Evaluation of Innovative Pedestrian Detection Systems to Increase Safety

Final Report

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Metric Conversion

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

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This report evaluates the potential of dynamic passive pedestrian detection (DPPD) and automated pedestrian detection (APD) systems to enhance pedestrian safety and optimize traffic operations at signalized intersections and midblock crossings. These systems aim to address the limitations of traditional push-button mechanisms by introducing and evaluating automated technologies such as automated pedestrian detection systems, motion sensors and smartphone-based pedestrian call capabilities. The study includes a comprehensive review of available technologies and vendors, development of evaluation and data collection plans, and a detailed analysis of their effectiveness through before-after studies conducted in Florida.

The findings demonstrate that these systems significantly reduce crossing risks, improve accessibility, and optimize traffic flow by enabling dynamic call extensions and cancellations based on pedestrian presence. Despite occasional detection challenges under adverse environmental conditions, the study confirms the feasibility of deploying these systems with appropriate calibration and maintenance protocols.

Recommendations include prioritizing high-pedestrian-traffic areas for deployment, integrating systems with existing traffic infrastructure, and providing public awareness campaigns and stakeholder training to ensure successful implementation. Future research is encouraged to refine sensor technologies and explore expanded applications, paving the way for safer and more efficient pedestrian mobility solutions.

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Executive Summary

This project explored the implementation and evaluation of dynamic passive pedestrian detection (DPPD) and automated pedestrian detection (APD) systems to improve pedestrian safety and optimize traffic operations at signalized intersections and midblock crossings. These advanced systems aim to address the limitations of traditional push-button mechanisms by incorporating automated technologies such as automated pedestrian detection systems, motion sensors and smartphone-based activation, ultimately ensuring safer and more efficient pedestrian mobility. This study achieved the following objectives through research, planning, evaluation, and analysis.

First, a thorough review was conducted to identify the latest advancements in DPPD and APD systems and their available vendors. This work was built upon previous research that identified and tested several products, expanding the analysis to include recent technological developments. The study reviewed systems that utilize thermal cameras, sensors, and algorithms to accurately detect pedestrians and integrate with traffic controllers. Vendors collaborated with the research team to conduct feasibility tests and validate system performance. For instance, technologies like DERQ's pedestrian detection platform and integration with Q-Free controllers were examined, providing valuable insights into the operational feasibility of these systems.

Second, evaluation, implementation, and data collection plans were developed to investigate the effectiveness of DPPD and APD systems in mitigating the risks of pedestrians for not pressing the pedestrian push-button to cross streets, and reducing the need for physical push-button interaction. These plans were tailored to examine features such as automatic pedestrian detection, touchless actuation, smartphone-based pedestrian calls, and dynamic signal adjustments. The study emphasized the importance of accommodating vulnerable road users, such as seniors and individuals with disabilities, by ensuring adequate crossing times and eliminating the need for physical button presses. Comprehensive data collection methodologies were implemented to measure system performance under real-world conditions, capturing pre- and post-deployment pedestrian behavior and safety outcomes.

Third, the effectiveness of these systems was evaluated through before-after studies conducted in Florida. These studies assessed pedestrian behavior, safety outcomes, and operational performance where these systems were deployed. Findings revealed that the systems significantly reduced crossing risks by enabling automated detection, and dynamically extending crossing times, and improved operational efficiency by canceling calls when pedestrians left the waiting area early. Performance metrics, including accuracy, sensitivity, and precision, demonstrated that these systems provided reliable pedestrian detection and enhanced traffic flow. Despite occasional challenges, such as detection inaccuracies due to environmental factors, intersection layout, or no separate pedestrian waiting areas for two different directions, the systems performed well overall, showcasing their potential for improving pedestrian safety and efficiency.

Lastly, the team developed implementation guidelines to support the deployment of these systems. These high-level guidelines were developed to outline when, where, and how to

implement APD and DPPD technologies effectively. These included recommendations for site selection, system integration with existing traffic infrastructure, calibration and maintenance protocols, and stakeholder engagement strategies. For instance, the guidelines recommend deploying these systems at high-pedestrian-traffic locations, such as school zones, transit hubs, and shopping districts, where compliance with traditional push-button mechanisms is typically low. Stakeholder training and public awareness campaigns were emphasized to ensure proper system usage and acceptance among the public and traffic management professionals. Additionally, recommendations for future research were provided, including the exploration of advanced sensor technologies, algorithm refinements, and expanded applications of smartphone-based pedestrian call systems.

Overall, this project has demonstrated that DPPD and APD systems offer a transformative approach to enhancing pedestrian safety and optimizing traffic management. These systems effectively address key challenges, including improving accessibility, reducing pedestrian-vehicle conflicts, and minimizing delays. By leveraging the findings and recommendations from this study, transportation agencies and urban planners can confidently deploy these technologies, creating safer, more efficient, and pedestrian-friendly urban environments. The study concludes with a roadmap for integrating these systems into Florida's roadways, paving the way for smarter mobility solutions and advancements in urban transportation infrastructure.

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List of Acronyms

ADAS	Advanced Driver Assistance System
AI	Artificial Intelligence
ANN	Artificial Neural Network
APD	Automated Pedestrian Detection
CUTR	Center for Urban Transportation Research
CAV	Connected Autonomous Vehicle
CNN	Convolutional Neural Network
DPPD	Dynamic Passive Pedestrian Detection
FDOT	Florida Department of Transportation
HAWK	High Intensity Activated Crosswalk Beacon
LPI	Leading Pedestrian Interval
ITS	Intelligent Transportation Systems
OBU	On-Board Unit
PSM	Personal Safety Message
PHB	Pedestrian Hybrid Beacon
PUFFIN	Pedestrian User-Friendly Intelligent Crossing
RRFB	Rectangular Rapid Flashing Beacon
RSU	Roadside Unit
SVM	Support Vector Machine
TERL	Traffic Engineering Research Laboratory
USF	University of South Florida
UWB	Ultrawide Band

1 Introduction

The main goal of this project was to evaluate the effectiveness of innovative pedestrian detection systems, including dynamic passive pedestrian detection (DPPD) and automated pedestrian detectors (APD), to enhance safety at signalized intersections and midblock crossings. The project aimed to address challenges associated with traditional push-button pedestrian calls by leveraging automated pedestrian detection systems, touchless and smartphone-based technologies to place, extend, or cancel pedestrian calls automatically. Through comprehensive testing, analysis, and the development of implementation guidelines, this project sought to improve pedestrian compliance, reduce crossing delays, and integrate advanced detection systems into traffic management practices for safer and more efficient pedestrian mobility.

1.1 Overview

Pedestrian safety has been a significant focus of the Florida Department of Transportation (FDOT) over the past decade due to the high number of pedestrian fatalities in the state. Data from the Florida Traffic Crash Facts Annual Report 2023 indicates that 791 pedestrian fatalities occurred in Florida in 2023, highlighting the critical need for improved safety measures [1]. FDOT has implemented various strategies to enhance pedestrian safety at signalized intersections and midblock crossings, including high-visibility crosswalks, rectangular rapid flashing beacons (RRFBs), pedestrian hybrid beacons (PHBs), leading pedestrian intervals (LPIs), educational campaigns, and roadway redesigns to improve walkability.

Despite these efforts, one persistent challenge is the reliance on push buttons for activating pedestrian calls. Field observations show that many pedestrians neglect to use these buttons, and this behavior was exacerbated during the COVID-19 pandemic due to concerns about surface contact. This issue underscores the need for alternative solutions that do not depend on direct interaction with push buttons.

Recent advancements in pedestrian detection technology offer promising solutions to address this challenge [2]. APD and DPPD systems can automatically activate pedestrian phases when a pedestrian enters the detection zone and deactivate the call if the pedestrian exits before crossing. Such systems enhance pedestrian safety while minimizing vehicle delays by optimizing the traffic controller's operations. Additionally, smartphone-based systems that allow pedestrians to place calls without physical interaction further contribute to touchless and efficient pedestrian crossing solutions.

This research focused on evaluating the effectiveness of APD, DPPD, and smartphone-integrated systems in improving pedestrian safety and urban mobility. The report includes development and deployment, implementation, data collection, and evaluation plans to assess the performance of these technologies in real-world scenarios. Furthermore, it reports the feasibility of deploying these systems on Florida's roadways to reduce the incidence of pedestrians crossing without activating a pedestrian call.

1.2 Project Objectives

The project's objectives are described below:

- Research the latest advancements in DPPD or APD systems currently available and identify vendors with available products. This was built on the previous project, which identified and tested several products.
- Develop evaluation, implementation, and data collection plans for investigating effectiveness of DPPD or APD systems to reduce pedestrians crossing without physically pressing a button to place a pedestrian call. This includes investigation of a system where a pedestrian call can be placed via a smartphone or motion sensor so there is no need for the pedestrian to physically press the push button.
- Complete a detailed evaluation of the effectiveness and benefits of using DPPD or APD systems in Florida via before-after studies of pedestrian behavior where such pedestrian detection technologies are deployed, including an investigation of extending or shortening pedestrian crossing times at midblock crossings and canceling the pedestrian call based on pedestrian presence at signalized intersections.
- Develop implementation guidelines on when, where, and how to deploy these systems, document analysis results and research findings from the evaluation, and provide recommendations.

1.3 Organization of Report

The rest of this report is organized as follows: Section 2 provides a comprehensive review of the existing literature and state of practice, highlighting current pedestrian safety challenges and the role of technologies such as APD and DPPD systems. Section 3 presents a feasibility study for implementing APD and DPPD systems on Florida roadways, examining technical, operational, and cost considerations. Section 4 details the development of plans for evaluating, deploying, and collecting data on these systems, ensuring a systematic approach to assessing their performance. Section 5 evaluates the effectiveness of touchless actuation, smartphone integration, and APD/DPPD systems in improving pedestrian safety and optimizing traffic operations. Finally, Section 6 summarizes key findings and offers recommendations for future implementation and further research.

2 Literature Review and State of Practice

This section presents a review and evaluation of the existing technologies that have been installed at signalized intersections or midblock crosswalks. In addition, the discussion covers the state-of-the-practice review conducted to identify products that can meet the requirements of automated pedestrian detection. The discussion also focuses on emerging technologies that have the potential to be used as APD or DPPD systems with RRFBs or PHBs. A comparison and documentation of the advantages and disadvantages of various technologies, as well as requesting precise technical details from suppliers and manufacturers, are also discussed. This resulted in surveying market products to compare them in terms of criteria defined by FDOT to find appropriate products to improve the safety of pedestrians. Key technologies and existing systems were also identified for further exploration based on findings from the literature review.

2.1 Overview of Automated Pedestrian Detection (APD)

The functionality of the APD system is presented and investigated in this section.

2.1.1 APD Functionality

Automated pedestrian detection functionality refers to the capability of a system or technology to detect and identify pedestrians in real time or in an automated manner. This functionality is commonly found in advanced driver assistance systems (ADAS) and autonomous vehicles to enhance safety and prevent crashes involving pedestrians. The automated pedestrian detection functionality typically relies on a combination of sensors, such as cameras, radar, and Lidar, along with advanced image processing and machine learning algorithms. Below is a general overview of how it works:

Sensor Data Acquisition: The system collects data from various sensors, including cameras, radar, and/or Lidar. Cameras capture visual information, radar detects objects based on radio waves, and Lidar uses laser beams to measure distances and create detailed 3D maps.

Object Detection: Using image processing techniques and sensor fusion, the system identifies objects within the sensor's field of view. This includes detecting pedestrians, vehicles, and other objects present in the environment.

Pedestrian Classification: Once pedestrians are detected, the system uses machine learning algorithms to classify and differentiate them from other objects. This classification helps determine potential risks and appropriate actions.

Tracking and Predictive Analysis: The system tracks the movement of pedestrians over time and predicts their future paths. By analyzing speed, direction, and other factors, it can anticipate potential conflicts and take proactive measures.

Warning or Intervention Systems: Based on the analysis and predictions, the automated pedestrian detection system can provide alerts or trigger an RRFB, PHB, or place a call in the traffic controller.

According to the Federal Highway Administration (FHWA) Traffic Control Handbook, inductive loops, radar, infrared, ultrasonic, and video processing are some of the most used technologies that can detect vehicles [3]. Pushbuttons are the only method used to implement pedestrian detection. APD devices can sense when a pedestrian is waiting at a crosswalk and automatically send a signal to the traffic controller to switch to a pedestrian “WALK” phase. Automated pedestrian detection functionality is continually evolving and improving as technology advances. It plays a crucial role in improving road safety by providing an additional layer of protection for pedestrians and assisting drivers in making informed decisions to prevent crashes.

2.1.2 Pilot Studies - State of Practice

Multiple systems are currently available in the market that utilize one or more of these technologies to accomplish varying degrees of detection and/or counting. A recent study published by Lin et al. [4], whereby forecasting the separations between the bounding box's center and edges, they were able to predict precisely the location of the pedestrians in the field of view.

In Nevada, a study by Nambisan et al. [5] was conducted to assess the efficiency of automatic pedestrian detection concerning smart crosswalk lighting. Smart lighting was implemented at a crosswalk located in the middle of a block, illuminating the crosswalk when a pedestrian was detected. The study examined pedestrian safety and behavior before-after the installation of this passive system. The findings indicated that the introduction of passive systems for smart lighting received positive feedback from pedestrians, as it resulted in a reduction in the percentage of pedestrians engaging in jaywalking.

An automated pedestrian identification method was proposed by Ramzan et al. [6], who proposed a robust pedestrian detection system that first uses optical flow to identify moving regions and then applies Histogram of Oriented Gradient (HOG)-based feature extraction for accurate classification, achieving efficient real-time performance. A quick adaptive pedestrian identification approach based on a cascade classifier with a ternary pattern was proposed by Cao et al. [7] in another study. A novel optimization approach was used to create the best threshold vector, allowing the cascade classifier to be modified to work with unseen scenes using just a few samples from those situations. They also unveiled a broad ternary detection pattern-based cascade classifier structure at the same time. Finally, they discovered that the ternary detection pattern can simultaneously distinguish pedestrians and non-pedestrians in each layer by contrasting their approach with the conventional binary detection pattern.

Various types of microwave radar exist, including Ultra-Wide Band (UWB) radar, frequency- or phase-modulated signal radar, and Doppler radar. These types of radar are categorized according to how electromagnetic waves are transmitted [8, 9]. Intelligent Transportation System (ITS) applications use UWB radar, a novel and developing technology that can detect motion with centimeter-level accuracy by detecting motorized vehicles and people. UWB radar can send and receive radio wave pulses with high accuracy. Based on the passage of time since the return signal, frequency- or phase-modulated waves (also known as frequency-modulated continuous waves, or FMCWs) can determine how far an item is. FMCWs, a class of microwave detectors that can detect changes in an object's immobile and passing frequencies, such as a pedestrian, were discussed in their study [8].

Passive infrared and automatic image processing technologies are combined to create thermal technology [10, 11]. By determining body temperature, thermal cameras function similarly to passive infrared sensors and produce infrared images. The fact that heat sensors are unaffected by changes in ambient light is a significant advantage. In the U.S., thermal cameras are a commercially accessible new technology. One current thermal sensor device for pedestrian detection is the FLIR TrafiOne Smart City Sensor [12]. It is capable of thermal detection in complete darkness, through shadows, and under sun glare, and it can provide real-time detection and monitoring 24/7. It can manage traffic signals by identifying pedestrians and bicycles approaching, waiting at the curbside, or walking on the crosswalk. It is possible to connect FLIR TrafiOne to the traffic signal controller using dry contact outputs or TCP/IP network connectivity to enable more dynamic traffic signal management based on presence or volume information.

According to research on automated pedestrian detectors, Doppler radar and passive infrared sensors provide accurate readings for angles and distances, depending on the scanner's frequency [13]. However, Viola et al. [14] pointed out that laser scanners have a limited detection range in bad weather like fog or snow because of the characteristics of optical-based image sensors. The signal processing in laser scanners is more sophisticated when compared to microwave radar or ultrasonic radar. Additionally, automated pedestrian detectors based on information about motion or pedestrian appearance have been created. Motion and appearance detection methods were combined to create a detector by the Bea Group [15]. The detection algorithm scanned over two consecutive frames of a video stream. This method of system implementation works at around four frames per second and has very low false detection rates, allowing it to detect pedestrians at very small scales. These detection algorithms can cover a complete image zone at every scale and are rapidly executed. To obtain high detection rates and very low false detection rates, the detectors are trained using massive datasets.

In a different experiment, researchers studied how to create a system for gathering data on pedestrian activity based on Lidar sensing technology, which was then put into use in two intersections [16]. After stabilizing for a few months, the created software was able to accurately record pedestrian behavior. Over many months, the created approach gathered tens of thousands of samples of pedestrian activity at each crossing. The data analysis demonstrates that pedestrians' "effective-perception-reaction (E-P-R)" time, defined as pedestrians' perception-reaction time to the onset of the “WALK” signal plus the walking time from the waiting area into the intersection, can be significantly decreased by using ADA-compliant (audible) pedestrian push buttons.

2.2 Overview of Dynamic Passive Pedestrian Detection (DPPD)

This section includes an explanation of the DPPD system and existing research on the system. Pilot studies conducted in the past will also be discussed.

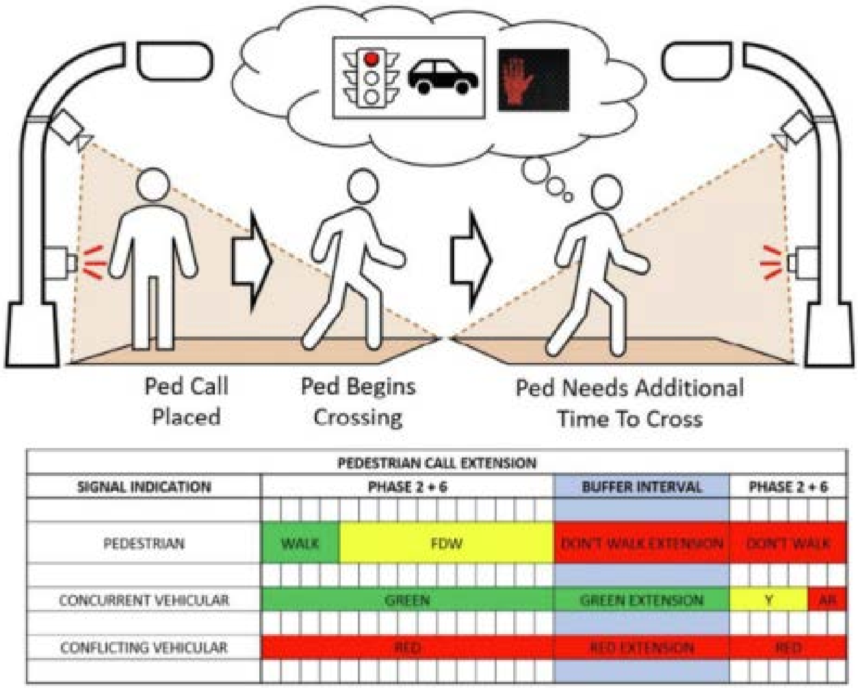
2.2.1 DPPD Functionality

In countries outside the United States, the Pedestrian User-Friendly Intelligent (PUFFIN) crossing is widely recognized as a notable application of the DPPD system [17]. This crossing system, implemented in the UK, Canada, and other nations, incorporates a signalized pushbutton-activated crossing that incorporates features to enhance efficiencies and pedestrian safety, such as pedestrian call cancellation and extension/truncation functions. To achieve these functionalities, two types of sensors are typically utilized: pressure-sensitive mats and radar.

The pressure-sensitive mats are positioned in the curb zone and monitor this specific area. For pedestrian detection to be maintained, individuals must stand on the mat. Radar sensors are placed at diagonal ends of the crossing and monitor the entire crossing area. These radar sensors can communicate with the signal controller, providing information on the presence of pedestrians in the crosswalk. Based on this data, the signal controller can adjust the duration of the pedestrian phase, either lengthening or shortening it accordingly [18-20]. Research studies have demonstrated that PUFFIN crossings lead to increased compliance among pedestrians and a reduction in conflicts between pedestrians and vehicles. However, it is important to note that the detection mechanisms employed in these crossings are not flawless. Companies have faced challenges delivering reliable curb zone detection with accurate pedestrian coverage, particularly under diverse weather and lighting conditions.

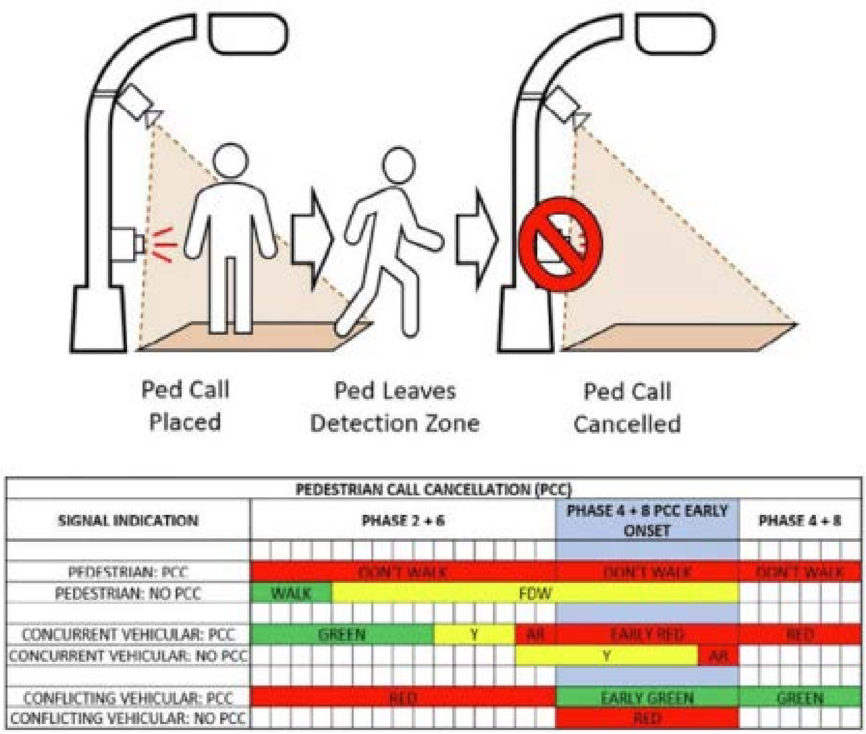
Currently, most actuated traffic signals use pushbutton cues to start the pedestrian phase. Once the service call is placed, this phase cannot be changed or canceled. Prolonging the pedestrian phase may cause undue delays for other crossing users if a pedestrian decides not to cross or to jaywalk. The start of the conflicting vehicular phase may put the pedestrian's safety in danger if they need more time to cross than the signal allows. With pedestrian call extension or cancellation features, DPPD has the potential to improve the operational effectiveness and safety of signalized crossings. If a pedestrian is seen in the crosswalk at the end of the planned walk time, pedestrian call extensions lengthen the phase time for a pedestrian crossing (see Figure 2-1) [21].

If a pedestrian presses a pedestrian push button, leaves the curb detection zone, and does not re-enter any detection zone for the same crossing within a predetermined amount of time, the signal controller would be able to terminate the pedestrian call, known as call cancellation (see Figure 2-2) [21]. The goal of pedestrian call cancellation is not to speed up "fast" pedestrians. It can reduce unnecessary delays for drivers. In that way, drivers can have the trust of pedestrian signals; hence, it helps improve pedestrian safety.



Source: [21]

Figure 2-1. Call extension



Source: [21]

Figure 2-2. Call cancellation

2.2.2 Pilot Studies – State of Practice

Beckwith et al. conducted a study that looked at passive detection for warning devices at un-signalized intersections [22]. The study was conducted to assess the ultrasonic, infrared, and radar systems for both short and long ranges in a controlled environment. The infrared system had a positive detection rate of almost 95%, which was an encouraging outcome. At close range, the ultrasonic sensor operated well (89%), but poorly (47%) at a distance. Although the radar was only tested at a considerable distance, it managed to detect objects 96% of the time.

Research by the Texas Transportation Institute (TTI) assessed the precision of an infrared and microwave radar sensor for usage in curbside and crosswalk zones for passive pedestrian detection [23]. This study employed a method that counted pedestrians as they passed through a detection zone. The real field conditions according to timestamped detection were subsequently verified using video recordings. Error rates were often in the 20% to 30% range for both systems, which was deemed to be too unreliable for present implementation. The main problems with the high mistake rates in the crosswalk zones were car related, in which the zone would be activated if stopped vehicles were in the crosswalk. Passive devices specifically could not detect stationary pedestrians in the curbside zones. The researchers explained that one curbside zone with a 9% error rate had a clear line of sight and a clearly defined waiting area.

Montufar et al. [24] examined the accuracy rate of three different passive pedestrian detectors—infrared, infrared-video combination, and microwave—in below-freezing temperatures. They discussed the findings in terms of selectivity (the proportion of successfully detected pedestrians to the total number of detections) and sensitivity (the number of legitimate calls divided by the total number of pedestrians). The researchers discovered that the average sensitivities for infrared, infrared-video combination, and microwave, dispersed across two separate sites, were 97%, 86%, and 62%, respectively. The same systems, however, only achieved average selectivity values of 14%, 43%, and 22%, respectively. According to these findings, the systems exhibited promising results for identifying pedestrians, but the selectivity of the sensor's detection required significant improvement.

A report published by the FHWA in 2001 assessed the effectiveness of automated pedestrian detection systems that operate passively [20]. The purpose of the study was to analyze how these systems could help reduce conflicts between pedestrians and vehicles. It was reported that the passive detection system would activate a service call when a pedestrian failed to press a pushbutton, allowing them to receive a "WALK" signal before deciding to jaywalk. If a pedestrian was still crossing the street when the "DON'T WALK" signal started flashing, the duration of the crossing time would be extended by 0.2-second intervals (up to a maximum of six seconds) until they completed the crossing. To conduct the study, four locations were chosen in the county, and the passive pedestrian detection systems were integrated into the signal controllers. According to the findings, the study revealed a significant 81% reduction in the number of pedestrians crossing the street when the "DON'T WALK" signal was steady. This decline occurred because a considerable portion of pedestrians were offered service during the "WALK" signal due to the passive detection system initiating a service call. The system contributed to an approximately 50% decrease in the proportion of pedestrians still present in the crosswalk when vehicles traveling in the opposite direction received a green light [20].

Alali et al. [25] studied parked cars along the sidewalk to identify and safeguard individuals who were crossing. They proposed a system for alerting drivers to occluded pedestrian traffic (ADOPT), which operates based on the theoretical underpinnings of a system that uses parked cars for various purposes, such as detecting the presence of a group of crossing pedestrians, forecasting the amount of time the last member of the cohort takes to clear the street, and sending alert messages to those approaching cars that may reach the crossing area while pedestrians are still in the street. Additionally, they ran a simulation using SUMO-generated cars and pedestrian traffic to demonstrate how well ADOPT detects and protects crosswalk pedestrians.

In Washington County, Oregon, at a signalized intersection and a mid-block crossing location, Larson et al. [21] evaluated the accuracy and dependability of two thermal sensors and one optical sensor for DPPD. The average accuracy rate for the thermal sensors, according to the results, was 89% at the signalized intersection and 82% at the mid-block position. The Late, Held, and Miss calls were the most typical inaccurate detection types for thermal sensors. At the signalized intersection, the optical sensor's average accuracy rate was 26%, while it was 83% in the middle of the block. Spotty, Late, and Miss calls were the most prevalent error types for optical sensors. When cars and bicycles on the road entered the detection zones, false detections happened more frequently for both types of sensors. The accuracy of thermal sensors was impacted by weather and illumination conditions, whereas the accuracy of optical sensors was simply impacted by pedestrian type.

In another study, Brunetti et al. [26] examined the field of application, acquisition technology, computer vision algorithms, and classification strategies of vision-based pedestrian detection systems. The three main application areas of video surveillance, human-machine interaction, and analysis have been covered. This study explored the distinctions between 2D and 3D vision systems as well as indoor and outdoor systems due to the wide range of acquisition technologies. It was discovered that the extraction of features, which requires the extraction of strong descriptors that must aid in the discrimination of pedestrians, was the most challenging phase in the construction of the pedestrian detection system. They pointed out that to create novel applications for pedestrian detection, several factors should be considered, including the accuracy level that should be attained, whether it is possible to create a simple model of the background using background subtraction, and feature-based methods for categorizing pedestrians, such as support vector machine (SVM) or artificial neural network (ANN) and convolutional neural network (CNN).

In contrast to the United States, where passive pedestrian detection is still in its infancy, PUFFIN crossings have been using the technology since 1992. When there are people around, pressure mats or infrared detectors react by canceling service requests or extending the signal phase for people crossing the street. According to studies done by Hughes et al. [20], these crossings improve pedestrian compliance and decrease conflicts between pedestrians and moving vehicles.

2.3 Smartphone Applications

A pilot study was conducted to explore the potential of utilizing smartphone applications to assist visually impaired individuals in navigating street crossings. One such project, sponsored by the Minnesota Department of Transportation and conducted by the University of Minnesota, developed an automated pedestrian system that operates on smartphones [27]. This system aimed to support wayfinding and navigation for visually impaired individuals at both signalized and un-signalized intersections. The researchers collaborated with traffic controllers to transmit traffic signal phasing and timing information to visually impaired users through a secure and private wireless network. The primary objective of the project was to assess the effectiveness and usefulness of the smartphone-based accessible system in assisting visually impaired individuals as they traverse intersections. The reported accuracy of the smartphone's location at each test site ranged from four to eight meters, with an average accuracy of 5.6 meters, indicating its current position accuracy. Additionally, the team conducted tests to evaluate the accuracy of the text and audible messages displayed on the smartphone when users performed single and double taps. Out of 137 message correctness tests, the system successfully provided 132 (96%) correct feedback regarding intersection geometry and signal status information [27].

The functionality of Crosswatch, a smartphone-based system that uses computer vision to guide blind and visually impaired travelers at traffic intersections, was addressed by Coughlan et al. [28], which includes a wide variety of "what," "where," and "when" information concerning traffic intersections. Computer vision was strengthened with data from other sources, such as GIS and smartphone sensor data, to gather this information. In a separate study, Fusco et al. [29] discussed new developments in Crosswatch. The research described two elements of Crosswatch that help users properly align to crucial features like walk lights, pushbuttons, and crosswalks, such as position determination and relative orientation to the crosswalk markings in the intersection. Additionally, the study pointed out two key contributions made by changing a user interface that was put to the test by blind volunteer testers, making it simpler to acquire intersection images than with earlier iterations of Crosswatch and showcasing the system's ability to localize the user with accuracy superior to that of GPS as well as an example of its ability to estimate the user's orientation.

Ivanchenko et al. [30] described a prototype portable system that alerts the user in real-time once the “WALK” light is illuminated. The system functions as a software application and uses computer vision algorithms to analyze video captured by the built-in camera to instantly determine whether a “WALK” light is present. An audible tone that alerts the user is played when a “WALK” light is found. A blind volunteer subject was used in experiments to show the system's proof of concept. In related work, Bohonos et al. [31] described a comprehensive hardware/software system called universal real-time navigational assistance (URNA), which allows Bluetooth-enabled cell phones to communicate pertinent location-aware information to blind people carrying them. They focused on the difficult scenario of an urban junction even though URNA can be used for many different purposes (such as an information kiosk at a mall or public transportation information at a bus stop). A description of the intersection topology and real-time notice of the status of the traffic lights are both presented to the user as he or she approaches the intersection.

Due to the limitations and potential inaccuracies of current GPS-based navigational aids for the visually impaired, especially in areas where GPS signals are obstructed like indoors or in urban canyons, Rose et al. [32] have proposed a human-computer system that combines two positioning systems to provide a more reliable estimate of the user's position. This system aims to assist blind pedestrians through tactile feedback. It incorporates a pedometric system that measures six degrees of freedom for navigation and combines it with GPS data to offer a positioning solution even in GPS-denied environments. In addition, the system utilizes an iPhone application to transmit the desired location and receive relevant information, such as signal phase and layout, from intelligent intersections that utilize dedicated short-range communication (DSRC). To evaluate the system's ability to guide users effectively, a test route was compared with map coordinates to assess any deviation from the intended path. The results confirmed that the proof-of-concept system can sufficiently guide a sighted user to their desired destination.

Bhatlawande et al. [33] proposed a model designed to assist individuals with visual impairments by employing machine learning and computer vision techniques to detect and classify pedestrians and vehicles on roads. The researchers conducted a comparative analysis of various classifiers, including random forest, decision trees, SVM (with three different kernels), and KNN, using scale-invariant feature transform (SIFT) and oriented fast and rotated brief (ORB) feature extraction methods to determine the most effective approach. The evaluation of different classifiers was based on metrics such as testing accuracy, F1 score, recall, precision, sensitivity, and specificity. The results indicated that random forest achieved the highest performance, with a testing accuracy of 87.58% when utilizing SIFT feature extraction. Chang et al. [34] introduced a wearable assistive system that utilizes artificial intelligence (AI) edge computing techniques to aid visually impaired individuals in safely navigating marked crosswalks, commonly known as zebra crossings. The proposed system consists of smart sunglasses, an intelligent device mounted on the waist, and an intelligent walking cane. Real-time zebra crossing image recognition is achieved through the implementation of deep learning techniques. The results demonstrated that the proposed system could achieve up to 90% accuracy in real-time zebra crossing recognition.

2.4 Comparison of Technologies: Pros and Cons

APD and DPPD systems are two different types of pedestrian detection systems used in the field of traffic safety. APD refers to a system that utilizes active sensors, such as radar or Lidar (Light Detection and Ranging), to detect and track pedestrians in real time. These sensors emit signals or beams and measure the time it takes for the signals to bounce back, allowing the system to detect objects, including pedestrians, based on the reflected signals. APD systems often use complex algorithms to analyze sensor data and identify pedestrians, and can provide precise information about the position, speed, and direction of detected pedestrians. This technology is commonly used in ADAS in autonomous vehicles.

2.4.1 Advantages of APD

- High Precision: Offers accurate detection, even in complex traffic environments.

- Real-Time Data: Provides immediate tracking and predictive analytics of pedestrian movements.
- Versatility: Can be integrated into ADAS and autonomous vehicles.

2.4.2 Limitations of APD

- Cost: Higher implementation costs due to the complexity of sensors and algorithms.
- Sensitivity Issues: Susceptible to performance degradation in adverse weather conditions (e.g., fog, heavy rain).
- Installation Complexity: Requires specialized expertise and infrastructure for deployment.

DPPD refers to a system that relies on passive sensors, such as cameras or infrared sensors, to detect and recognize pedestrians. These sensors capture visual or thermal information from the surroundings and analyze it using computer vision algorithms to identify pedestrians. DPPD systems can detect pedestrians based on various visual cues, such as body shape, movement patterns, or color contrast with the background. Unlike APD, DPPD does not actively emit signals, but rather passively observes the environment. It is commonly used in applications like surveillance systems, pedestrian safety systems, or traffic monitoring [5, 6, 12, 17, 28, 30].

2.4.3 Advantages of DPPD

- Cost-Effective: Typically, more affordable compared to APD systems.
- Lower Power Requirements: Passive sensors consume less energy, making them ideal for locations with limited resources.
- Environmental Adaptability: Infrared-based DPPD systems can function in low-light conditions, such as nighttime or shaded areas.

2.4.4 Limitations of DPPD

- Detection Accuracy: May have lower precision in distinguishing pedestrians from non-pedestrian objects in crowded environments.
- Weather Dependency: Performance can vary under extreme weather conditions, such as snow or intense sunlight.
- False Positives: More prone to triggering false detections due to reliance on visual cues.

In summary, the main difference between APD and DPPD lies in the type of sensors they use and their approach to detecting pedestrians. APD relies on active sensors like radar or Lidar, while DPPD uses passive sensors like cameras or infrared sensors. Each technology has advantages and limitations, and its suitability depends on the specific application requirements. This report will focus on APD and DPPD, which have been researched at the federal level. The use of APD systems to add a pedestrian call extension or cancel a pedestrian call has been researched but has not been widely applied due to their sensitivity or accuracy issues and price. The research has shown that modern pedestrian detection devices can help solve the push-button issue. In addition to automated pedestrian detection, there are ways to place a call if a pedestrian is in the presence zone and remove the call when a pedestrian leaves the zone [2, 10]. This can aid in reducing delays when pedestrians cross the road after pushing the button (and placing a call) before the call is served by removing the call from the next phase in the traffic controller.

2.5 Current Products Availability

As a result of the literature review, researchers at CUTR focused on reviewing the available products on the market, investigating the functions and capabilities of candidate systems, and finalizing the systems for testing under a controlled environment and pre-deployment field testing. The goal was to select at least two types of available pedestrian detection technologies and available automated pedestrian detection systems that have the potential to be used as APD or DPPD systems with RRFBs or PHBs via pilot deployment at both midblock and signalized intersection locations. This also includes thermal (infrared) and optical (RGB) cameras to detect pedestrians crossing the street.

To choose products that have the necessary capabilities and functionality, the criteria defined by FDOT should be met, which are as follows:

- Place a pedestrian call with touchless actuation (pedestrian waves at the sensor),
- Accurately detect pedestrians at waiting areas of a signalized intersection or a midblock crossing with RRFBs or PHBs and identify intended crosswalk(s) use,
- Place a pedestrian call to a traffic controller after detecting pedestrian(s) at waiting areas of a signalized intersection or a midblock crossing with RRFBs or PHBs,
- Extend or shorten the pedestrian call time depending on the pedestrian presence on the crosswalk,
- Remove (cancel) a pedestrian call from a traffic controller before the pedestrian phase is served if the pedestrian leaves the waiting area early before the call is served at a signalized intersection, and
- Place a pedestrian call via smartphone without the need to push a button.

Table 2-1 shows the availability of products on the market for APD or DPPD and the product’s specifications. As shown in the table, there are six products available that passed the team’s criteria to be tested and evaluated in terms of cost, accuracy, strengths, and limitations, level of effort, installation requirements, maintenance requirements, liability and accessibility, and typical application environment. Each was assessed in a controlled environment for its suitability for this research project. To choose the products that meet the FDOT’s goals, we defined the procedure that facilitates the process of selecting.

First, we researched and determined the available products from the vendor and manufacturers in the market, in terms of usage and features. Second, we contacted vendors and manufacturers to obtain detailed information on features, capabilities, pricing, and availability of their technologies that might fit our criteria. Third, we reviewed available and acquired information to develop a short list of candidate technologies.

Table 2-1. Summary of Available Products for APD or DPPD

Product's name	Usage	Product's specification
iDS Product	Detection of pedestrians, vehicles, touchless actuation	Touchless actuation/without pushing buttons. Provides touchless iDetect activation with inconspicuous, weather-proof radar and an adjustable detection range of 1-20 inches. The iDS2 Accessible Pedestrian System (APS) consists of Push Button Stations (iDS2 PBS) installed on poles with existing pairs of button wires, and an Intelligent Central Control Unit installed in the traffic cabinet. All the available setup and maintenance procedures may be performed using a compatible iOS device. A Wi-Fi connection is also available. It provides: • Extended Walk Volume • Walk Interval Settings • Clearance Interval Settings • Don't Walk Interval Settings
FLIR TrafiOne Smart City Sensor	Detection of vehicles, bicyclists, pedestrians	All-in-one sensor with 24/7 detection and in various weather conditions, no need for additional lighting, low maintenance. Fast setup over a secure Wi-Fi connection with Wi-Fi monitoring capabilities, visual HD stream and setup of ped signal phase adjustments.
Blue City Lidar	Detection of pedestrians, vehicles, touchless actuation	Traffic controller connection with customizable virtual loop Multimodal detection and count data with 360 field of view Up to 70m coverage radius Multimodal detection and classification Count data integration into traffic controllers LTE enabled Visualization of multimodal count data with: Speed and trajectory analytics Conflict analytics Red light runners and jaywalking Signal Performance Measures (SPM)

Table 2-1. Summary of Available Products for APD or DPPD (continued)

Product's name	Usage	Product's specification
Migma Auto Button	Detection of pedestrian, touchless actuation	Visual Indicator: LED turned on after pedestrian detection Activation Time: < 1 second Detection Zone: Adjustable manually (no software) Power: 100 - 240VAC (default) or solar External Wiring: (1) Power wire to AC power or solar (2) Relay wire to push button terminals Closure Time: 1 - 10 seconds Sensor Height: 7 - 13 ft Dimension: 10'' x 9'' x 4'' Enclosure: NEMA Type 3R+ and IP55 Rated Temperature: -13 °F — 140 °F (-25 °C — 60 °C) Humidity: 0% ~ 96% Pedestrian Detector Sensor: PIR motion sensor Sensing Range: 30 ft (sensor to pedestrian) Comm Distance: >600 ft (sensor to base station)
Miovision	Pedestrian detection, counts	Detection metrics for occupancy ratios, arrivals on red, arrivals on green, and phase interval Access rolling 90-day count data for vehicles, bicycles, and pedestrians Optional advance detection data for vehicles approaching the intersection Uses machine learning and AI, to increase smart sense performance in situations such as shadows, glare, weather conditions, and nighttime hours The vendor allows technology users to access a full suite of video-based applications from a single platform The Traffic Link platform provides functionalities such as clean, clear data visualization, understanding metrics, and their cause

2.6 Product Quote

The research team identified vendors with available products and obtained quotes for the products. The research team obtained three quotes from three vendors, including Migma, Miovision, and Tapconet (with FLIR TrafiOne), which can be found in Appendix A.

3 Feasibility Study for Current APD and DPPD System Implementation

This section investigates the feasibility of implementing these advanced solutions in real-world traffic signal systems by exploring practical applications and development methodologies in collaboration with traffic controller vendors.

The objective is to conduct a feasibility study in collaboration with at least one traffic controller vendor to develop a method to achieve the following:

- Place a pedestrian call once a pedestrian is detected,
- Remove or cancel a pedestrian call from a traffic controller before the pedestrian phase is served if the pedestrian(s) leaves the waiting area early before the call is served at a signalized intersection,
- Extend pedestrian call if a pedestrian is still present in the crosswalk after the countdown time is complete, and
- Place a pedestrian call via smartphone without the need to push a button.

The goal was to enhance the functionality and efficiency of traffic signal systems, particularly in managing pedestrian movements at midblock or signalized intersections. Also, to ensure the success of the feasibility study, it was crucial to work with vendors of existing products to incorporate the features discussed above.

This project was built on the work conducted under project BDV25-977-44, where the team was able to use an automated pedestrian detection system and input a pedestrian call into the traffic controller. This project advanced the features to extend and cancel the call if needed based on pedestrian presence at the intersection.

The team engaged vendors from Florida that offer ITS solutions to local agencies and the FDOT districts in the area. The implementation can be achieved in different ways. Figure 3-1 shows a basic schematic diagram of how the system works: a camera or other sensor is used as an APD to detect pedestrians. The waiting area (yellow) is located on the sidewalk, and the system is monitoring for pedestrians in this detection zone. Once a pedestrian enters this area, the system sends a signal to the traffic controller, and the traffic controller sends a signal to the pedestrian signal head to display the “WALK” signal and countdown. This is the basic function of an APD.

For this project, the additional functionality comes when the APD monitors the waiting area (yellow) and if the pedestrian who was initially present leaves before the call is served, then the pedestrian call is removed from the signal cycle (not served). In addition, the system monitors the crosswalk (red area), and if a pedestrian needs additional time (because they entered late or are moving slow), the system extends the pedestrian “WALK” signal time so that the pedestrian has enough time to cross the crosswalk.

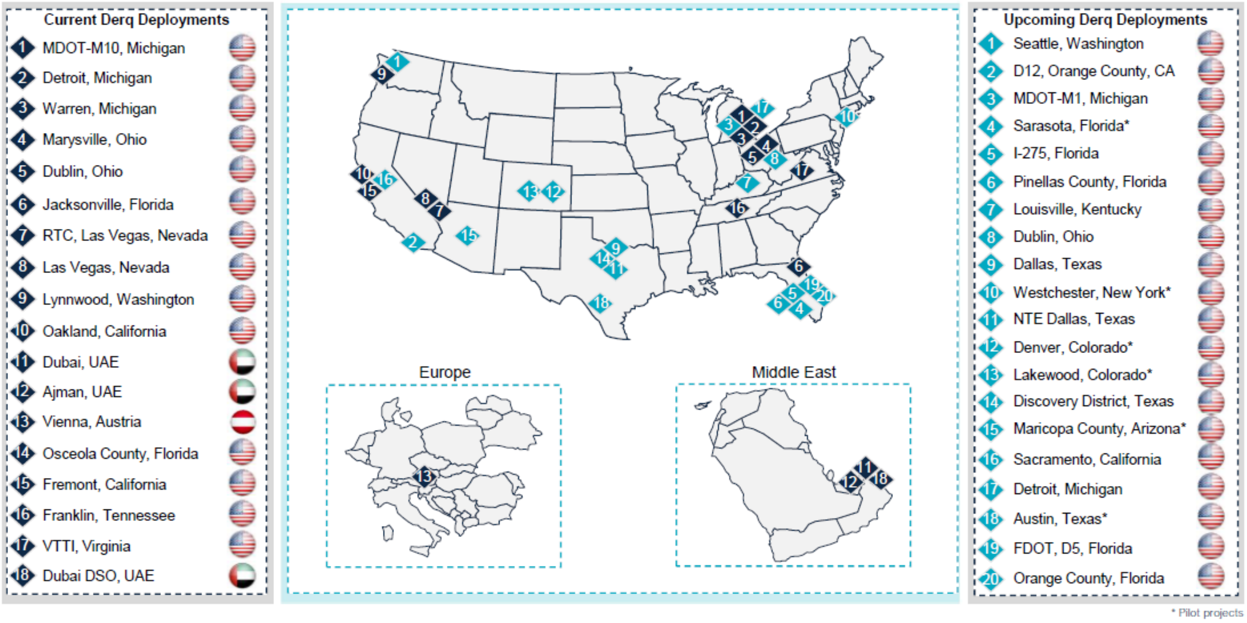
Source: CUTR

Figure 3-1. Schematic of the automated pedestrian detection system

3.1 APD Technologies

This section aims to illustrate possible solutions to the APD and cancel/extend issue. In general, the functionality can be achieved by using dedicated sensors (cameras) for this purpose, which can send a signal to the controller and be used as any other detection input from the controller. Recently however, and with the implementation of new modules and advanced analytics, technology companies offer additional solutions for intersections using only one module. This way, the system can be used for several features including pedestrian detection.

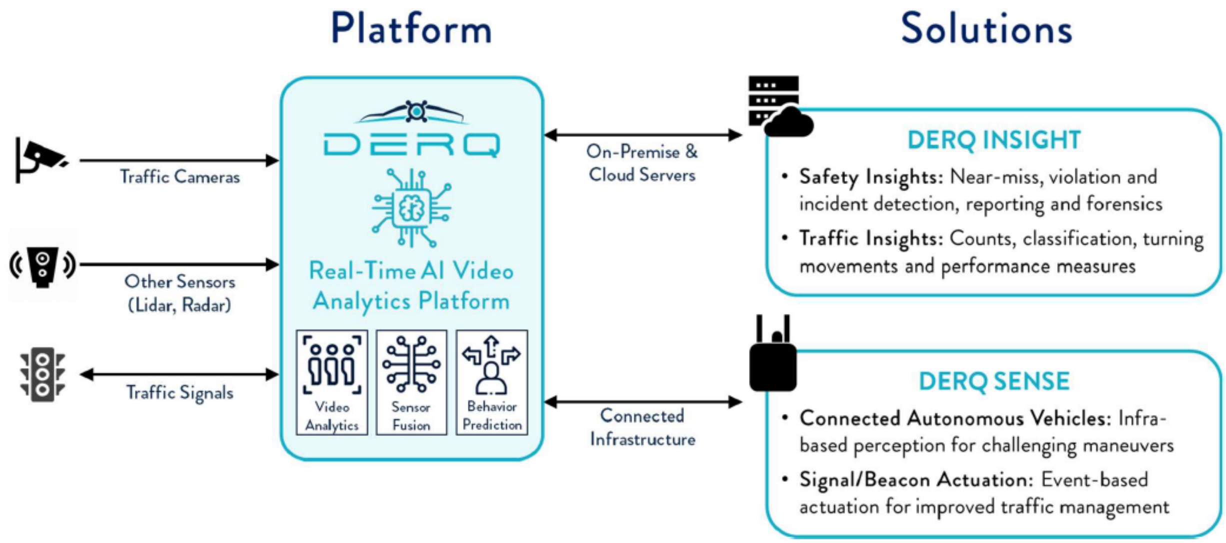
One such solution is offered by DERQ, an AI and edge computing company with a software analytics platform that uses AI to make intersection and mid-block crossing safer for road users, including pedestrians. The AI platform obtains data from traffic cameras and other sensors and enters it into a real-time analytics engine to deliver actionable safety and traffic insights and connected infrastructure solutions to agencies. The company is currently working on several projects, including one current and five upcoming deployments in Florida, as shown in Figure 3-2.



Source: DERQ

Figure 3-2. Current and future deployments

The DERQ technology platform is a real-time AI analytics platform, which empowers advanced solutions for traffic management and connected autonomous vehicles (CAVs). Figure 3-3 displays this technology platform, which obtains data from existing or new sensors (i.e., traffic cameras, Lidar, and Radar), and uses a sensor fusion to provide safety insights such as near miss, violation and incident detection, and reporting/forensics reports. In the context of this project, the platform can be used to detect pedestrians and then provide the information to the traffic controller to display the appropriate pedestrian signals when needed.



Source: DERQ

Figure 3-3. DERQ Technology platform

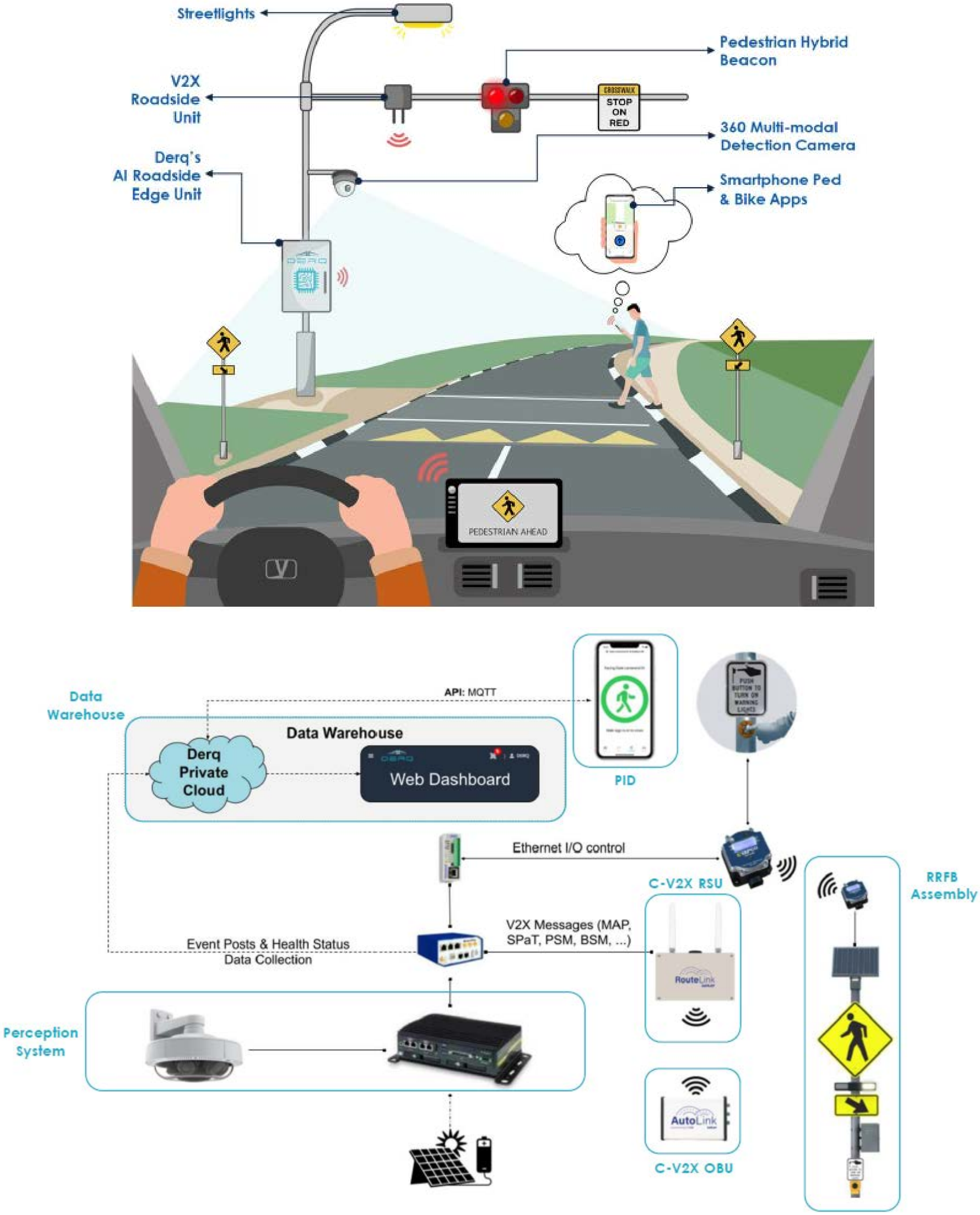
It is important to note that even though this technology platform offers a variety of services, in the context of this project we are investigating its capabilities for the functionality described in Section 2. The project investigates implementation of the APD system under two different scenarios:

- Midblock crossing with RRFB or High-Intensity Activated Crosswalk (HAWK) signal
- Signalized intersection

The following sections showcase the information provided by the company for the two scenarios.

3.1.1 Midblock Crossing

For this project, the solution does not need to include a CV infrastructure, but it is shown as an example for the future. As shown in Figure 3-4, the solution includes a 360° multimodal detection camera, which can be used to detect pedestrians and vehicles. The signal is then processed by the roadside edge unit and activates the PHB or RRFB accordingly. In addition to detection, this solution can offer near-miss and pedestrian compliance analytics, which can help practitioners to implement outreach or enforcement campaigns. The diagram shows the flow of data from the camera/edge unit to the cloud and roadside unit (RSU) for CV applications. The most important aspect of this project is that the RRFB or PHB is activated when a pedestrian is detected.

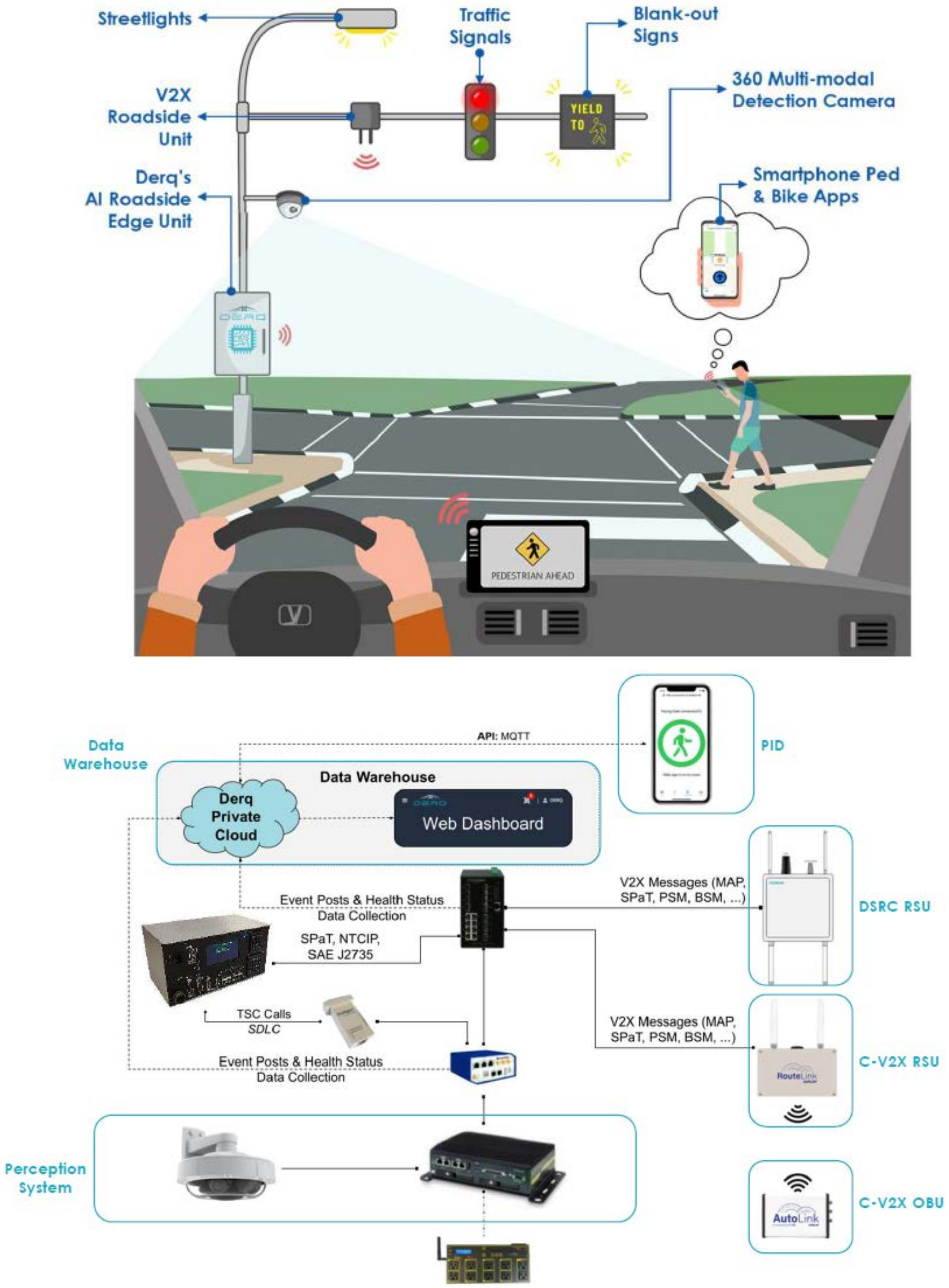


Source: DERQ

Figure 3-4. DERQ Sense for midblock crossings

3.1.2 Signalized Intersection Crossing

In the case of a signalized intersection, the technology is similar to the midblock crossing with a few differences. As shown in Figure 3-5, a camera is used again to detect waiting pedestrians with the edge unit, which then sends a signal to traffic signal and blankout signs used to warn turning vehicles of the presence of pedestrians. This process can be enhanced with CV technology in the future, which will then send the appropriate personal safety message (PSM) to be used by CVs.



Source: DERQ

Figure 3-5. Intelligent signalized intersection crossing

The diagram includes the perception system (camera and edge unit) as well as the interface for the traffic controller and data warehouse, which houses the data. This allows for analytics to be reported after certain events. In addition, on the right side, the RSUs and on-board unit (OBU) are for the CV environment used in the future.

3.2 Pedestrian Detection Functionality

The main component of APD at midblock or signalized intersections is the detection function. This function can be achieved via different technologies. The project team completed project BDV25-977-44, where several detection sensors were evaluated for functionality. After testing, it was deemed that an infrared camera sensor performed the best, providing high accuracy and flexibility for the needs of pedestrian detection at midblock locations or signalized intersections. This camera (shown in Figure 3-6) provides the accuracy and flexibility needed to determine custom detection zones where they are needed. This type of sensor is a standalone sensor and has only one function, which is to detect pedestrians inside the detection zone and provide input to a controller.

Source: FLIR

Figure 3-6. The FLIR TrafiOne

The company has developed a new sensor called TrafiSense AI, as shown in Figure 3-7. This product, an intelligent thermal imaging sensor for traffic monitoring in complex urban environments, has been designed to reliably detect and classify road users. Featuring AI algorithms built on 25+ years of traffic detection and best-in-class thermal imaging, TrafiSense AI delivers continuous vision and data collection for safer, more efficient cities. It is capable of tracking multiple objects in any lighting condition and the advanced edge-based AI technology can effectively control intersections, help protect vulnerable road users and gather detailed traffic data for better city planning decisions. These sensors can be used at either midblock or signalized intersections for the pedestrian detection function needed in APD systems.

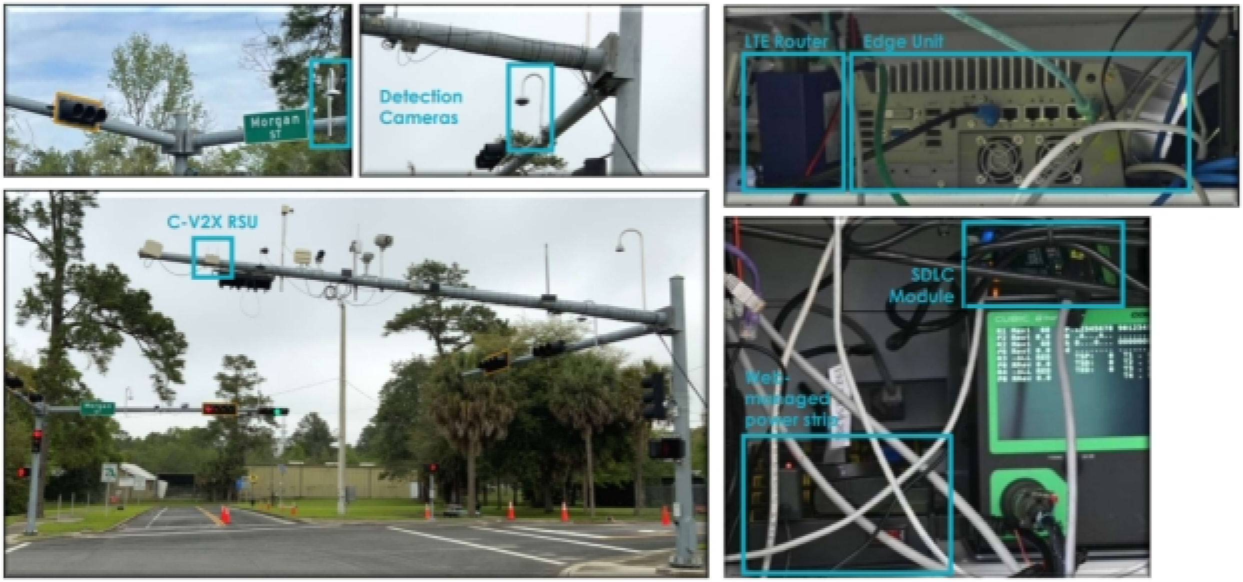
Source: FLIR

Figure 3-7. The FLIR TrafiSense

The specific technologies used for pedestrian detection can vary and may include video cameras, radar sensors, lidar sensors, or other advanced technologies. These systems aim to improve overall traffic safety by ensuring that pedestrians are given sufficient time and priority at intersections and crosswalks.

When implementing sensor technologies, it is important to ensure their integration with the rest of the system to deliver the signal needed for the pedestrian call. As mentioned in Section 3.1, the DERQ technology platform can use any camera or other sensor input and activate passive pedestrian detection. Passive pedestrian detection typically refers to the use of sensor technologies to identify and track pedestrians without requiring active participation or interaction from the pedestrians.

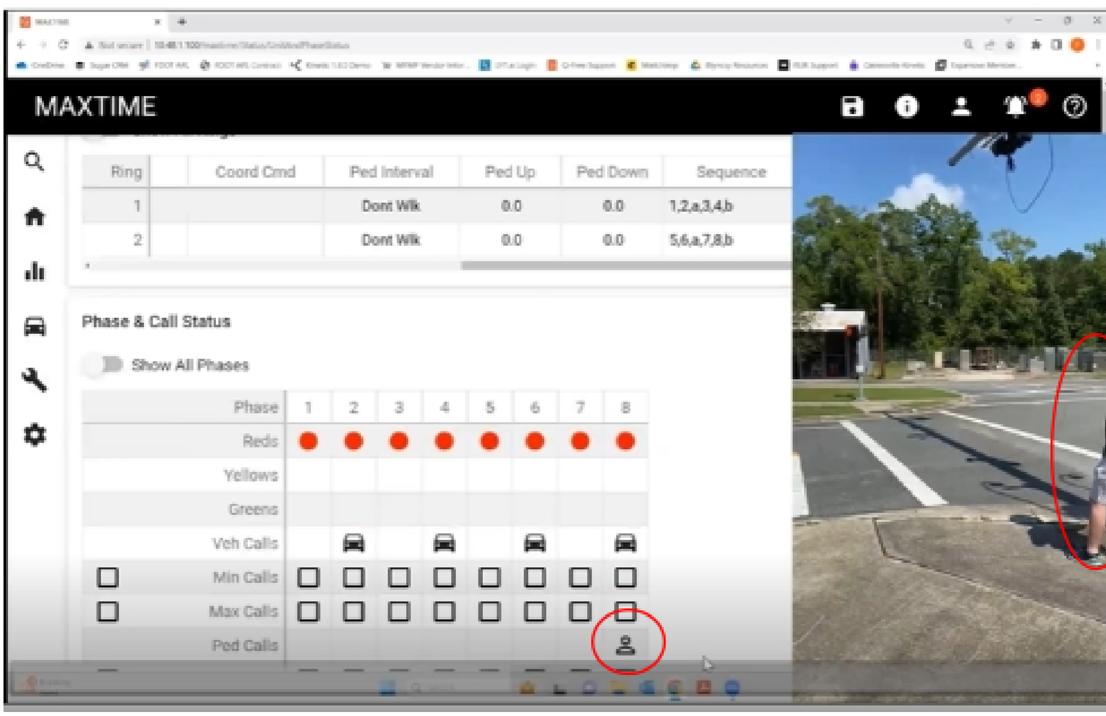
The team worked with a DERQ system vendor that showcased its functionality at the Traffic Engineering Research Laboratory (TERL) in Tallahassee, FL. Figure 3-8 shows the setup at the intersection at the TERL. The camera is used for detection, and the edge unit is used for identification of the users, sending signals to the controller to perform the pedestrian call functions.



Source: Control Technologies

Figure 3-8. Signalized intersection setup at the TERL

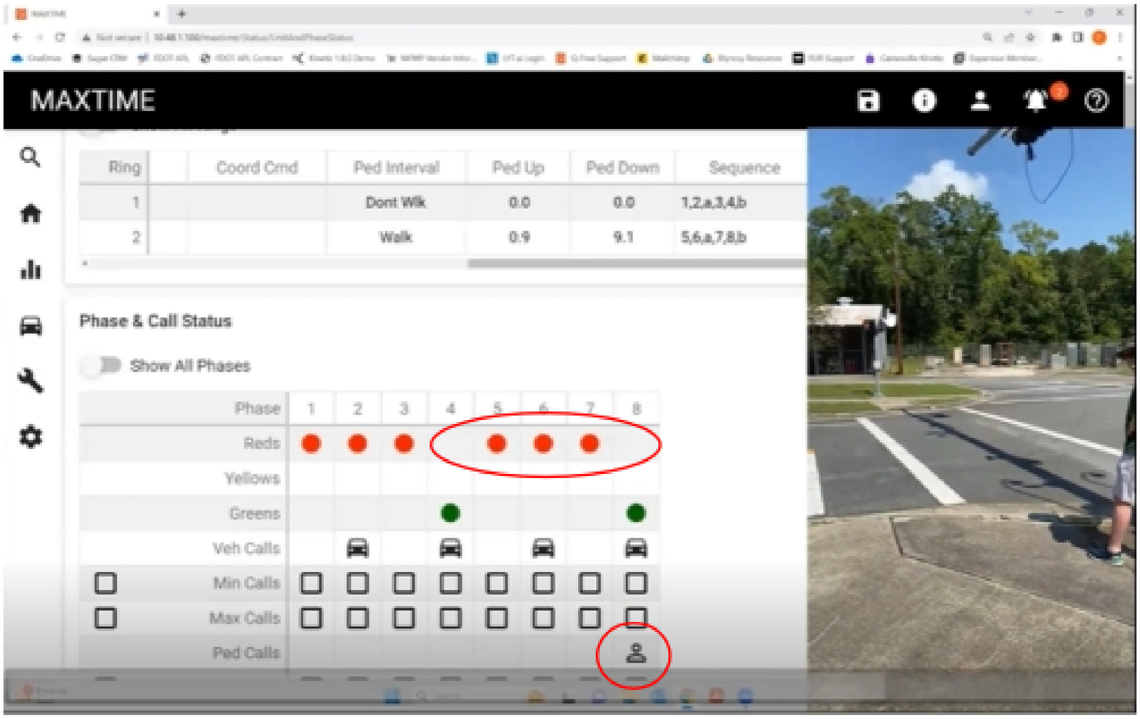
Figure 3-9 shows a screen of the traffic controller during the test. As shown, a pedestrian walks to the sidewalk area at the corner of the intersection on the right, and a pedestrian call is placed under the ped calls in Phase 8.



Source: Control Technologies

Figure 3-9. The pedestrian is detected, and a call is placed

Subsequently, the call is served, as shown in Figure 3-10. The “WALK” sign is displayed along with Phase 4 and Phase 8.



Source: Control Technologies

Figure 3-10. Pedestrian call is served

This example showcases the pedestrian detection function with the DERQ platform, but as described earlier, this can be achieved via other sensors whose dedicated function is to detect pedestrians and send a signal to the controller.

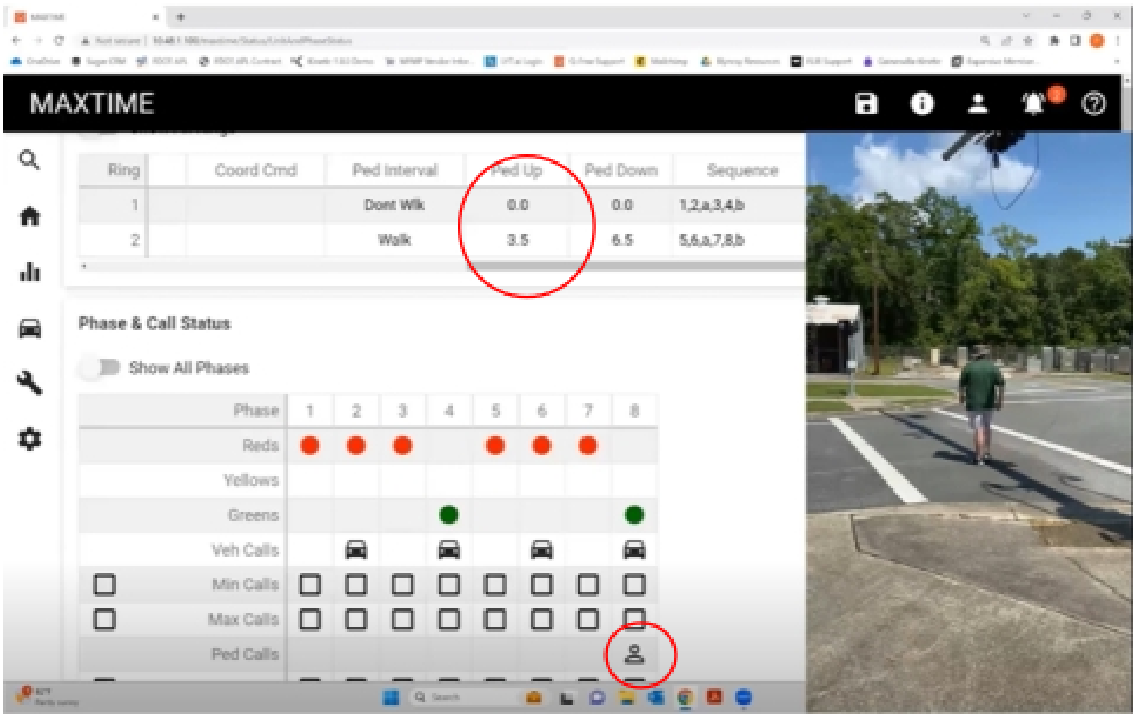
3.3 Extending or Canceling the Pedestrian Calls

As discussed earlier, one of the objectives of this project is to further investigate the functionality of the APD systems to provide the opportunity to extend or cancel the pedestrian call as needed. This functionality is needed to either extend the green time if a slow-moving pedestrian is still present past the original “WALK” time or cancel the call if the pedestrian leaves the detection zone and the call no longer needs to be served. Extending the call will increase safety by providing more time for pedestrians to cross if needed. Canceling the call reduces delay for vehicles, eliminating the need to service the call, thereby saving time for vehicles.

This functionality is achieved by monitoring the crosswalk using the same sensor used for detection or additional sensors if needed. A 360° camera has served this purpose as it can be used to monitor both the sidewalk area for detecting pedestrians, as well as the crosswalk to perform the extension function.

3.3.1 Extending the Pedestrian Call

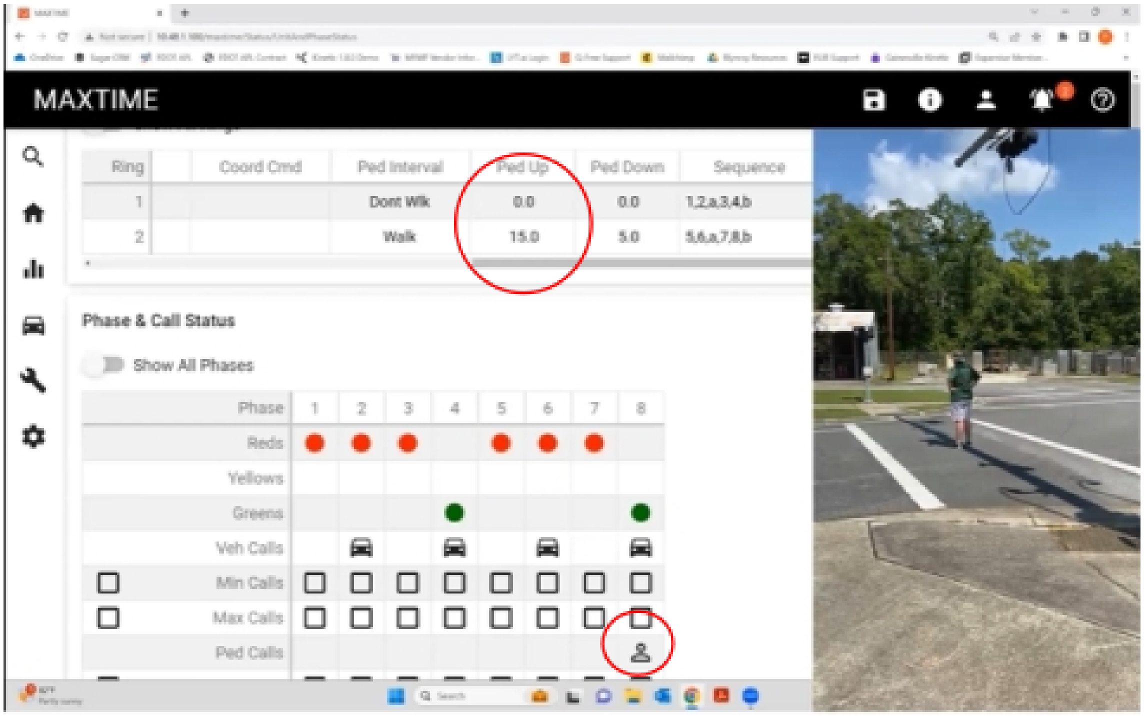
This is needed in cases where the crossing experiences periods of slow-moving pedestrians, intoxicated pedestrians, or is close to a venue that experiences a large volume of pedestrians at specific days/times. During testing at the TERL, the pedestrian movement is treated like a vehicular movement. A walk time of 10 seconds is used, with a 5-second extension and a maximum of 40 seconds for the "WALK" movement before the countdown is displayed. Figure 3-11 shows the pedestrian walking after phase 8 is serviced and "WALK" is displayed for 3.5 seconds.



Source: Control Technologies

Figure 3-11. Pedestrian call is serviced

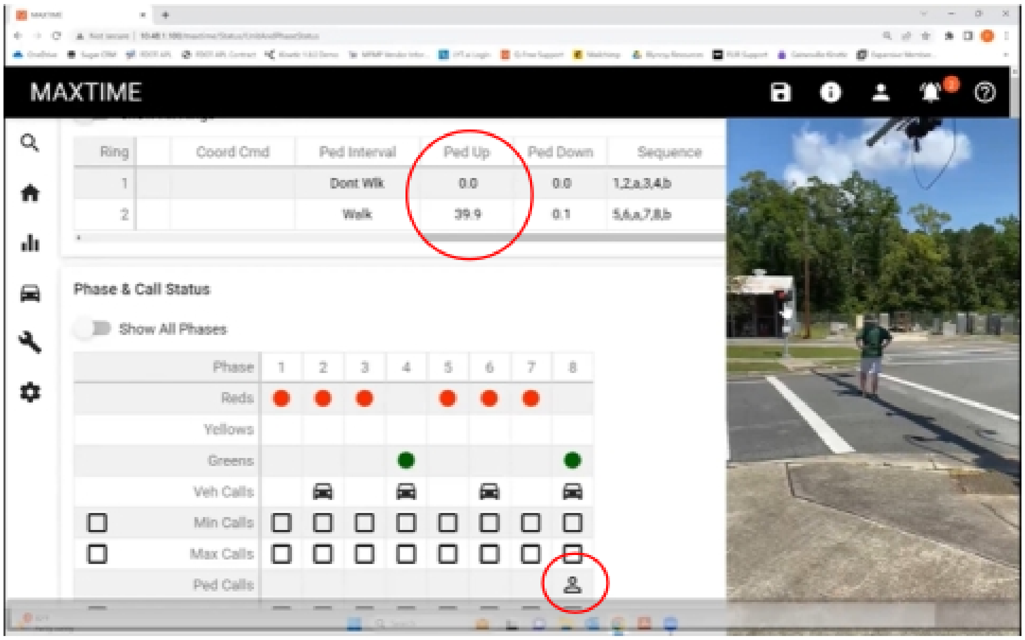
The pedestrian then stops in the middle of the crosswalk to simulate a slow-moving pedestrian or constant demand. Figure 3-12 shows the pedestrian stopped in the crosswalk, and the pedestrian "WALK" signal is displayed for 15 seconds (10s original + 5s extension).



Source: Control Technologies

Figure 3-12. Pedestrian "WALK" is extended

The "WALK" signal is then maxed out to 40 seconds before it changes to countdown. Figure 3-13 shows the "WALK" time at 39.9 seconds before it changes to flash/countdown.



Source: Control Technologies

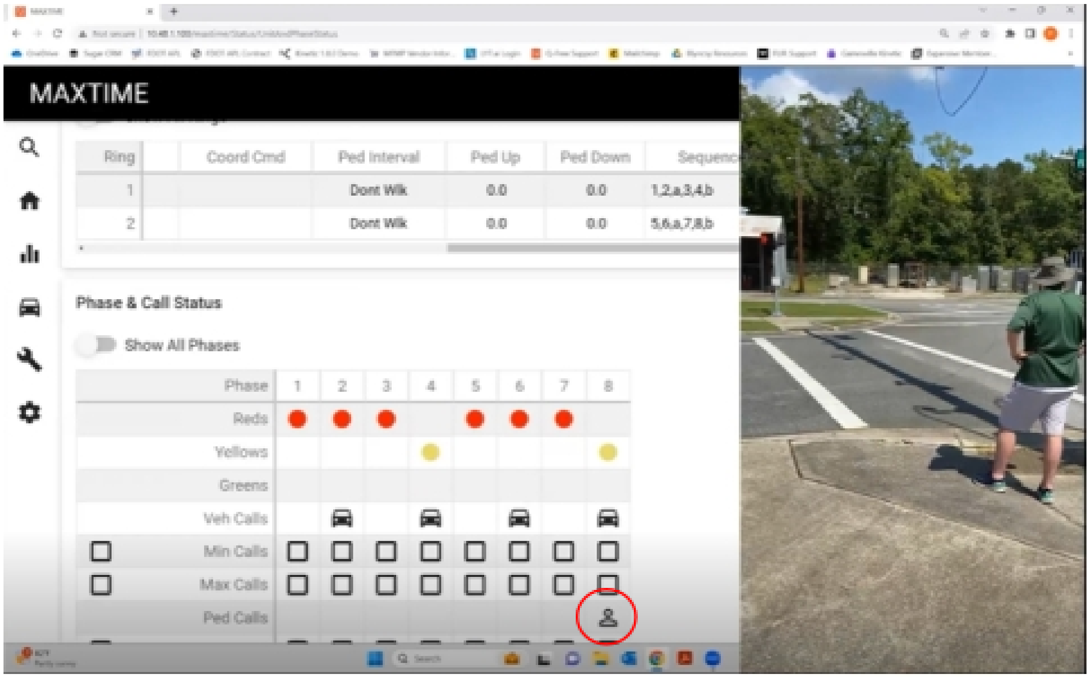
Figure 3-13. Pedestrian "WALK" is maxed out

This example is exaggerated for a scenario where there is a larger volume of pedestrians needing to cross the crosswalk. In reality, the max time can be adjusted to provide enough time for a slow-moving pedestrian to cross the crosswalk while the “WALK” signal is displayed.

3.3.2 Canceling the Pedestrian Call

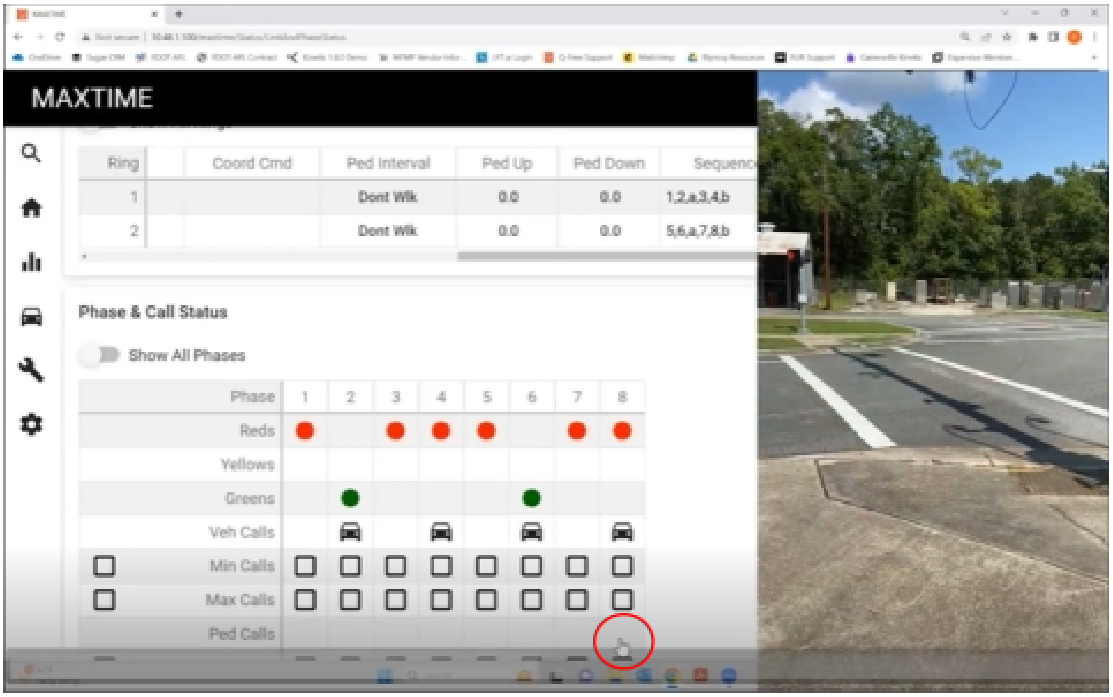
On the opposite side of the extension, there is a need to cancel the pedestrian call if there is no need to be served. Currently, once a pedestrian pushes the button, the pedestrian call is locked in the signal cycle and will be served when it is time. If the pedestrian finds a gap in the traffic and crosses the road before this happens, then the pedestrian call is served while no one is there to cross the road. This can be eliminated by using APD systems.

During the test at the TERL, a pedestrian waiting is first detected (Figure 3-14) but then leaves the detection zone. Once the pedestrian leaves the zone, the pedestrian call is no longer present in the cycle, as shown in Figure 3-15. This functionality can reduce delays because many pedestrians cross at the next available gap, thereby eliminating the need to serve a call when no one is waiting to cross. The functionality shown in the figures comes from a specific vendor of traffic controllers and the DERQ detection platform. The traffic controller that has this built-in functionality is shown in Figure 3-16. The pedestrian call cancelation was also showcased during the first project via a custom logic script programmed into the controller. This was achieved by holding the pedestrian call (not entering the call into the cycle) until the last second before the phase change. If a pedestrian was still present, the pedestrian call was entered and served. If a pedestrian left the scene, it never entered the cycle. This method can be used with any traffic controller.



Source: Control Technologies

Figure 3-14. Pedestrian is detected and call is placed



Source: Control Technologies

Figure 3-15. Pedestrian call is cancelled

Source: Q-Free

Figure 3-16. XN traffic controller

3.4 Integration of Smartphone and Touchless Applications

The last function that this project is focused on is the ability to use a smartphone to trigger pedestrian detection and call for crossing. This is especially useful for disabled pedestrians or during a situation like the COVID-19 pandemic, when pedestrians did not want to touch the push button. The smartphone application can provide a solution to the issue of pedestrians who do not want to push the button, encouraging their use while crossing the street.

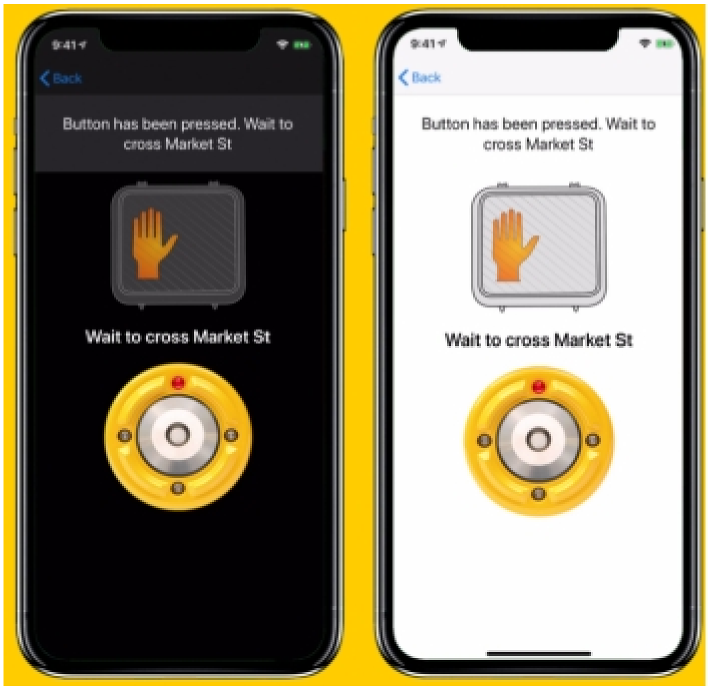
For touchless actuation, the team identified a product that enables touchless actuation via a radar sensor in the push button. The product provides a traditional push button but can also detect pedestrians when they wave at the sensor, similar to touchless faucets and soap dispensers.

Figure 3-17 shows this product which encompasses both a traditional push button and a wave function for touchless actuation. By incorporating this product, an agency can provide additional functionality without the cost of the advanced sensors and additional units.

Source: PedSafety

Figure 3-17. The PedSafety touchless pushbutton

Lastly, the team investigated actuation via a smartphone application. A product called PedApp by Polara is available that can serve this need. The user can install the app on their smartphone, and the phone connects to the button via Bluetooth technology when in close proximity. The pedestrian can choose which direction to cross and push the appropriate button on their phone, thereby sending the signal to the push button interface. Figure 3-18 shows the application in use on a smartphone screen.



Source: Polara

Figure 3-18. Smartphone application

3.5 Findings and Recommendations

This section was focused on conducting a feasibility study to investigate the features of APD systems and add functionality to midblock crossings and signalized intersections. The project team built upon the knowledge developed on the previous project, where an APD with a thermal camera was used to detect pedestrians and send a signal to an RRFB and a traffic controller. The signal activated the RRFB at a midblock crossing and entered a pedestrian call in the traffic controller via a custom logic script. The script was also responsible for cancelling the call if a pedestrian left the detection scene before it was served.

The project team worked with a vendor of ITS technologies in Florida, which provided results of testing performed at the TERL in Tallahassee. Using the technology platform from DERQ, and in conjunction with a traffic controller from Q-Free, the vendor was able to showcase the following:

- The pedestrian is detected when arriving at the waiting area of a midblock crosswalk or signalized intersection.
- As soon as the pedestrian is detected, the pedestrian call is placed in the controller cycle.
- If the pedestrian leaves the area before the call is served, the call is canceled.
- If the pedestrian stays, the call is serviced. The "WALK" signal is displayed for a pre-determined time. If the pedestrian is still in the crosswalk, the "WALK" signal is

extended by a pre-determined time, and it continues to be extended until it reaches a max time. Then the flashing/countdown is displayed.

- Using a separate product from PedSafety, it is possible to add touchless actuation to midblock/intersections by waving at the push button.
- Using a separate product from Polara, it is possible to virtually push the button on a smartphone via an application that connects with the push button module.

Based on these results, the CUTR team is confident that the technology works as described and can provide the necessary features to a signalized intersection or midblock crossing control devices.

4 Evaluation Framework, Deployment, and Data Collection

This section focuses on the evaluation approaches, deployments of APD and DPPD systems, and data collection. Pedestrian safety and creating safer, more pedestrian-friendly roadway facilities are among Florida's top transportation goals. Improving pedestrian safety also plays a vital role in fostering more sustainable and livable communities (*2*). Despite the benefits of measures such as high-visibility crosswalks, RRFBs, PHBs, LPIs, and educational campaigns, their effectiveness can be undermined by pedestrian non-compliance with push-button systems, as discussed in Section 2. The reluctance to use push buttons, especially during the COVID-19 pandemic, underscored the need for automated and touchless solutions.

To ensure the success of this project, the research team developed evaluation, implementation, and data collection plans. These plans aim to assess the effectiveness of APD and DPPD systems and investigate the feasibility of smartphone-based pedestrian call systems in real-world scenarios. By addressing key safety challenges, these technologies can create more walkable and pedestrian-friendly environments.

This section begins by defining the evaluation objectives and criteria, followed by an explanation of the framework and methodologies used in the assessment process. It describes the pilot site selection and testing procedures, as well as the data collection approach, detailing the tools and types of data involved.

4.1 Evaluation Objectives and Criteria

Here, we outline the objectives and criteria of the evaluation plan, emphasizing the importance of implementing innovative pedestrian detection systems to enhance safety and efficiency in pedestrian crossings through automated and touchless technologies.

4.1.1 Objective of Evaluation Plan

The objective of the evaluation plan is to investigate the effectiveness of DPPD or APD systems to: (1) reduce pedestrian crossing risks without the need to physically press a button to place a pedestrian call, (2) cancel pedestrian calls when a pedestrian leaves the waiting area before the call is served, and (3) extend pedestrian crossing time when needed. The use of these systems is expected to result in an increase in pedestrian safety when crossing at an intersection or midblock crossing.

4.1.2 Criteria for Evaluation

The research team has defined criteria that the automated system must meet to be a candidate for this evaluation. The goal, as stated above, is to improve the safety of pedestrians by allowing them to cross the road with the pedestrian signal activated automatically or with little input from them. The criteria are summarized below:

The system must:

- Place a pedestrian call with touchless actuation (pedestrian waves at the sensor),

- Accurately detect pedestrian(s) at waiting areas of a signalized intersection or a midblock crossing with RRFBs or PHBs, and identify intended crosswalk(s) use,
- Place a pedestrian call to a traffic controller after detecting pedestrian(s) at waiting areas of a signalized intersection crossing with RRFBs or PHBs,
- Extend the pedestrian call time depending on the pedestrian presence on the crosswalk,
- Remove or cancel a pedestrian call from a traffic controller before the pedestrian phase is served if the pedestrian leaves the waiting area early before the call is served at a signalized intersection, and
- Place a pedestrian call via smartphone without the need to push a button.

It is noteworthy to mention that the first two criteria are considered the same for two different sensors. In the first case (touchless actuation), the pedestrian activates the system by waving at a sensor without making physical contact, which results in their detection and actuation. In the second case (pedestrian detection), the pedestrian is detected after entering the sensor's walking zone. Both can be used at midblock (triggering RRFB or PHB) or at signalized intersection locations.

4.2 Evaluation Framework and Methodology

This section presents the methodology and performance metrics used to evaluate the effectiveness of APD and DPPD systems, focusing on before-after studies and performance measures to assess their impact on pedestrian safety outcomes comprehensively.

4.2.1 Evaluation Method

Like many other studies that have used a before-after method [2, 20, 35], the team aims to utilize this method to assess the results of the installed systems before and after their deployment.

The use of before-after studies in the context of APD or DPPD to evaluate the effectiveness of these systems in improving pedestrian safety is widely documented. The methodology used is similar to a generic before-after study design but is tailored specifically to assess the impact of APD or DPPD on pedestrian safety outcomes. That methodology is as follows.

Baseline data collection: The study begins with the collection of data on pedestrians crossing the road before the APD or DPPD is implemented. This data serves as a baseline against which the post-APD or post-DPPD results can be compared.

APD or DPPD implementation: Pedestrian detection systems, which typically involve using sensors, cameras, and algorithms to detect pedestrians and provide alerts to drivers, are installed at specific locations. The implementation may vary depending on the specific technology that is being evaluated.

Post-APD or -DPPD data collection: After the installation of the APD or DPPD system, data is collected again using the same method as in the baseline data collection phase. This data captures the pedestrian safety outcomes after the APD or DPPD has been introduced.

Data analysis: The data collected during the before and after periods were then analyzed to evaluate the impact of the APD or DPPD on pedestrian safety. Statistical methods were employed to compare the pre-and post-APD or -DPPD data and determine any significant changes or improvements in pedestrian safety analysis.

Evaluation of effectiveness: The findings of the before-after study were evaluated to determine the effectiveness of the APD or DPPD system in increasing pedestrian safety. If the data analysis indicated an improved safety outcome, it suggested that the APD or DPPD had a positive impact on pedestrian safety.

Like other before-after studies, it was essential to consider potential confounding factors and limitations of the study design, such as changes in user behavior, environmental factors, or concurrent safety interventions. These factors should be accounted for in the data analysis or through control groups to isolate the specific impact of the APD or DPPD on pedestrian safety outcomes.

4.2.2 Performance Measurement

Each system was evaluated according to performance measures defined by the research team, which helped decide whether the system performed accurately or not. To do this, four terms were used:

- True Positive (TP) means a pedestrian was present and was detected by the system.
- False Positive (FP) means a pedestrian was not present, but the system reported detection.
- False Negative (FN) means a pedestrian was present but was not detected by the system.
- True Negative (TN) means a pedestrian was not present and was not detected by the system.

A confusion matrix (shown in Figure 4-1) represents the summary of the prediction results on a classification problem. The table consists of color codes showing that the green cells (TP and TN) are the desirable outcomes of the system, whereas the other two cells are measures that can be adjusted depending on the requirements of the system. For this application, it is more desirable to minimize the FN where a pedestrian is not present, but the system shows detection because this would lead to further delays. The FP needs to be low as well because we do not want pedestrians to wait without being detected.

		Pedestrian Presence	
		Positive	Negative
System Detection	Positive	True Positive (TP)	False Positive (FN)
	Negative	False Negative (FN)	True Negative (TN)

Figure 4-1. Confusion matrix

The confusion matrix depicted in Figure 4-2 provides insights into various performance metrics of the model, including accuracy, precision, recall, and F1 score. These metrics aid in comprehending the model's effectiveness. These metrics can also be computed using the confusion matrix. Notably, NPV represents the negative predicted value. Five performance values are defined as follows:

- Accuracy is the ratio of the records that the model correctly classified over the total number of records.
- Precision is the ratio of the positives that are correctly identified by the model over total positive records.
- Sensitivity is the ability of a test to correctly identify true positives.
- Specificity is the ability of a test to correctly identify true negatives.
- F1 score is a weighted average of the precision and recall/sensitivity, with a best score at 1 and worst score at 0.

		Pedestrian Presence		
		Positive	Negative	
System Detection	Positive	True Positive (TP)	False Positive (FN)	Precision= $\frac{TP}{TP+FP}$
	Negative	False Negative (FN)	True Negative (TN)	NPV= $\frac{TN}{TN+FN}$
		Recall or Sensitivity= $\frac{TP}{TP+FN}$	Specificity= $\frac{TN}{TN+FP}$	Accuracy= $\frac{TP+TN}{TP+TN+FN+FP}$

Figure 4-2. Confusion matrix with accuracy, recall/sensitivity, specificity, and NPV

Table 4-1 shows the defined performance measurements of all six criteria, which are based on the concepts discussed previously. The first two are combined.

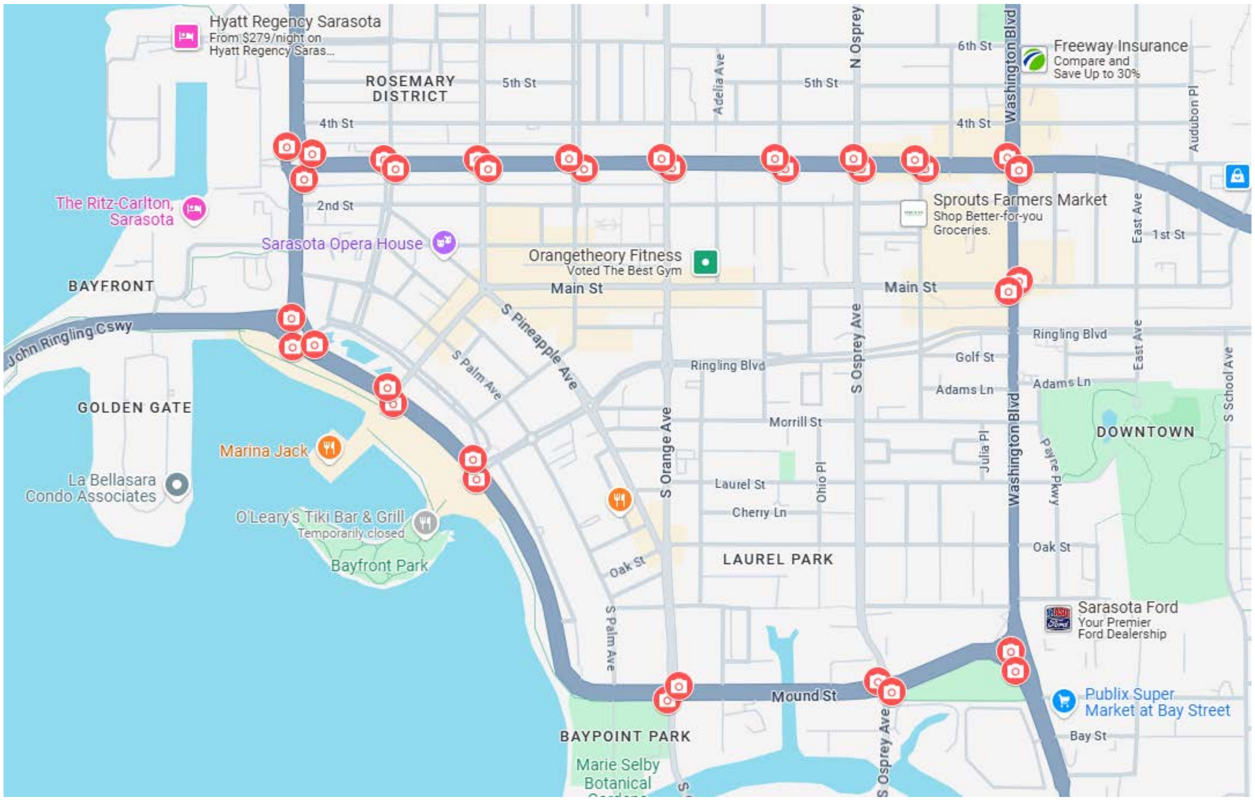
Table 4-1. Performance Measures for Automated Detection Systems

Criterion	Performance Measurement	Description
Touchless Actuation or Pedestrian Detection	True Positive (TP) Actuation	The pedestrian waved at the sensor or was in zone and the sensor was actuated.
	False Negative (FN) Actuation	The pedestrian waved at the sensor or was in zone, but the sensor was not actuated.
	False Positive (FP) Actuation	The pedestrian was not present, but the sensor was actuated.
	True Negative (TN) Actuation	The pedestrian was not present AND the sensor was not actuated.
Place a Call into the Traffic Controller	True Positive (TP) Call	The system places a pedestrian call to a traffic controller after detecting pedestrian(s) in waiting areas.
	False Negative (TN) Call	The system did not place a pedestrian call to a traffic controller after detecting pedestrian(s) in waiting areas.
Extend Pedestrian Call Time	True Positive (TP) Extension	The traffic controller extends the pedestrian time after detecting pedestrians successfully.
	False Negative (FN) Extension	The traffic controller fails to extend the pedestrian time after detecting pedestrians.
Remove/Cancel a Pedestrian Call	True Positive (TP) Cancelation	The traffic controller cancels the pedestrian call after pedestrian was initially detected, call was placed and pedestrian leaves detection zone.
	False Negative (FN) Cancelation	The traffic controller does not cancel the pedestrian call after pedestrian was initially detected, call was placed and pedestrian leaves detection zone.
Pedestrian Call via Smartphone App	True Positive (TP) actuation via smartphone	The pedestrian successfully places a call using the smartphone app and the call is served.
	False Negative (FN) actuation via smartphone	The pedestrian does not place a call using the smartphone app, but the call is served.

4.3 Test Site Selection

The City of Sarasota worked with FDOT to acquire and install the DERQ system for a connected vehicle (CV) project at several intersections on three key corridors in Sarasota. The city acquired and deployed the selected DERQ AI platform for pedestrian detection systems. The CUTR project team worked closely with the City of Sarasota and its vendor and technology provider to identify and select six test sites for evaluation of the DPPD system, including four signalized intersections and two midblock locations. This decision was made based on the project timeline, the deployment schedule of the City of Sarasota, and the opportunity to evaluate the APPD system at more study sites. The CUTR project team also considered sites in District 5 where the same system would be installed in the last quarter of 2024. This was out of the project's timeline, so the City of Sarasota was selected as the collaboration partner for this FDOT research project.

The City of Sarasota anticipated implementing its DPPD system with CV applications at 16 signalized intersections and two midblock crosswalks, mainly located in the heart of downtown Sarasota. Figure 4-3 shows the 16 signalized intersections implementing the new DPPD system.



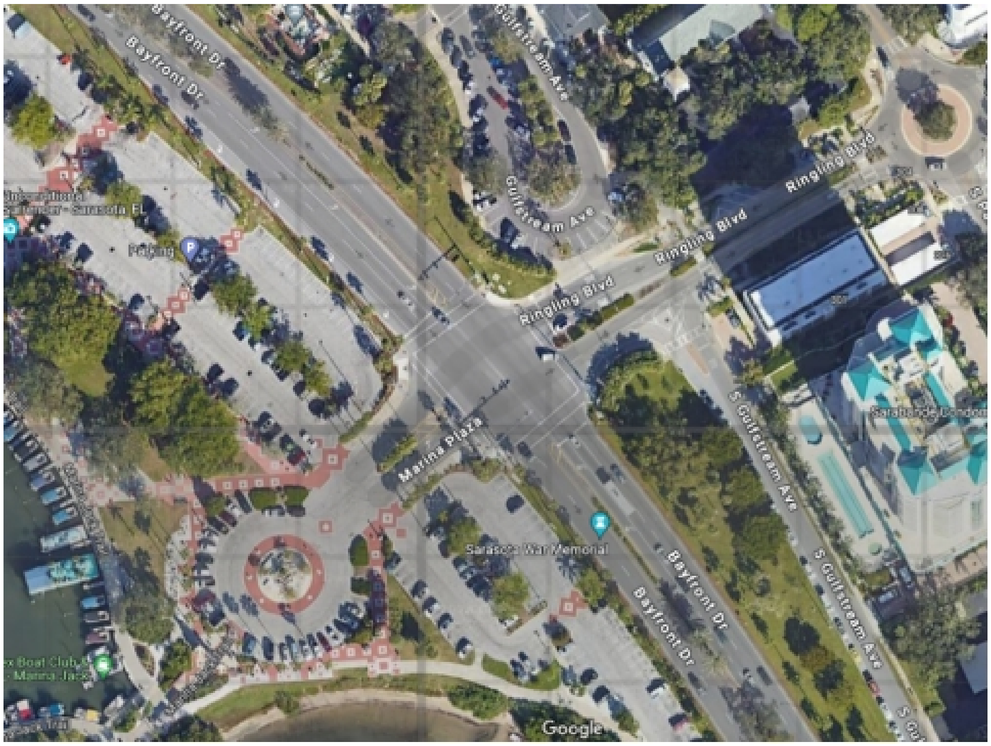
Source: City of Sarasota

Figure 4-3. Selected deployment locations in the City of Sarasota

As shown in Figure 4-3 , all the systems are installed on Fruitville Road, Washington Blvd (US-301), and US-41. The CUTR research team, in collaboration with the City of Sarasota, Control Technologies, and DERQ, chose four intersections with four approaches and two midblock locations with PHB to conduct data collection, analysis, and evaluation. Figure 4-4 through Figure 4-7 show the four signalized intersections selected for investigation and evaluation and Figure 4-8 and Figure 4-9 display the midblock crosswalk locations with PHB.

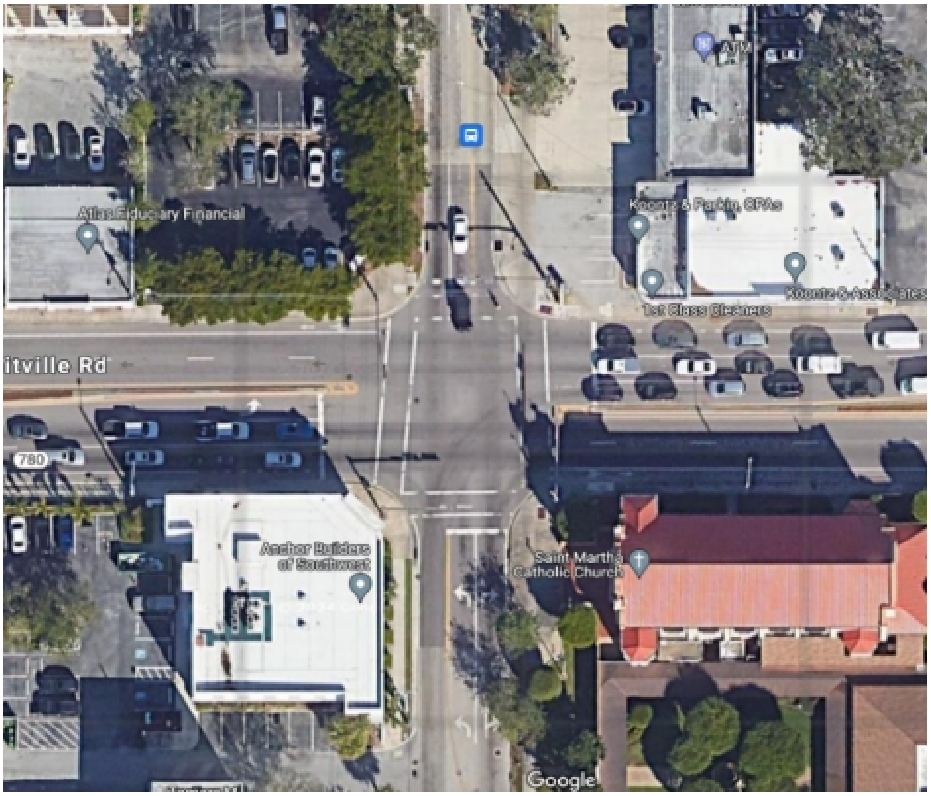
Source: Google Maps

Figure 4-4. Signalized intersection at US-301 and Main Street



Source: Google Maps

Figure 4-5. Signalized intersection at US-41 and Ringling Road



Source: Google Maps

Figure 4-6. Signalized intersection at Fruitville Road and Orange Avenue

Source: Google Maps

Figure 4-7. Signalized intersection at Main Street and US-41

Source: Google Maps

Figure 4-8. Midblock crosswalk at Bahia Vista Street and Legacy Trail

Source: Google Maps

Figure 4-9. Midblock crosswalk at Legacy Trail and S Tuttle Avenue

4.4 Installation of Pedestrian Detection Systems

In collaboration with the City of Sarasota, the CUTR project team participated in, observed, and documented the DPPD system installation in Sarasota to understand the installation parameters, system configuration, functionality, and limitations. Below are the details on how the DPPD system using DERQ's AI platform works.

4.4.1 AI-enabled Automated Pedestrian Detection

The Sarasota DPPD systems were installed in March and April 2024 at 16 signalized intersections on Fruitville Road, Washington Blvd (US-301), and US-41, and midblock locations on Bahia Vista St. at Legacy Trail and Tuttle Ave at Legacy Trail. Figure 4-10 shows the DPPD system installation at the intersection of Fruitville Rd and Lemon Ave.

Source: CUTR

Figure 4-10. DPPD system installation at the Fruitville Rd and Lemon Ave intersection

4.4.2 Touchless Automated Pedestrian Detection System

The CUTR project team collaborated with the City of Tampa to evaluate a location with touchless actuation. The study site was located at the Meridian Ave and Kennedy Blvd intersection in Tampa. It was equipped with a system illustrated in Figure 4-11, which was installed at all crosswalks of the intersection. The team visited the site and performed tests to determine effectiveness. The system worked 100 percent of the time without any false positives. Once the pedestrian waves their hand, the system detects and enters the call into the controller, in the same way as if a push button was pressed.

Source: CUTR

Figure 4-11. The PedSafety system installed at a City of Tampa intersection

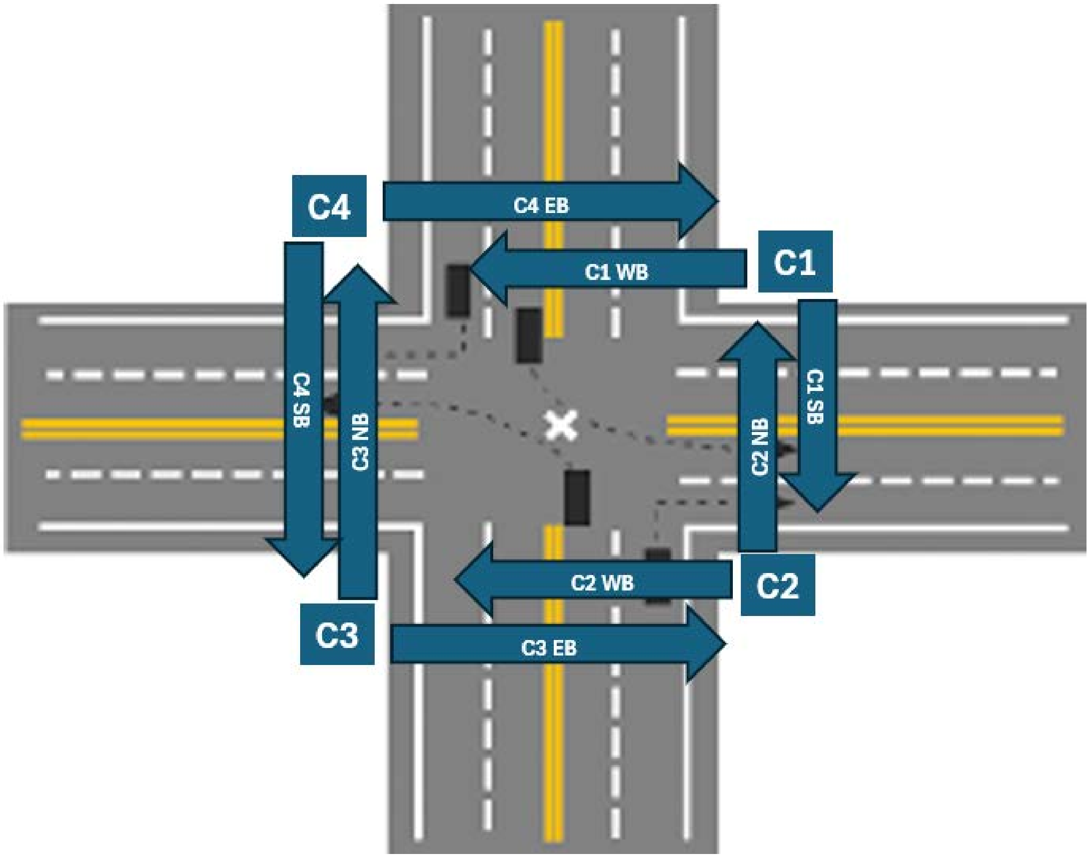
4.5 Data Collection

This section discusses how the data required for analysis has been collected. One of the project's objectives is to evaluate how the installed system could benefit road users, so a before-after study was conducted. The before period covers the time when crossing counts and behavior were collected before the installation of the system. The after period covers the same sites and includes data collected after installing the systems. The data collection includes observations and staged behavior to identify how the system works. Six test locations have been selected, as outlined in Section 4.3. These include four signalized intersections, and two midblock crosswalks equipped with PHBs.

4.5.1 Before Period

As mentioned earlier, the first phase is to collect data for the period before the APD/DPPD system is installed. For this, we collected data for four signalized intersections and two midblock crosswalks. The research team has also defined criteria to evaluate the installed automated system.

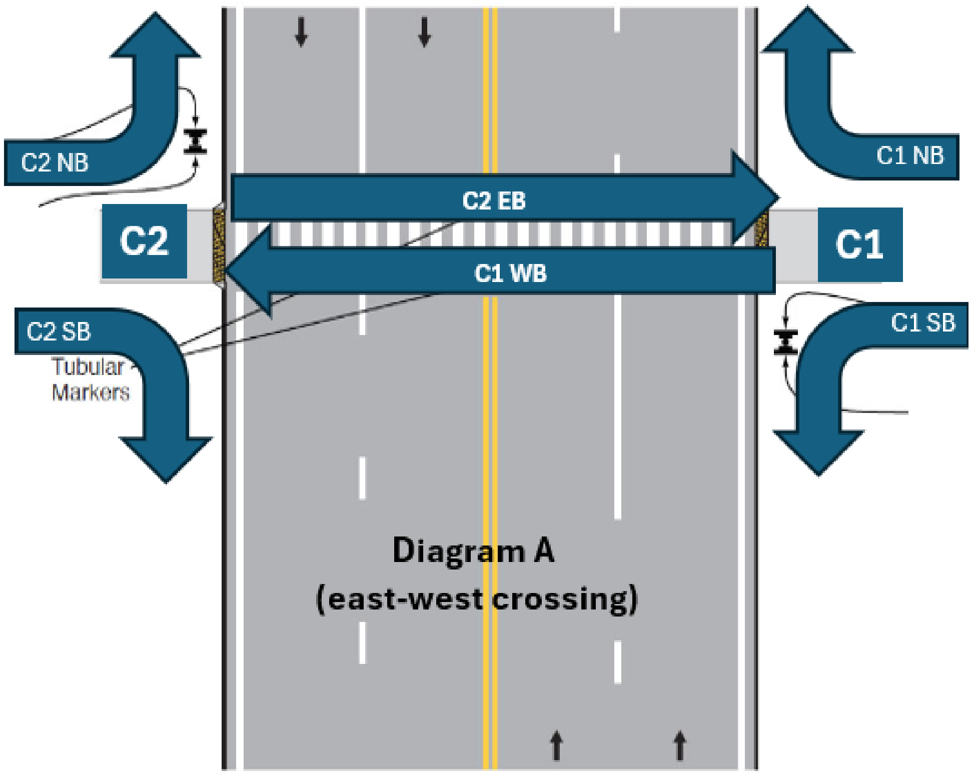
To gather the data, the research team collected pedestrian and bicycle crossing counts and observations for all directions, as shown in Figure 4-12. Since each signalized intersection has four corners, starting from C1 through C4, the observers collected when and how pedestrians crossed each crosswalk. For instance, a pedestrian in corner C1 can cross south or west, while a pedestrian in corner C3 can cross north or east.



Source: CUTR

Figure 4-12. Signalized intersection data collection diagram

For the two midblock crosswalks, a similar concept was used but modified to accommodate the differences in directions (see Figure 4-13). The midblock crosswalk has two corners, including C1 and C2.



Source: CUTR

Figure 4-13. Midblock crosswalk data collection diagram

Scenarios Observed Before Data Collection:

- Percentage of pedestrians who push the button.
- Percentage of pedestrians who push the button and cross on the walk signal.
- Percentage of pedestrians who push the button and cross on a red signal.
- Percentage of pedestrians crossing the walk signal without pushing the button.
- Percentage of pedestrians crossing on red signal without pushing the button.

At mid-blocks, where there was a high volume of both pedestrians and bicyclists, observations included:

- Percentage of pedestrians and cyclists who push the button.
- Percentage of pedestrians and cyclists who push the button and cross on the walk signal.
- Percentage of pedestrians and cyclists who push the button and cross on a red signal.
- Percentage of pedestrians and cyclists who cross on the walk signal without pushing the button.
- Percentage of pedestrians and cyclists who cross on the red signal without pushing the button.

Details on the data collected for the before period follow.

4.5.1.1 Four-Way Intersection Crosswalks

The team collected behavior data in the method described above, at four intersections. The data collected is shown in Table 4-2. The sites are shown in Figure 4-14 through Figure 4-17. Detailed analysis on the data collected is presented in Section 5.

Table 4-2. Pedestrian Observations at Signalized Intersections

Intersection	% (n)
Fruitville Rd & US-301	14% (171)
Ringling & US-41	26% (329)
Orange Ave & Fruitville Rd	26% (328)
Main St & US-41	34% (418)
Total	100% 1,246

Source: Google Maps

Figure 4-14. Fruitville Rd and US-301 four-way intersection

Source: CUTR

Figure 4-15. Ringling Blvd and US-41 four-way intersection

Source: CUTR

Figure 4-16. Orange Ave and Fruitville Rd four-way intersection

Source: CUTR

Figure 4-17. Main Street and US-41 four-way intersection

4.5.1.2 Midblock Crosswalks

The team collected data at two midblock crosswalks with PHB. Table 4-3 shows the number of observations for each. In addition, the sites are shown in Figure 4-18 and Figure 4-19. Detailed analysis on the data collected is presented in Section 5.

Table 4-3. Pedestrian and Cyclist Observations at Midblock Crossings

Observations	% (n)
Legacy Trail & Bahia Vista	51% (244)
Legacy Trail & Tuttle Ave	49% (232)
Total	100% (476)

Source: CUTR

Figure 4-18. Legacy Trail and Bahia Vista midblock crosswalk

Source: CUTR

Figure 4-19. Legacy Trail and Tuttle Ave midblock crosswalk

4.5.2 After Period

The after-data collection focused on evaluating the APD's operation. The data collection was conducted at four signalized intersections and one midblock location. Three of the intersections were the same as in the before period: Fruitville Rd & US-301, US-41 & Ringling Blvd, and Orange Ave & Fruitville Rd. For the fourth intersection, the City of Sarasota could not implement pedestrian detection because the controller runs two intersections, so a fourth location was selected at Fruitville Rd and Lemon Ave. For the midblock crosswalks, only the Legacy Trail and Tuttle Ave location was functional.

For all locations, the following scenarios were observed:

Scenario 1: Place a Call into the Traffic Controller:

True Positive (TP) Call: The system placed a pedestrian call to a traffic controller after detecting pedestrian(s) in waiting areas. A team member walked into the waiting zone, and if a ped call was served (walk signal activated), it was marked as a TP.

False Negative (FN) Call: The system did not place a pedestrian call to a traffic controller after detecting pedestrian(s) in waiting areas. A team member walked into the waiting zone, and if a ped call was not served (walk signal not activated), it was marked as a FN.

Scenario 2: Extend Pedestrian Call Time:

True Positive (TP) Extension: The traffic controller extended the pedestrian time after detecting pedestrians successfully. A team member walked into the crosswalk during the walk signal and crossed at a slow pace so that the green time was over, so the pedestrian time was forced into an extension (past the recorded normal green time). If this was successful, then it was marked as a TP.

False Negative (FN) Extension: The traffic controller failed to extend the pedestrian time after detecting pedestrians. A team member walked into the crosswalk during the walk signal and crossed at a slow pace so that the green time was over, but the pedestrian time was not forced into an extension (past the recorded normal green time). This was marked as a FN.

Scenario 3: Remove/Cancel a Pedestrian Call:

True Positive (TP) Cancellation: The traffic controller canceled the pedestrian call after the pedestrian was initially detected, the call was placed, and the pedestrian left the detection zone. A team member walked into the detection zone, stayed for 10 seconds (call is placed) and then walked away from the zone. If the call was not served it was marked as a TP.

False Negative (FN) Cancellation: The traffic controller did not cancel the pedestrian call after the pedestrian was initially detected, the call was placed, and the pedestrian left the detection zone. A team member walked into the detection zone, stayed for 10 seconds (call is placed) and then walked away from the zone. If the call was served it was marked as a FN.

The study analyzed the collected data to determine the feasibility and effectiveness of the installed pedestrian call system enhancements.

5 Evaluation of Effectiveness of APD/DPPD Systems

In our urbanized world, the effectiveness of touchless actuation, smartphone integration and APD, DPPD systems has become paramount in ensuring the safety and convenience of pedestrians and motorists alike (*24*). These systems represent cutting-edge technology in transportation, promising to enhance efficiency, mitigate risks, and optimize pedestrian and vehicle flows in various urban environments. In this evaluation, the team investigated the efficacy of these technologies, examining their performance in real-world scenarios and overall urban mobility. Through rigorous analysis and empirical evidence, we aim to provide valuable insights into the strengths, limitations, and potential applications of touchless actuation, smartphone integration, automated pedestrian detection, and dynamic passive pedestrian detection systems in modern urban transportation networks. This section presents a before-after data analysis, evaluation results, and research findings on the effectiveness of APD/DPPD systems studied in this project. It also offers guidelines developed by the research team for implementing passive pedestrian systems at signalized intersections and midblock locations.

5.1 Data Analysis and Evaluation: Before Period

The CUTR research team analyzed the data collected during the before period, when the APD/DPPD system had not yet been installed.

5.1.1 Four-way Intersection Crosswalks

Table 5-1 presents a summary of the measures collected at the four signalized intersections before the deployment of the detection system.

Table 5-1. Summary of Measures for Intersections

Performance Index	Name of Signalized Intersection			
	Fruitville Rd & US 301	US 41 & Ringling Blvd	Orange Ave & Fruitville Rd	Main Street & US 41
Percentage of pedestrians who pushed the button	64% (109)	80% (264)	95% (313)	98% (410)
Percentage of pedestrians who pushed the button and crossed on Walk	46% (78)	80% (262)	74% (242)	100% (416)
Percentage of pedestrians who pushed the button but crossed on Do Not Walk	4% (6)	3% (9)	6% (20)	2% (10)
Percentage of pedestrians who crossed on Walk (did not have to push button)	30% (52)	12% (40)	2% (7)	2% (7)
Percentage of pedestrians who crossed on Do Not Walk without pushing button	18% (30)	5% (18)	24% (77)	0.24% (1)

5.1.2 Midblock Crosswalks

Table 5-2 presents a summary of the measures collected at the two midblock crosswalks before deployment of the detection system.

Table 5-2. Summary of Measures for Midblock Crosswalks

Performance Index	Legacy Trl & Tuttle Ave	Legacy Trl & Bahia Vista St
Percentage of pedestrians and cyclists who pushed the button	83% (187)	82% (199)
Percentage of pedestrians and cyclists who pushed the button and crossed on WALK	75% (173)	73% (177)
Percentage of pedestrians and cyclists who pushed the button and crossed on DON'T WALK	4% (10)	10% (25)
Percentage of pedestrians and cyclists who crossed on WALK without pushing the button	32% (49)	9% (23)
Percentage of pedestrians and cyclists who crossed on Do Not WALK without pushing the button	6% (12)	7% (18)

5.2 Data Analysis and Evaluation: After Period

The team waited one month after installation to allow the system to pass its initial training period. The results of the data collection for the after period are summarized below.

5.2.1 Four-way Intersection Crosswalks

Scenario 1: Place a Call into the Traffic Controller

The team collected 398 crossings at four intersections, with 222 (56%) during the day and 176 (44%) at night. A detailed breakdown of TP and FN actuation by light condition is provided in Table 5-3 below.

Table 5-3. System Performance for Placing Pedestrian Calls at Signalized Intersections

Location	Measure	Daytime	Nighttime	Weighted Average
Fruitville Rd & Orange Ave	True Positive (TP) Actuation	98%	95%	97%
	False Negative (FN) Actuation	2%	5%	3%
Fruitville Rd & Lemon Ave	True Positive (TP) Actuation	89%	48%	69%
	False Negative (FN) Actuation	11%	52%	31%
Ringling Blvd & US 41	True Positive (TP) Actuation	74%	28%	48%
	False Negative (FN) Actuation	26%	72%	52%
US-301 & Fruitville Rd	True Positive (TP) Actuation	97%	57%	83%
	False Negative (FN) Actuation	3%	43%	17%

The analysis found that the automated pedestrian detector system performed differently during daytime and nighttime. During the day for all four intersections, the True Positive (TP) rate was 91%, and a False Negative (FN) rate of 9%. During nighttime, however, the TP fell to 54%. This shows that nighttime detection is not as accurate as daytime. This might be due to lower detection accuracy with low lighting, as not all intersections are well-lit. Each intersection and each crosswalk exhibited slightly different results.

Scenario 2: Extend Pedestrian Call Time

For this scenario, the team collected 298 crossings, with 154 (52%) during the day and 144 (48%) at night. The system's ability to extend pedestrian calls was tested. The system successfully extended the calls in the NB and SB directions. This feature was not active for the EB-WB directions. As shown in Table 5-4, the True Positive (TP) rate varied from 100% to 57%, depending on location. Based on the data, it looks like the system performs better during the daytime, which might be related to detection accuracy for a pedestrian in the crosswalk.

Table 5-4. System Performance in Extending Pedestrian Call Time at Signalized Intersections

Location	Measure	Daytime	Nighttime	Weighted Average
Fruitville Rd & Orange Ave	True Positive (TP) Actuation	100%	100%	100%
	False Negative (FN) Actuation	0%	0%	0%
Fruitville Rd & Lemon Ave	True Positive (TP) Actuation	96%	37%	68%
	False Negative (FN) Actuation	4%	63%	32%
Ringling Blvd & US 41	True Positive (TP) Actuation	77%	42%	57%
	False Negative (FN) Actuation	23%	58%	43%
US-301 & Fruitville Rd	True Positive (TP) Actuation	*	*	*
	False Negative (FN) Actuation	*	*	*

* Pedestrian detection was not active at this location

Scenario 3: Remove/Cancel a Pedestrian Call

For this scenario, 280 crossings were collected, with 180 (64%) during the day and 100 (36%) at night. This scenario evaluated the system's ability to cancel pedestrian calls when the pedestrian leaves the detection zone. The system's performance was measured by how often it correctly canceled the call (True Positive Cancellation) and how often it failed to do so (False Negative Cancellation). This feature was not active at all crosswalks. The data presented is for the crosswalks where extension was active. The results show that the system performed well in the Northbound (NB) and Southbound (SB) directions, with high TP rates as shown in Table 5-5.

Table 5-5. System Performance in Canceling Pedestrian Calls at Signalized Intersections

Location	Measure	Daytime	Nighttime	Weighted Average
Fruitville Rd & Orange Ave	True Positive (TP) Actuation	57%	49%	53%
	False Negative (FN) Actuation	43%	51%	47%
Fruitville Rd & Lemon Ave	True Positive (TP) Actuation	81%	63%	75%
	False Negative (FN) Actuation	19%	37%	25%
Ringling Blvd & US 41	True Positive (TP) Actuation	77%	59%	70%
	False Negative (FN) Actuation	23%	41%	30%
US-301 & Fruitville Rd	True Positive (TP) Actuation	*	*	*
	False Negative (FN) Actuation	*	*	*

* Pedestrian call cancellation was not observed at this location

5.2.2 Midblock Crosswalk

During the data collection period and within the project's timeframe, only one of the two midblock crosswalks at Legacy Trail and Tuttle Ave was activated with automated pedestrian detection. The second one experienced electrical issues after a lightning storm and was not active.

Scenario 1: Place a Call into the Traffic Controller

In this scenario, the pedestrian detection system performed flawlessly in both the Eastbound (EB) and Westbound (WB) directions, successfully placing a pedestrian call to the traffic controller in every instance where a pedestrian was detected. As shown in Table 5-5, the True Positive (TP) rate was 100%, meaning the system reliably triggered the necessary pedestrian calls without any failures both during daytime and nighttime.

Table 5-6. Pedestrian Call Performance at Legacy Trail and Tuttle Ave Midblock

Measure	Daytime	Nighttime	Weighted Average
True Positive (TP) Actuation	100%	100%	100%
False Negative (FN) Actuation	0%	0%	0%

Source: CUTR

Figure 5-1. Legacy Trail and Tuttle Trail midblock crosswalk

Scenario 2: Extend Pedestrian Call Time

The system demonstrated a high success rate with minor False Negatives when extending pedestrian call time, meaning it generally extended it effectively when needed. However, there were a few instances during nighttime where the system failed to do so. As shown in Table 5-7, the True Positive (TP) rates remained high, but the occasional False Negative (FN) indicates that the system did not always extend the call as expected only during nighttime.

Table 5-7. Pedestrian Call Time Extension Performance at Legacy Trail and Tuttle Ave Midblock

Measure	Daytime	Nighttime	Weighted Average
True Positive (TP) Actuation	100%	84%	97%
False Negative (FN) Actuation	0%	16%	3%

Scenario 3: Remove/Cancel a Pedestrian Call

This feature was not activated at the midblock crossings; therefore, no data was collected.

5.3 Overall Summary of Analysis Results

The data collection process aimed to evaluate pedestrian behaviors and the effectiveness of an automated pedestrian detection system at various intersections and midblock crossings. Before the system's implementation, data was gathered at four intersections: Fruitville Rd & US-301, US-41 & Ringling Blvd, Orange Ave & Fruitville Rd, and Main Street & US-41, as well as two midblock crossings: Legacy Trail & Bahia Vista Ave and Legacy Trail and Tuttle Ave. The results showed varying levels of pedestrian compliance with signals. For instance, at Main Street and US-41, 98% of pedestrians pushed the button, and 100% crossed on the walk signal, indicating high compliance. In contrast, Orange Ave and Fruitville Rd had significant noncompliance, with 24% of pedestrians crossing on red without pushing the button. Midblock crossings presented mixed compliance levels, especially among cyclists, with notable safety concerns at Legacy Trail and Bahia Vista, where 10% crossed on red after pushing the button.

After implementing the automated pedestrian detection system, data were collected to assess the system's performance in automatically placing pedestrian calls, extending call times, and canceling calls when necessary. Data were collected at three of the same intersections and one additional intersection. Only one midblock crosswalk was active during data collection in the after period.

At the intersection crosswalks, the system performed with the following results:

- The system performed better during daytime than nighttime. The highest observed accuracy was 98% during daytime and 95% during nighttime. Some intersections seem to have issues that need to be addressed with algorithm training.
- The system had the highest accuracy (100% TP) in extending pedestrian calls and 0% FN, which is essential to ensure pedestrian safety and smooth traffic flow. As with detection, some intersections exhibited less accuracy, which can be adjusted by fine-tuning the algorithm.
- The system seems to be less accurate in canceling calls, with 81% being the highest TP rate and 57% the lowest TP rate. This means the system needs to be adjusted to achieve a higher accuracy.

At the midblock crossing at Legacy Trail and Tuttle Ave, the system performed with the following results:

- The system performed with a 100% accuracy rate in placing calls and extending call times.
- Overall, while the system shows promise in improving pedestrian safety, it still requires refinement in canceling pedestrian calls to ensure its overall effectiveness.
- Table 5-8 shows the defined performance measurements of all criteria, which are based on the concepts discussed in previous sections. The best results achieved for each criterion are shown. During data collection, different environmental factors (weather) and lighting might have affected the performance of the system.

The team was not able to test the smartphone application as only one vendor offers it. The team is working to implement at least one at the USF Tampa campus for testing.

Table 5-8. Best Performance Results Achieved for Automated Detection Systems

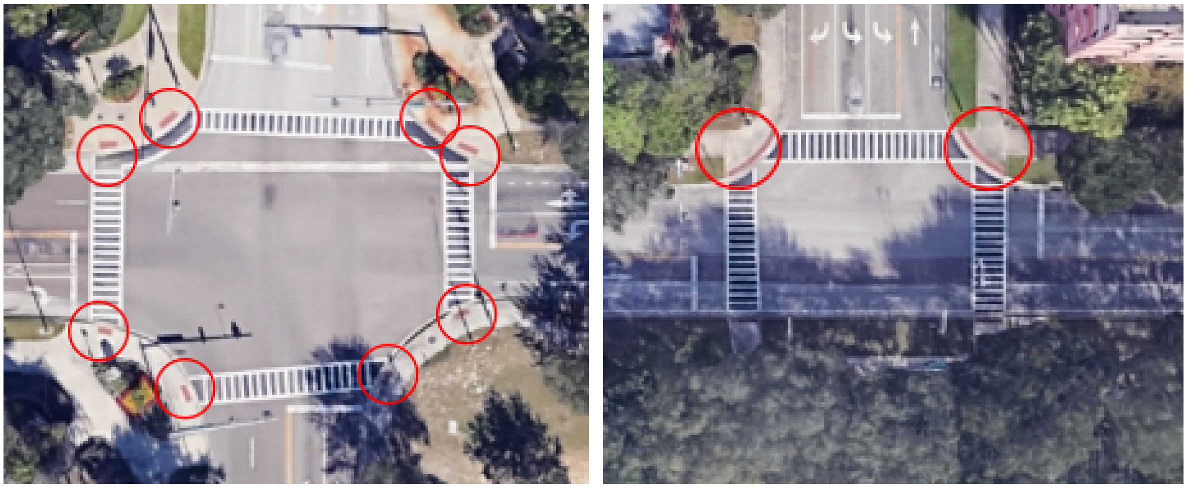
Criterion	Performance Measurement	Description	Best Result Intersection	Best Result Midblock
Touchless Actuation	True Positive (TP) Actuation	The pedestrian was detected (this was observed by the red LED light on the push button).	100%	Not deployed
	False Negative (FN) Actuation	The pedestrian was present, but the sensor was not actuated (this was observed by the red LED light on the push button).	0%	Not deployed
Pedestrian Detection	True Positive (TP) Actuation	The pedestrian was detected (this was not directly observed but assumed given that a call was placed).	97%	100%
	False Negative (FN) Actuation	The pedestrian was present, but the sensor was not actuated (this was not directly observed but assumed given that a call was not placed).	3%	0%
Place a Call into Traffic Controller	True Positive (TP) Call	The system places a pedestrian call to a traffic controller after detecting pedestrian(s) in waiting areas.	97%	100%
	False Negative (TN) Call	The system did not place a pedestrian call to a traffic controller after detecting pedestrian(s) in waiting areas.	3%	0%
Extend Pedestrian Call Time	True Positive (TP) Extension	The traffic controller extends the pedestrian time after detecting pedestrians successfully.	100%	97%
	False Negative (FN) Extension	The traffic controller fails to extend the pedestrian time after detecting pedestrians.	0%	3%
Remove/ Cancel a Pedestrian Call	True Positive (TP) Cancelation	The traffic controller cancels the pedestrian call after pedestrian was initially detected, call was placed and pedestrian leaves detection zone.	75%	--
	False Negative (FN) Cancelation	The traffic controller does not cancel the pedestrian call after pedestrian was initially detected, call was placed and pedestrian leaves detection zone.	25%	--

5.4 Implementation Guidelines

Implementing passive pedestrian systems at signalized intersections and midblock locations involves careful planning and consideration of various factors to ensure safety, accessibility, and efficiency. Based on the literature review in the project Deliverable 1, collected data, experiences obtained, and data analysis results from Task 4, the CUTR project team has developed guidelines for where, when, and how to implement these systems:

5.4.1 Where to Implement Passive Pedestrian Detection Systems

1) *High Pedestrian Traffic Areas at Signalized Intersections and Midblock Crossings*: Install APD or DPPD systems at signalized intersections or midblock crosswalks using RRFB or PHB with high pedestrian volumes, such as those near schools, shopping centers, transit hubs, and residential areas.
2) *Locations with Low Compliance with Traffic Signals:* Implement systems at signalized crosswalks at intersections and midblock locations to ensure pedestrians' compliance with traffic signals and enhance pedestrian safety and also reduce unnecessary vehicle delays by cancelling unneeded pedestrian calls to cross urban and suburban corridors.
3) *High Crash Zones:* Install systems at intersections or midblock locations using RRFB or PHB with a history of pedestrian-related crashes or near locations with high potential for such incidents.
4) *Accessibility Needs:* Focus on locations with significant accessibility needs, such as areas frequented by individuals with disabilities, elderly pedestrians, or those with limited mobility.
5) *Signalized Intersections with Separate Waiting Areas:* Install systems at a signalized intersection with separate waiting areas instead of joint areas for two directions to obtain higher and more accurate pedestrian detection rates since the system will be more certain on the specific crosswalk the pedestrian there is waiting for. For example, the site on the left of Figure 5-2 is better than the site on the right of Figure 5-2.



Source: Google Maps

Figure 5-2. Example of waiting zone for each crosswalk

5.4.2 When to Implement Passive Pedestrian Detection Systems

1) *During New Infrastructure Projects*: Integrate passive pedestrian detection systems during the planning and construction phases of new signalized intersections, new midblock crosswalks with RRFB or PHB, or major upgrades to existing ones.
2) *When Upgrading Existing Signals*: Consider adding passive pedestrian detection systems when upgrading traffic signal infrastructure or when reconfiguring pedestrian crosswalks.
3) *In Response to Pedestrian Safety Concerns*: Implement these systems when identified through safety audits, crash data, or community feedback as needed to improve pedestrian safety.

5.4.3 How to Implement Passive Pedestrian Detection Systems

The successful implementation of a passive pedestrian detection system involves several key steps, ranging from planning, acquisition, and design to deployment and maintenance. Detailed implementation guidelines, including steps and processes, are provided below:

1) *Define Objectives, Site Locations, and Requirements*: Determine the specific objectives of the system, such as improving safety at intersections, detecting and placing a call for a pedestrian who does not press a pedestrian push button, and extending pedestrian crossing time when needed. Identify candidate sites (e.g., signalized intersections, midblock locations with RRFB or PHB) needed for implementing passive pedestrian detection systems. Consider factors like budget, infrastructure, environmental conditions, and regulatory requirements.
2) *Conduct a Feasibility Study*: Evaluate the intended deployment area and location, including traffic patterns, pedestrian flow, lighting conditions, and any potential obstacles. Research available technologies and consult with potential vendors for passive pedestrian detection systems, their performances, hardware (e.g., fisheye cameras, sensors) and software (AI platform) requirement, and their capital, installation, and maintenance costs. Assess their suitability for the application based on accuracy, cost, and integration complexity of the system.
3) *Select Appropriate Systems and Vendors*: Based on the feasibility study, consult and obtain quotes from potential system vendors for the system acquisition and implementation. Select an appropriate system vendor and the passive pedestrian detection system for implementation.
4) *Develop a System Implementation and Integration Plan*: Develop a detailed system implementation and integration plan including type of cameras, number of cameras, sensor or camera placement, data flow, and integration with existing infrastructure. Plan how the detection system will interface with other systems, such as traffic lights, warning signs, or central monitoring systems.
5) *Conduct a Pilot Study or Deployment and Testing*: Work with the selected system vendor and agency staff to conduct a pilot study or real-world pilot deployment and testing of

the selected passive pedestrian detection system to validate its functionality and performance under various conditions to ensure it meets the desired objectives, system accuracy and reliability.

6) *Preparation for System Installation and Integration*: Work with the selected vendor and agency staff to prepare the needed cameras, sensors, communication, associated hardware, and associated software or AI platform for data processing, analysis, and user interface in the selected locations and agency traffic management center.
7) *Deployment*: Complete the full installation of all sensors and software in the operational environment at all selected sites. Configure the system for optimal performance, including calibrating sensors and setting thresholds for detection.
8) *Training and Documentation*: Train engineers, operators, and maintenance personnel on how to use and manage the system. Provide detailed documentation for system operation, maintenance, and troubleshooting.
9) *Monitoring and Maintenance*: Regularly monitor the system's performance to ensure it operates correctly and effectively detects pedestrians. Perform routine maintenance to address wear and tear, software updates, and any necessary repairs.
10) *Evaluation and Optimization*: Evaluate the system's impact on pedestrian safety and traffic management. Collect feedback from users and stakeholders. Make adjustments and improvements based on performance data and feedback to enhance the system's effectiveness. Ensure the system continues to meet regulatory requirements and standards. Incorporate advancements in technology and updates to algorithms or hardware as needed.

By following these steps, a transportation agency can implement a robust passive pedestrian detection system that enhances pedestrian safety and accessibility at signalized intersections and midblock crosswalks with RRFB or PHB, creating a more pedestrian-friendly urban environment. The agency can also enhance traffic operation efficiency in various environments.

6 Conclusions and Recommendations

This research has demonstrated the potential of APD and DPPD systems to increase pedestrian safety and traffic operations. These systems address critical limitations of traditional push-button mechanisms by introducing automated detection and dynamic adjustments of pedestrian signal timing. By enabling features such as automated pedestrian detection, touchless actuation, smartphone-based pedestrian calls, call cancellations, and dynamic call extensions, these technologies ensure that pedestrians can cross safely and efficiently without unnecessary delays to drivers. Vulnerable road users, including children, the elderly, and individuals with disabilities, particularly benefit from these advancements, as they accommodate varying crossing speeds and minimize direct interactions with physical devices.

The feasibility studies conducted as part of this project have validated the practicality of integrating APD and DPPD systems into existing traffic infrastructure. Vendor collaborations and real-world testing have shown that these technologies can be successfully implemented in diverse urban environments. However, occasional challenges, such as reduced detection accuracy under extreme weather or low-light conditions, emphasize the need for regular calibration and robust technology design. While the study illustrates the effectiveness of these systems, it also acknowledges the importance of public education and stakeholder engagement to promote widespread adoption and ensure operational success.

The before-after studies of APD and DPPD field implementations through this research project showed promising results and provided valuable research findings. They highlight that the adoption of such systems contributes significantly to reducing crossing risks of pedestrians and bicyclists at signalized intersections and midblock crossings with RRFBs or PHBs by enabling automated detection to place a pedestrian call to traffic signal controllers and dynamically extending crossing times when needed. The APD and DPPD systems can also improve traffic flow and reduce vehicle delays by canceling unneeded pedestrian calls when pedestrians leave the waiting zone early, thereby enhancing overall efficiency. It effectively addresses the safety concerns of pedestrians crossing streets without pressing the push button.

The intent for implementing APD and DPPD systems is not to replace pedestrian push buttons but enhance pedestrian and bicyclist safety at signalized intersections and midblock crossings. The APD and DPPD systems deployed in the before-after studies generally showed high accuracies in pedestrian detection, extending crossing time, and canceling unneeded pedestrian calls during daytime but the performance degraded during nighttime likely due to low lighting as not all intersections in the study were well lit. There is still room for improvement in the APD and DPPD systems.

APD and DPPD systems can effectively enhance pedestrian safety by enabling automated pedestrian detection and dynamically extending crossing times, and improving operational efficiency by canceling calls when pedestrians left the waiting area early. However, these systems are not intended to replace pedestrian push buttons but rather to complement them by improving safety at signalized intersections and midblock crossings. The before-after studies demonstrated that APD and DPPD achieved high accuracy in detecting pedestrians, extending crossing times when needed, and canceling unnecessary pedestrian calls, particularly during the daytime. However, their performance declined at night, likely due to insufficient lighting and other factors at some study locations. While these systems show great potential, there is still room for improvement, especially in enhancing nighttime detection capabilities.

To fully leverage the potential of APD and DPPD systems, several recommendations are proposed:

- Implement these systems at intersections and midblock crossings with significant pedestrian activity or historically low compliance with traditional infrastructure, such as locations near schools, shopping centers, and transit hubs.
- Install systems at a signalized intersection with separate waiting areas instead of joint areas for two directions to obtain higher and more accurate pedestrian detection rates since the system will be more certain on the specific crosswalk the pedestrian there is waiting for.
- Develop regular calibration schedules and maintenance plans to address environmental factors and ensure consistent detection accuracy.
- Ensure sufficient lighting at designated intersections and midblock crossings to enhance system detection accuracy.
- Collaborate with traffic management agencies and vendors to ensure seamless integration with current signal control systems and facilitate interoperability.
- Educate pedestrians, drivers, and other stakeholders on the benefits and proper usage of these technologies to encourage compliance and trust.
- Offer comprehensive training programs for traffic professionals, city planners, and vendors to ensure proper installation, operation, and troubleshooting of the systems.
- Encourage continued research into emerging sensor technologies, detection algorithms, and the expanded application of smartphone integration to refine system capabilities and address current limitations.
- Develop and disseminate clear guidelines for system deployment, including criteria for site selection, performance evaluation, and long-term maintenance planning.

In conclusion, the deployment of APD and DPPD systems has the potential to transform urban pedestrian environments, offering enhanced safety, improved efficiency, and greater accessibility. By addressing the challenges and leveraging the opportunities identified in this study, transportation agencies and urban planners can implement these innovative technologies effectively, paving the way for smarter and safer mobility solutions in the future.

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Appendix – Vendor Quotes and Product Information

UNIVERSAL SIGNS & ACCESSORIES
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Quote
 # EST-008821

3001 Orange Avenue
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Bill To
University of South Florida
DIV. OF ACCOUNTING & FIN.
TAMPA, FL 33620

Ship To
Central Receiving Tampa Campus
4202 Fowler Ave CRS100
TAMPA, FL 33620-9000

Estimate Date :	07.14.23
Expiration Date: :	08.13.23
Delivery Preference :	None

#	Item & Description	Qty	Rate	Amount
1	RRFB Assembly, Solar Powered, Back to Back SKU : Z 654-2-22 Solar, Touchless Pushbutton, FLIR Thermal Activation Consists of the following items: 1) [N500351]Controller, 12V, Prostar-15, 120652, Hollow, Radio, FLIR, 12V Relay, Delay Timer - 1 EA 2) [N142048]Universal Cabinet Mounting Bracket, SOP Cabinets 108766, 108045, 120652, Includes U-Bolt Hardware - 1 EA 3) [NSLR-85-B]85W / 12V Solar Panel Package, 4.5" OD, Top of Pole Mount - 1 EA 4) [N2180-35AHAGN-BAT]Battery, 35Ah 12V AGM Lead Acid - 3 EA 5) [N138089]RRFB Assembly, Universal Mount - 2 EA 6) [NSPTRAFFIC]Guardian FS Torx, PN 501-0821CT, Bluetooth Add on PN 5010653 w/ 5x7 Al DS Sign - 1 EA 7) [N146153-50]Cable, Bulk, 6C 18AWG, Outdoor/Burial Rated, ICEA E2 Color, 50 foot pre-cut length - 1 EA for 2 poles 8) [N141259]TrafiOne 195, Assembly, Thermal Sensor With Bracket and Cables - 1 EA 7) [DP00003]Pole Package, 15' x 4.5" OD, To Include: Pole, Base, Four J-Bolts and Hardware - 1 EA 8) [ad52713030az0edd]Sign, W11-2, 30 x 30 x 080, FYG DG3, Diamond, DOT Holes, 1.5 in radius - 2 EA 9) [ad28402412az0add]Sign, W16-7PL, 24 x 12 x 080, FYG DG3, Horizontal, DOT Holes, 1.5 in radius - 1 EA 10) [ad39152412az0add]Sign, W16-7PR, 24 x 12 x 080, FYG DG3, Horizontal, DOT Holes, 1.5 in radius - 1 EA 11) [EF00003]FDOT Sign Mounting Kit, 4.5" OD, for 30" Diamond - 2 EA 12) [EF00005]FDOT Sign Mounting Kit, 4.5" OD, for 24 x 12 Horizontal Rectangle - 2 EA	2.00 EA	12,125.00	24,250.00
2	TAPCO On Site to Oversee Install SKU : NRS10114	1.00	3,510.00	3,510.00
			Sub Total	27,760.00

Migma

Migma Systems, Inc.

1600 Providence Highway
Walpole, MA 02081
508-660-0328
508-660-0288 Fax
www.migmasys.com

July 11, 2023

Mohsen Momenitabar
University of South Florida

Quote of Migma AutoButton

Description	QTY	Unit Price	Amount
MigmaDSFB – AutoButton (Part #: MDSBP0218ABAC) - One base station (*wireless receiver, timer and AC-DC converter*) - Two PIR sensors (*one for one side of crosswalk*) - Pushbutton interface module - User Guide - All necessary mounting hardware (*brackets, bolts, nuts, banding strips, etc.*)   	**1** (for one crosswalk)	**$850.00**	**$850.00**
Shipping (UPS ground shipping)	**1**	**$30.00**	**$30.00**

Total: $880.00

Migma

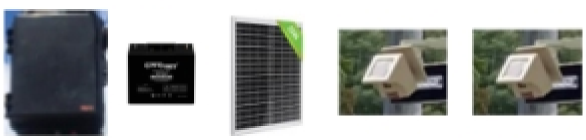
Migma Systems, Inc.

1600 Providence Highway
Walpole, MA 02081
508-660-0328
508-660-0288 Fax
www.migmasys.com

July 24, 2023

Mohsen Momenitabar
University of South Florida

Quote of Migma AutoButton (Solar Power)

Description	QTY	Unit Price	Amount
MigmaDSFB – AutoButton (Part #: MDSBP0218ABAC) - One base station (*wireless receiver, timer and AC-DC converter*) - One 20W battery - One 25Ahr solar panel - Two PIR sensors (*one for one side of crosswalk*) - Pushbutton interface module - User Guide - All necessary mounting hardware (*brackets, bolts, nuts, banding strips, etc.*) 	**1** (for one crosswalk)	**$1250.00**	**$1250.00**
Shipping (UPS ground shipping)	**1**	**$50.00**	**$50.00**

Total: $1300.00

miovision

Quote Q-24407

Version Q-24407-20230728-1422

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137 Glasgow Street, Suite 110 Kitchener, ON N2G 4X8
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kmccoy@miovision.com
Shipping Contact: Mohsen Momenitabar
mmomenitabar@usf.edu

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United States

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United States

Product Name	Price	Qty	Total
Miovision Core DCM (with Discrete Detection)	$11,995.00	2	$23,990.00
Universal SmartView 360 Mount with Universal Hub	$480.00	3	$1,440.00
Miovision Detection	$4,295.00	2	$8,590.00
Ethernet Cable (1000 ft)	$1,600.00	2	$3,200.00
Universal SmartView 360 Extension	$400.00	3	$1,200.00

Shipping & Handling	$0.00
Subtotal (Net) :	USD 38,420.00
Tax :	USD 2,027.40
Total :	USD 40,447.40

The Customer hereby agrees to order the products outlined above at the prices indicated, and acknowledges it has read, understands and agrees to be bound by the terms and conditions outlined at:
https://miovision.com/legal/msa
For customers paying by credit card, a Miovision accounts receivable representative will contact you by phone to obtain credit card details. Please note that in order to complete payment the Miovision representative will require you to provide the applicable Quotation reference number.