In progress, but dependent upon acquiring sufficiently precise user location. This functionality already works for simplified 2-phase intersections; and will be extended to more complex intersection in Year 2, pending resolution of the issue with localization accuracy.	Functional	Formal Test	PDS
SR-061	If the user intends to make two consequent crosses at an intersection, the system shall provide information that enables the user to determine which cross should occur first.	Satisfied	This requirement is to help the user to minimize wait time. However, instead of dictating a crossing direction to the user, the app presents both crossing options but also includes information about which crossing direction is currently green and how much time in that green phase remains. So, the user has all the information to determine which crossing should be taken first.	Functional	Formal Test	PDS
SR-062	The system shall be able to provide real time information (signal phase, timing, etc.) about the traffic signal system.	Satisfied		Functional	Formal Test	PDS
SR-063	The system shall be able to notify the user when Walk time is extended.	Satisfied		Functional	Formal Test	PDS
SR-064	The system shall be capable of informing the user to cross when the signal indicates Walk and there is enough time left for the user to cross.	Satisfied		Interface	Formal Test	PDS

#	Requirement	Req. Status	Notes	Req. Type	Verification Method	Sub-System
SR-065	The system should have the capability of coordinating the signal timing plans with anticipated user arrivals.	Not Done		Functional	Formal Test	IIS
SR-066	The system shall have the capability to notify the traffic signal system of the intersection crossing intention of the user.	Satisfied		Functional	Formal Test	IIS
SR-067	The system should be able to determine the user speed crossing an intersection.	Not Done	In progress, but dependent upon acquiring sufficiently precise user location. The team plans to investigate alternate approaches such as DSRC signal-strength estimation, introduction of external Bluetooth beacons at the intersection, and localization based on multiple GPS devices to improve accuracy of GPS-based location services.	Functional	Analysis	PDS
SR-068	The system should be capable of computing time required for a user to cross a specific intersection.	Satisfied		Functional	Analysis	PDS

#	Requirement	Req. Status	Notes	Req. Type	Verification Method	Sub-System
SR-069	The system should have the capability to track the user's progress through the crosswalk (from one corner to the other).	Not Done	In progress, but dependent upon acquiring sufficiently precise user location. The team plans to investigate alternate approaches such as DSRC signal-strength estimation, introduction of external Bluetooth beacons at the intersection, and localization based on multiple GPS devices to improve accuracy of GPS-based location services. It needs to be determined how often the progress should be updated (e.g., every second).	Functional	Formal Test	PDS
SR-070	The system should be capable of identifying the user's delays in crossing an intersection.	Not Done	In progress, but dependent upon acquiring sufficiently precise user location. The team plans to investigate alternate approaches such as DSRC signal-strength estimation, introduction of external Bluetooth beacons at the intersection, and localization based on multiple GPS devices to improve accuracy of GPS-based location services.	Functional	Formal Test	PDS
SR-071	The system should be capable of identifying the users' drift from the crosswalk when crossing an intersection.	Not Done	In progress, but dependent upon acquiring sufficiently precise user location. The team plans to investigate alternate approaches such as DSRC signal-strength estimation, introduction of external Bluetooth beacons at the intersection, and localization based on multiple GPS devices to improve accuracy of GPS-based location services.	Functional	Formal Test	PDS

#	Requirement	Req. Status	Notes	Req. Type	Verification Method	Sub-System
SR-072	The system should be capable of communicating with the user regarding his/her progress crossing an intersection.	Not Done	In progress, but dependent upon acquiring sufficiently precise user location. The team plans to investigate alternate approaches such as DSRC signal-strength estimation, introduction of external Bluetooth beacons at the intersection, and localization based on multiple GPS devices to improve accuracy of GPS-based location services.	Functional	Formal Test	PDS
SR-073	The system shall enable the user to notify the system of his/her delay crossing an intersection.	Removed	This requirement has been removed as pedestrians should not be encouraged to interact with the PDS while crossing the intersection, and the signal timing should be adjusted by the system without this interaction.	Interface	Demonstration	PDS
SR-074	The system should be capable of communicating the user's delay to the traffic signal system in real time.	Not Done	In progress, but dependent upon acquiring sufficiently precise user location.	Interface	Formal Test	PDS
SR-075	The system shall have the capability to allow for dynamic extension of minimum crossing time constraint if an unexpected delay is detected	Partially Satisfied	Everything but the actual detection of the unexpected delay has been implemented.	Functional	Formal Test	IIS
SR-076	The system should notify the user of her/his deviation from the crosswalk.	Not Done	In progress, but dependent upon acquiring sufficiently precise user location. Notification will be via audio signal and/or haptic feedback, but this has not been decided.	Interface	Formal Test	PDS
SR-077	The system should provide directional guidance to help the user get back in the safe zone path in case of a drift.	Not Done	In progress, but dependent upon acquiring sufficiently precise user location. Notification will be via audio signal.	Interface	Formal Test	PDS

#	Requirement	Req. Status	Notes	Req. Type	Verification Method	Sub-System
SR-078	The system should notify the user of his delay crossing an intersection.	Removed	This requirement has been removed as pedestrians should not be encouraged to interact with the PDS while crossing the intersection, and the signal timing should be adjusted by the system without this interaction.	Interface	Formal Test	PDS
SR-079	The system should have the capability to advise users on how to exit the crosswalk by providing guidance to the exit point (whether there is a curb or a cut-out, grade, etc.)	Defer	Deferred due to the challenge of acquiring sufficiently precise user location. More detailed information on the intersection geometry will be provided to the pedestrian. Will rely on the pedestrian to find the appropriate crossing position.	Functional	Formal Test	PDS
SR-080	The system shall be able to provide a notification when the user successfully crosses an intersection.	Not Done	In progress, but dependent upon acquiring sufficiently precise user location. Note that by "provide a notification" we do not necessarily mean the app should make an announcement. Currently, when the user clicks the "complete crossing" button, the UI switches back to the select crossing option screen (in case the user wants to do a 2nd cross at this intersection). With adequate localization we are hoping to remove this button. If additional notification of completion is necessary, then this should necessarily be a setting that can be turned off (because it could get annoying) by the user.	Functional	Formal Test	PDS

#	Requirement	Req. Status	Notes	Req. Type	Verification Method	Sub-System
SR-081	The system shall be capable of identifying a location (i.e. coordinates) of interest at the intersection	Partially Satisfied	Accuracy of identification will depend on accuracy of the app's localization method, and will be quantified as part of the app's performance evaluation	Performance	Analysis	PDS
SR-082	The system shall correctly identify the intersection at which the user is located.	Satisfied		Performance	Analysis	PDS
SR-083	The system shall correctly identify the intersection corner at which the user is located.	Partially Satisfied	Accuracy of identification will depend on accuracy of the app's localization method, and will be quantified as part of the app's performance evaluation	Performance	Analysis	PDS
SR-084	The system shall correctly determine whether a user has begun crossing an intersection and is delayed to the extent that the current GREEN phase must be extended.	Not Done	Accuracy of progress monitoring will depend on accuracy of the app's localization method, and will be quantified as part of the app's performance evaluation	Performance	Analysis	PDS
SR-085	The system shall correctly detect when a user veers outside of the crosswalk.	Not Done	Accuracy of detection will depend on accuracy of the app's localization method and will be quantified as part of the app's performance evaluation. There will not be multiple levels of alarming for increasing distance of deviation.	Performance	Analysis	PDS
SR-086	The system shall increase blind users' perceived safety crossing an intersection.	Partially Satisfied	This requirement is subjective and will be evaluated through surveys conducted with field test participants. Year 1 field test evidence indicated a "YES".	Performance	Analysis	PDS
SR-087	The system shall reduce the number of cycles a blind user waits to feel safe crossing the intersection.	Partially Satisfied		Performance	Analysis	PDS

#	Requirement	Req. Status	Notes	Req. Type	Verification Method	Sub-System
SR-088	The system shall increase the percentage of new intersections crossed by a user.	Removed	This requirement has been removed as it is somewhat of a derivative of SR-087, and there does not seem to be any way to measure its satisfaction other than to ask participants if the PedPal mobile app would encourage them to cross new intersections. Given this, it seems not useful and has been removed.	Performance	Analysis	PDS
SR-089	The system shall decrease the total time it takes for the user to cross an intersection (from arrival at the intersection to completion of the crossing) compared to the user's unassisted crossing time.	Partially Satisfied	Need to determine the achievable threshold by further analysis.	Performance	Analysis	PDS
SR-090	The system shall improve the user travel time through a sequence of intersections from the user's baseline travel time.	Partially Satisfied	Need to determine the achievable threshold by further analysis.	Performance	Analysis	PDS
SR-091	The system should ingest, store and access relevant information about the intersection and its corners, including presence and location of curb cuts at corners to facilitate entry into the crosswalk and presence of traffic islands in different crossing directions.	Not Done	This will be provided in lieu of SR-037, SR-038, SR-039, SR-042, SR-044 and SR-045, pending the availability of external resources. Companion requirement with SR-046.	Data	Inspection	PDS
SR-092	The system should be able to ingest, store, and access information on an intersection's traffic signal system.	Satisfied		Data	Inspection	PDS

#	Requirement	Req. Status	Notes	Req. Type	Verification Method	Sub-System
SR-093	The system should be able to ingest, store, and access information on an intersection's traffic signal system's operational status.	Deferred	Deferred as there is no mechanism or third-party service that currently provides dynamic information about a traffic signal's operational status. It is possible in the future through integration of the SURTRAC traffic control system with an overall traffic management system that such information could be provided. Hence, we propose to keep this requirement but defer it to a future follow-on effort.	Data	Inspection	PDS
SR-094	The system should be able to ingest, store, and access information on whether an intersection is equipped for DSRC communications	Satisfied		Data	Inspection	PDS
SR-095	The system shall be able to ingest, store, and access MAP message data.	Satisfied		Data	Demonstration	PDS
SR-096	The system shall be able to ingest, store and access SPaT message data.	Satisfied		Data	Demonstration	PDS
SR-097	The system should have a data validation process.	Partially Satisfied		Data	Inspection	PDS
SR-098	The system should be able to ingest, store and access data from external sources (e.g., through appropriate APIs)	Not Done		Data	Demonstration	PDS
SR-099	The system shall be able to ingest, store and access a user's travel plan,	Not Done		Functional	Demonstration	PDS

#	Requirement	Req. Status	Notes	Req. Type	Verification Method	Sub-System
SR-100	The system shall collect information about what kind of assistive technology or mobility aid the pedestrian is using.	Satisfied		Data	Inspection	PDS
SR-101	The system shall be able to determine, prior to the user's arrival, if an upcoming intersection is adjacent to the user's bus route transfer point	Not Done		Functional	Demonstration	PDS
SR-102	The system shall be able to ingest or determine the user's embarkation bus stop and desired bus route number.	Not Done	Our assumption is that the system will be ingesting bus stop and route information (possibly through a third-party app like Transit) and the system will determine whether the bus stop is relevant to the current intersection that is being approached.	Functional	Demonstration	PDS
SR-103	The system shall be able to determine, prior to the user's arrival, the user's expected arrival time at the intersection.	Not Done		Functional	Demonstration	PDS
SR-104	The system shall be able to determine if there is an approaching bus with the desired bus route number.	Not Done	Capability depends on an ongoing companion project with Port Authority of Allegheny County and/or interoperability with a 3rd party app like Transit.	Functional	Demonstration	IIS
SR-105	The system shall be able to estimate the time at which the bus is expected to depart from the bus stop	Not Done	Capability depends on an ongoing companion project with Port Authority of Allegheny County and/or interoperability with a 3rd party app like Transit.	Functional	Demonstration	IIS

#	Requirement	Req. Status	Notes	Req. Type	Verification Method	Sub-System
SR-106	The system shall be able to determine if additional crossing time must be allocated to ensure that the bus remains at the bus stop until the user can embark.	Not Done		Functional	Demonstration	IIS
SR-107	The system shall be able to allocate the additional crossing time to ensure that the bus remains at the bus stop until the user can embark.	Not Done		Functional	Demonstration	IIS
SR-108	The system shall not store any PII data.	Satisfied		Data	Inspection	PDS

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