

AN ABSTRACT OF THE THESIS OF

McKenna Milacek for the degree of Master of Science in Civil Engineering presented on May 16, 2022

Title: Evaluation of a Pedestrian Call Extension and Cancellation System at a Midblock Trail Crossing

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David Hurwitz

Signalized intersections often provide pushbuttons to call for pedestrian service to minimize conflicting movements between road users. Signalized midblock crossings typically increase safety for pedestrians in locations with high traffic volumes and multiple lanes in each direction. However, unnecessary vehicular delay occurs from “ghost” pedestrian intervals when someone activates the pedestrian phase and then jaywalks. Safety issues also arise when pedestrians remain in the crosswalk at the end of the Flashing Don’t Walk phase, and vehicles receive the circular green. A Pedestrian Call Extension and Cancellation System was evaluated at a signalized midblock trail crossing in Hillsboro, OR. Thermal sensors and new traffic controller logic were implemented to detect pedestrian locations and passively cancel or extend calls. A longitudinal before-after study was conducted to evaluate how vehicular delay and pedestrian behavior was impacted with installation of the system. Reasons for cancellations and extensions were also documented. A total of 1,649 observations before system installation and 3,002 observations after were recorded. Vehicular delay decreased significantly, and most cancellations were determined to be caused by jaywalkers. Considerations for installation in different contexts are discussed.

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Evaluation of a Pedestrian Call Extension and Cancellation System at a Midblock Trial Crossing

by
McKenna Milacek

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

McKenna Milacek, Author

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1.0 INTRODUCTION

Pedestrian Call Extension and Cancellation systems have the potential to increase safety, decrease vehicle delay, and reduce emissions at signalized pedestrian crosswalks. Typical pedestrian signal timing facilitates traffic movements at crosswalks to minimize conflicts between users, but safety and operational issues continue to occur. Static models of operation rely on pedestrians to activate pushbuttons. Pedestrian intervals are then served based on real-time traffic demand or in coordination with neighboring signals. Pedestrians will occasionally choose to jaywalk or will require additional time to complete the crossing maneuver due to slower walking speeds or late entry. Pedestrian Call Extension and Cancellation systems attempt to minimize the impacts of such occurrences. Dynamic passive pedestrian detection (DPPD) allows the system to extend crossing intervals for late entering or slow-moving pedestrians without additional human intervention. If a pedestrian decides to jaywalk or abandon the detector zone prior to service, the dynamic system will cancel the actuated call. Although a pushbutton activation is required to initiate a call for service, the passive system does not require human input to access the extension or cancellation system

1.1 Pedestrian Call Extension

Traditionally, pedestrian signals follow set timing parameters determined by the 85th percentile observed walking speed, as explained in the Manual on Uniform Traffic Control Devices (MUTCD). According to Section 4E.06, pedestrian walking and clearance intervals must allow someone walking 3 feet per second to cross starting from a position 6 feet away from the curb edge or allow someone walking 3.5 feet per second from the curb edge at the end of the walk interval to cross completely (Federal Highway Administration 2009). Although this is sufficient for most situations, issues arise with slower pedestrians, large groups, and pedestrians

beginning to cross during the clearance interval. Additional conflicts with opposing vehicles (e.g., permissive left-turning vehicle conflict with pedestrians in congruent phase) may occur, thus creating undesirable conditions for pedestrians. The extension improves these conditions by adding one to ten seconds to the Solid Don't Walk (SDW) buffer interval when a pedestrian is detected in the crosswalk at the termination of the pedestrian phase. After the Flashing Don't Walk (FDW) change interval ends, pedestrians are presented with the SDW indication. This configuration is shown in **Figure 1**. Traditionally, vehicles would receive the green indication at the onset of the SDW. However, when the pedestrian phase is extended, the vehicular green is concurrently delayed. This provides slower pedestrians additional time to cross and reduces the number of vehicle-pedestrian conflicts.

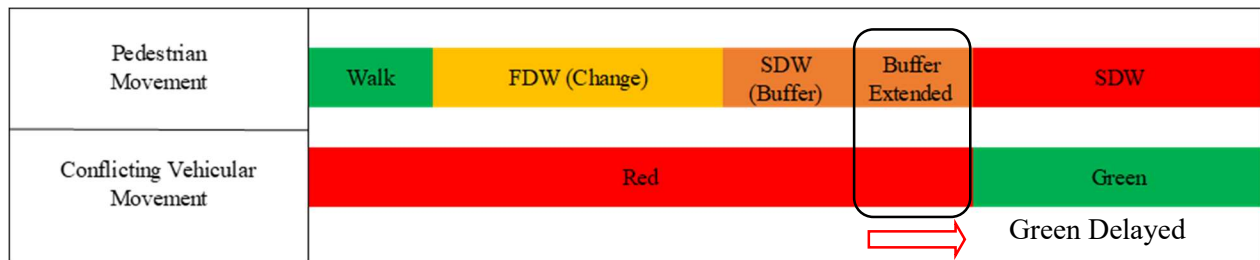
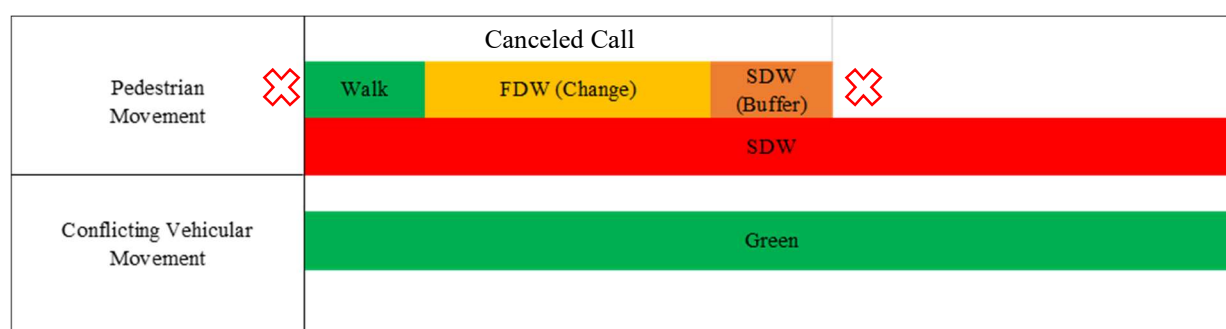


Figure 1- Pedestrian Call Extension Signal Timing

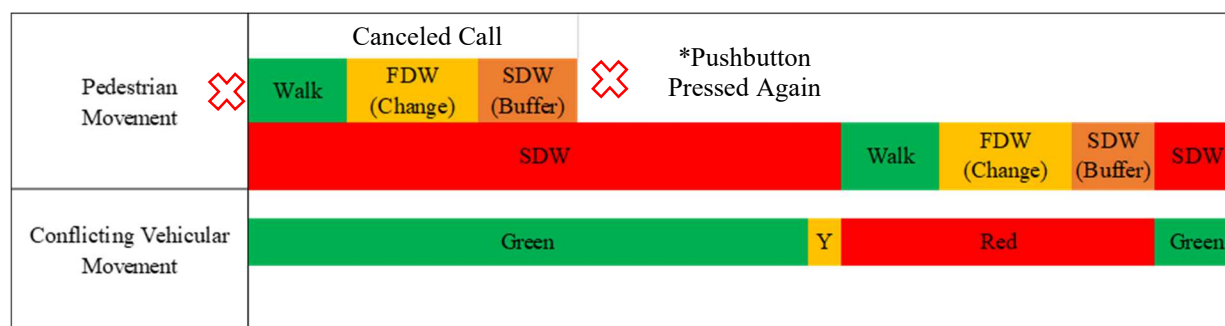
1.2 Pedestrian Call Cancellation

The static active system requires pedestrian pushbutton activation, which places a call for service that occurs in coordination with nearby signals or when there is an acceptable gap in real-time traffic. Once a call is placed, it is locked in. In many cases, pedestrians often press the pushbutton but abandon the detection zone by jaywalking, crossing elsewhere, or not crossing at all. When traffic allows, the controller serves the pedestrian interval, and vehicular traffic must wait for the pedestrian phase to time, although no pedestrians are present. The dynamic passive system aims to reduce unnecessary vehicle stops for these “ghost” pedestrian phases. When

pedestrians abandon the detection zone, an audible message stating the service call has been canceled plays in English and Spanish, and the pedestrian interval is not served. Instead, the pedestrian's SDW indication remains, and the vehicular green stays constant as if no call for service occurred. If the pedestrian returns and pushes the button again, the pedestrian service occurs. This is shown in **Figure 2**. If the pedestrian fails to return, the call will remain canceled. If another call is placed and canceled within five minutes of the first cancelation, a fail-safe occurs, and the pedestrian service occurs. Finally, in the instance of a pedestrian standing in the curb zone for five minutes, pressing the pushbutton, and then leaving the detection zone, the controller will continue to serve the pedestrian in an error mode.



(a)



(b)

Figure 2- Pedestrian Call Cancellation Timing with (a) no second button push and (b) a second button push to reinstate the pedestrian phase.

While the system may not entirely deter pedestrians from jaywalking, it provides several benefits to all road users. It reduces vehicular delay by eliminating the possibility of a “ghost”

pedestrian phase. Doing so, it increases safety by reducing rear-end crash exposure and decreasing emissions and idling during unnecessary stops.

1.3 Research Questions

After installing and testing the dynamic passive pedestrian detection technology and implementing the call extension and cancelation system logic, six research questions were proposed to evaluate the system's performance:

Research Question 1: How accurate is the pedestrian call extension and cancelation system?

Research Question 2: To what extent does the pedestrian *call cancelation system* reduce vehicular delay and increase pedestrian delay?

Research Question 3: To what extent does the pedestrian *call extension system* increase vehicular delay and reduce pedestrian delay?

Research Question 4: Does the pedestrian call cancelation system impact the number of pedestrians who choose to jaywalk at the crossing?

Research Question 5: Are the cancelation messages effective at getting people to return to the waiting zone to push the button? Do they stay in the zone or depart after the second button push?

Research Question 6: Does pedestrian behavior change with increasing exposure to the pedestrian call cancelation system?

The goal of this study is to evaluate how the Pedestrian Call Extension and Cancelation System impacts delay for vehicles and pedestrians while assessing any changes in pedestrian behavior. In doing so, the effectiveness and accuracy in the extension and cancelation functions are also evaluate.

2.0 LITERATURE REVIEW

A comprehensive literature review was conducted to identify the gaps in knowledge regarding pedestrian call extension and cancelation technology. This chapter summarizes these findings and documents the motivation for the study.

2.1 Pedestrian Treatments at Midblock Crossings

There has been an increased emphasis on improving pedestrian safety on the surface transportation system in United States. In 2019, pedestrian fatalities accounted for half of all fatal crashes involving vulnerable road users (VRU) (Reish 2021). Most pedestrian fatalities also occur on arterial roadways away from intersections (Hauer 2020). Improving conditions for pedestrians is crucial but finding a balance between safety and efficiency is also important. While pedestrian crossing treatments address safety, vehicle delay is also affected. The following study addresses the importance of efficiency while serving pedestrians safely.

Mid-block crossings provide pedestrians with a safe and visible route across the street in locations between intersections. However, in areas with high speeds, high traffic volumes with infrequent gaps, or high youth, elderly, or disabled pedestrian volumes, additional traffic control may be necessary (Broek 2011). Several treatments exist to improve safety for users at midblock crossings. There are several examples, including but not limited to: Rectangular Rapid-Flashing Beacons (RRFB), Pedestrian Hybrid Beacons (PHB or HAWK), signalized midblock crossings, Pelican Crossings, and Puffin Crossings, which all help to allow pedestrians to cross safely at midblock crosswalks. This study analyzes a signalized midblock crossing before and after installing a Pedestrian Call Extension and Cancelation System, which attempts to improve efficiency for vehicles and provides additional safety features for pedestrians.

RRFBs consist of two rectangular yellow lights that flash at a high frequency when activated and are typically used to enhance pedestrian and school crossing locations (Blackburn

et al. 2018). An interim approval for use of RRFBs was added to the MUTCD in 2018 (Federal Highway Administration 2018). Nonetheless, several studies report significant increases in vehicular yielding behavior and fewer pedestrian-vehicle conflicts at RRFB locations (Brewer et al. 2015; Domarad et al. 2013; Foster et al. 2014). Unlike signalized midblock crossings and PHBs, RRFBs allow vehicles to proceed as long as the crosswalk is clear of pedestrians. PHBs, as referred to in the MUTCD, are used in conjunction with pedestrian signal heads, signs, and pavement markings, similar to a signalized midblock crossing. However, they consist of two circular red lights above a single circular yellow that remain dark until activated. Flashing and solid lights control traffic during the pedestrian interval (Blackburn et al. 2018; Federal Highway Administration 2009). Vehicular yielding behavior at PHBs has been reported as high as 96% (Fitzpatrick and Pratt 2016), with vehicular delay when vehicles remain stopped at a red light after pedestrians finish crossing (i.e., unnecessary delay) of less than one second (Godavarthy and Russell 2016). Unnecessary delay also occurs when pedestrians press the button and jaywalk or walk away from the crosswalk.

Traditional signalized midblock crossings consist of a typical signal head that remains green until a call for service is placed by a pedestrian. Signalized midblock crossings are often at locations with heavy traffic as fewer acceptable gaps would occur natural. Interestingly locations with heavier vehicle traffic also result in higher vehicular compliance and safer crossing conditions for pedestrians (Fitzpatrick et al. 2006, 2014). However, studies suggest that signalized midblock crossings can cause additional, unnecessary vehicular delay (Godavarthy and Russell 2016; Zhao et al. 2017). One study found that driver compliance at signalized midblock crossings was 98.8% but yielded an average of 11.2 seconds of unnecessary delay (Godavarthy and Russell 2016). While PHBs minimized unnecessary delay in comparison, no

solution currently exists to minimize such delay at already-existing signalized midblock crossings in the United States.



(a)



(b)



(c)

Figure 3- Examples of (a) PHB, (b) RRFB, (c) Signalized Midblock Crossing in Oregon

Pelican and Puffin crossings are typically seen in European contexts, notably in the UK. The Pelican requires a pedestrian to press the pushbutton to activate a Walk symbol (flashing

green person), and vehicular traffic is presented with a circular Red. After a set amount of time the green person begins to flash, indicating that pedestrians should no longer initiate crossing maneuvers, and vehicles receive a flashing yellow (Walker et al. 2005). The Pelican is the most similar to a signalized midblock crossing.

The Puffin was designed to reduce vehicular delay while increasing safety for pedestrians (Hassan et al. 2013, 2014; Walker et al. 2005). The Puffin crossing detects pedestrians throughout the crossing maneuver using pressure sensitive mats and radar sensors and varies the vehicular phase accordingly. The Puffin also has the ability to cancel the pedestrian phase if the pedestrian jaywalks or walks away from the crossing. This ability reduces the number of unnecessary pedestrian phases, and therefore reduces vehicular delay (Hassan et al. 2014; Walker et al. 2005). If no pedestrians are detected in the curb-side detector when the pedestrian interval is appropriate, the traffic signals remain green (Hassan et al. 2014). To that end, the Puffin crossing does not inform pedestrians of a cancelation.



(a)



(b)

Figure 4-Examples of (a) Pelican and (b) Puffin Crossings in the UK (City of Bristol 2014)

While the Pelican crossing operates similarly to a signalized midblock crossing, the United States lacks a system that passively cancels and varies pedestrian calls, like the Puffin. While RRFBs allow vehicles to proceed through a crosswalk after a pedestrian clears the path, the compliance rates are lower than at PHBs and signalized midblock crossings. PHBs reduce the unnecessary delay compared to signalized midblock crossings. However, limited solutions currently exist to increase efficiency while maintaining safety at existing signalized midblock crossings, thus motivating the current study.

2.2 Signal Timing at Signalized Midblock Crossings

It is clear that signalized midblock crossings can increase vehicular delay by interrupting traffic flow between intersections. Particularly, on-demand pushbutton phases at midblock crossings have the ability to break the green waves at upstream and downstream intersections (Teketi and Pulugurtha 2019). Long delays also occur when vehicles wait for pedestrian intervals to terminate after a pedestrian finishes crossing or when the pushbutton is activated and the pedestrian jaywalks or walks away.

The MUTCD states that traffic signals within half a mile of a midblock crossing should be coordinated, and engineering judgement should be used to determine the appropriate timing and phasing (Federal Highway Administration 2009). No standard currently exists to minimize vehicular delay at signalized midblock crosswalks.

Several signal timing models have been developed in an attempt to optimize operations at existing signalized midblock crossings. Zhao et al. developed a model that optimizes signal timing to address pedestrian and vehicular efficiency at midblock crossings (2017). Ma et al. proposes three signalization control types to optimize cycle length and offsets with coordinated signals at two-stage midblock crossings (2010). It was noted that pedestrian compliance does affect system efficiency. Although Ma et al. suggests that pedestrian compliance affects system efficiency, neither study considers scenarios with high frequency jaywalking events.

Safety implications resulting from jaywalking events have been addressed in other previous studies. Wang et al. demonstrated that as pedestrian wait time increased, the likelihood of them crossing also increased (Wang et al. 2011). Others have developed an adaptive pushbutton control at signalized midblock crossings that reduce the impact on traffic flow and minimizing pedestrian wait time (Wu et al. 2022). The authors suggest that long pedestrian wait times may lead to pedestrians ignoring the signal control over time, as they function more as placebo buttons. Again, there is a gap in existing research for addressing high jaywalking rates and the associated vehicular delay.

2.3 Detection for Call Extension and Cancellation

The MUTCD defines the design walking speed as 3.5 ft/s to determine the length of the pedestrian clearance time. Walking speeds up to 4.0 ft/s may be used at locations with extension

systems installed to provide slower pedestrians additional clearance time (Federal Highway Administration 2009). Typically, the pedestrian interval at a signalized midblock crossing is determined as a function of walking speed and the crosswalk. An extension system provides slower pedestrians with additional time to safely cross, although the United States currently lacks a standard device that serves such a purpose.

Both the extension and cancelation system developed for this technology require a passive detection system that tracks pedestrian movements. The MUTCD also states that “passive pedestrian detection may be used to automatically adjust the pedestrian clearance time” (Federal Highway Administration 2009). Pressure-sensitive mats and radar are typically used to operate the Puffin crossings. The pressure-sensitive mats determine occupancy in the waiting zone, whereas radar monitors the entire crosswalk (Davies 1999; Hughes et al. 2001; Manston 2011). However, various weather and lighting can present accuracy and coverage inconsistencies (Davies 1999; Manston 2011). Pressure-sensitive mats often require additional signage to ensure pedestrian compliance and rain can absorb radar energy, leading to inaccuracies. Radar also only detects moving pedestrians (Manston 2011).

Several other sensors have been evaluated for dynamic passive pedestrian detection (DPPD) in the United States. Beckwith and Hunter-Zaworski (1998) assessed long- and short-range ultrasonic, infrared, and Doppler radar in Portland, Oregon, in the early development of DPPD. A Texas Transportation Institute study revealed that microwave radar and infrared sensors had extremely high error rates up to 30% (Turner et al. 2007). Infrared, infrared-video combined, and microwave sensors in cold temperatures were evaluated by Montufar and Foord (2011). Each study determined that additional system development was required to implement the sensors in DPPD scenarios.

Recent research at the study location tested optical and thermal sensors for DPPD in anticipation of the Pedestrian Call Extension and Cancellation System. Pedestrian type, weather and lighting conditions, and detection outcomes were recorded. The high-resolution thermal sensor had a mean accuracy rate of 87% and was affected by lighting and weather, but not pedestrian type. The optical sensor had a mean accuracy rate of 83% and was affected only by pedestrian type (Larson et al. 2020). In response to this study, the high-res thermal sensor remained at the mid-block crossing, and the Pedestrian Call Extension and Cancellation System was implemented. Pedestrians call for service by pressing the pushbutton, and Thermal imaging monitors pedestrian movements and cancels or extends calls accordingly.

2.4 Summary of Literature

As demonstrated, little research exists regarding pedestrian call extension and cancellation. Several midblock crossing traffic control devices that increase safety for pedestrians exist in the United States. While issues regarding signalized midblock crossings specifically have been identified, such as unnecessary vehicular delay, there is a lack of technology that mitigates these problems at existing signals. Pedestrian call cancellation and dynamic pedestrian interval timing exist in the UK, but similar ideas have not been applied at scale in the United States.

One of the primary gaps in knowledge is minimizing vehicular delay while maintaining safety benefits at signalized midblock crossings. Several models exist that attempt to optimizing signal timing, however high jaywalking rates are not considered as a confounding factor. While other studies attempt to address the jaywalking problem, association between jaywalking and vehicular delay are not robustly discussed. Finally, while various studies have tested the accuracy of several sensor types, the application of thermal sensors for dynamic passive pedestrian detection is limited.

As a result, there is a need for a dynamic system that decreases vehicular delay at signalized crosswalks while maintaining pedestrian safety. The development of the Pedestrian Call Extension and Cancellation System was designed to achieve this. This study attempts to fill the gaps in knowledge regarding vehicular delay and pedestrian safety at signalized midblock crosswalks and adding to existing information about dynamic passive pedestrian sensors.

3.0 METHODOLOGY

The following section outlines the methodology used to conduct the study, including the pilot location, study set up, system descriptions, variables of interest, and data collection and transcription.

3.1 Pilot Location

The pilot site identified to implement the passive pedestrian cancellation and extension system is located at a signalized mid-block crossing Evergreen Parkway and Rock Creek Trail in Hillsboro. Evergreen Parkway is classified as a collector with a speed limit of 45 mph and an ADT of approximately 16,800 vehicles per day. The Rock Creek Trail serves the community by providing connectivity in Northeast Hillsboro. The trail has high pedestrian and bicycle volumes, most of which are recreational trips, likely contributing to a high frequency of jaywalking. The crosswalk consists of two 27-ft crossings and a 16-ft wide median. The crosswalk, sidewalk, and trail are 10 ft, 6 ft, and 12 ft, respectively. Additionally, the crosswalk includes a raised median and refuge island, a coordinated signal, and nighttime illumination. The crossing is shown in **Figure 5**.



Figure 5- The Rock Creek Trail Crossing on Evergreen Parkway

The trail crossing is signalized and runs in coordination on 90 second cycle lengths with upstream and downstream signals during morning (7:00 AM to 8:30 AM) and afternoon peaks

(3:30 PM to 6:30 PM). During off-peak hours, the signal runs free (uncoordinated), and only local traffic demand is considered. The crossing runs entirely uncoordinated on weekends. In the original configuration, the crosswalk runs a 7-second walk interval with a 19-second pedestrian clearance interval. In the event of a slow-moving pedestrian, the call extension system increases the SDW, and concurrent vehicular red, between one and ten seconds. The installation of the Pedestrian Call Extension and Cancellation System does not otherwise impact signal timing. Thermal passive pedestrian detection sensors detect pedestrians as they enter, navigate, and exit the crosswalk area. The crosswalk is segmented into five detection zones: two curb zones, two crosswalk zones, and one median zone.

3.2 Study Methodology

The Pedestrian Call Extension and Cancellation System is designed to improve safety and reduce delays and emissions for all road users. However, to achieve these outcomes, the system must work with a reasonably high degree of accuracy. For this reason, a longitudinal before-after study was developed to analyze the shift in operational performance measurements observed during a pilot of the extension and cancellation system. The experiment occurred in three (3) stages: before system installation, two weeks after the final installation, and two months after the final installation. An outline of the study methodology is shown in **Figure 6**.

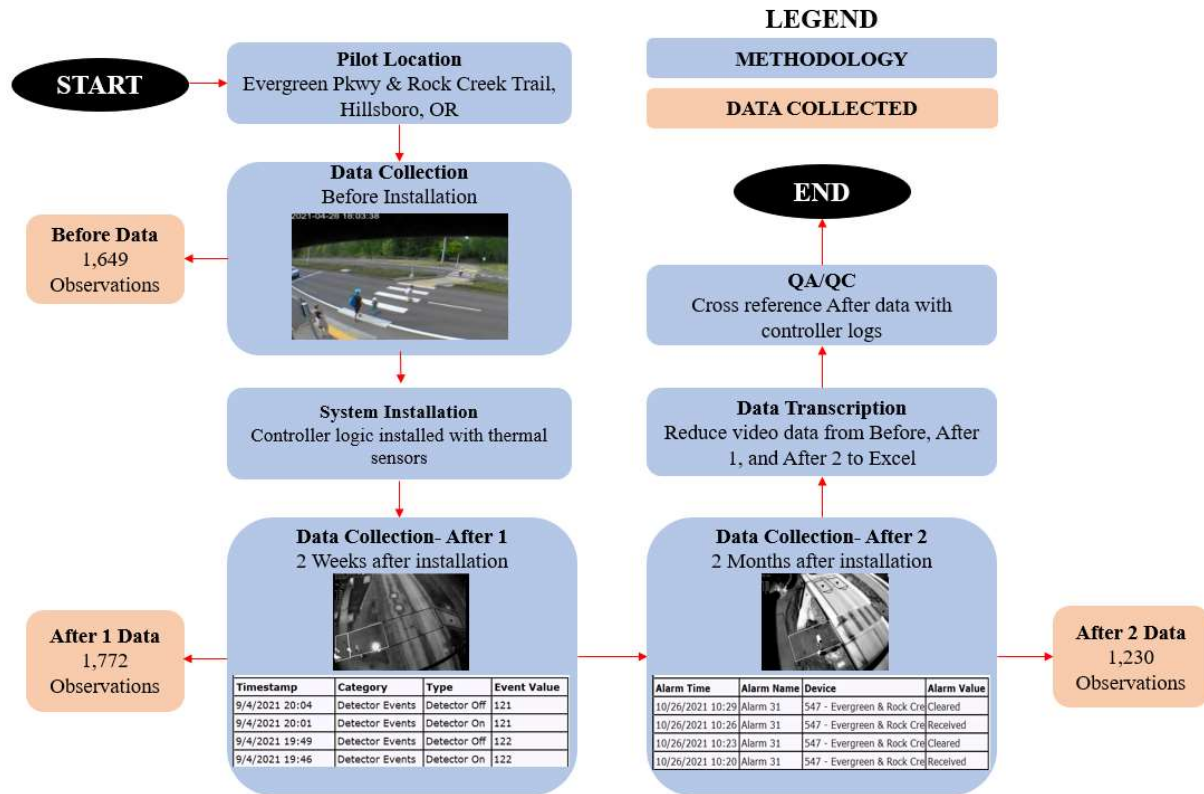


Figure 6- Outline of the Study Methodology

In each phase, temporary optical cameras were installed to record pedestrian movements in 12-hour intervals for one week (seven days). Four cameras were positioned around the pilot location to capture the entire crosswalk, pedestrian indication, and vehicular traffic, as shown in **Figure 7**. The NW and SE cameras view the crosswalk. Both were high-definition cameras that allowed researchers to observe pedestrians pressing the push button and view of the pedestrian indication. The NE and SW cameras showed eastbound and westbound traffic, stop lines, and vehicular indications. **Figure 8** displays the four camera views used for data collection. Thermal detection sensors are located on the same poles as the NW and SE cameras. Combined with outputs from the controller log, researchers evaluated the crossing and waiting behaviors of pedestrians.

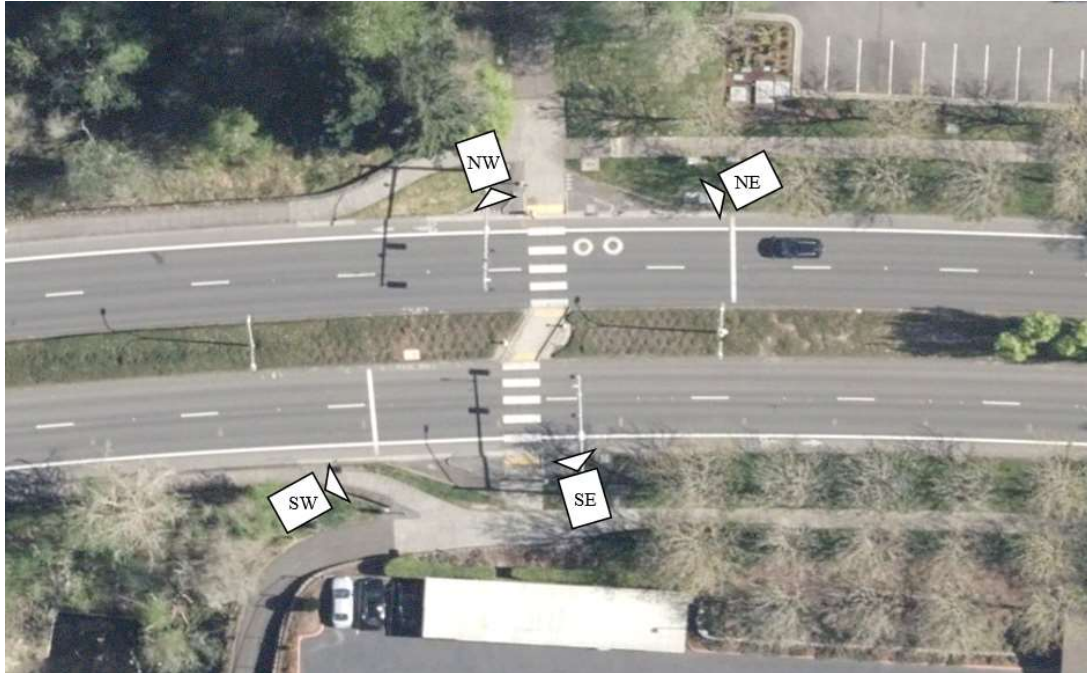


Figure 7- Approximate Camera Locations at the Study Site for Observation



(a)



(b)



(c)



(d)

Figure 8- Camera Views (a) NE Camera, (b) SW Camera, (c) NW Camera, (d) SE Camera

Transcription templates were developed for the before and after conditions to describe pedestrian waiting behaviors, pedestrian crossing behaviors, and traffic conditions. The after-installation transcription had additional independent variables pertaining to the call extension and cancelation system. In addition to comparing waiting and crossing behaviors, the other independent variables provide crucial information regarding the efficiency of the system that is compared over time.

3.3 Pedestrian Call Extension and Cancelation System Descriptions

A thermal detection system detects pedestrians in the crosswalk. The system does not trigger the crossing interval – pedestrians must press the pushbutton for service. New controller logic was developed to alter service calls based on pedestrian movement detected by the Thermal Sensors (High- and Low- Res) installed at the test location in Spring 2019 (Hurwitz and Larson 2020; Larson et al. 2020). The detection zone on the south side of the crosswalk is divided into two (2) parts: 10-ft by 16-ft rectangle in the waiting zone and a 10-ft by 25-ft area that detects the sidewalk beyond. The north side of the crosswalk spans from the edge of sidewalk to the edge of the trail, covering a 12-ft by 22-ft area. The curb zones are displayed in Figure 9. These curb zones appear white when occupied and are outlined in black when empty. When occupancy in a curb zone is dropped after a call of service, the pedestrian interval cancels. If a pedestrian is detected in the crosswalk zones in at the end of the FDW phase, an extension will occur until the pedestrian enters the curb zone.

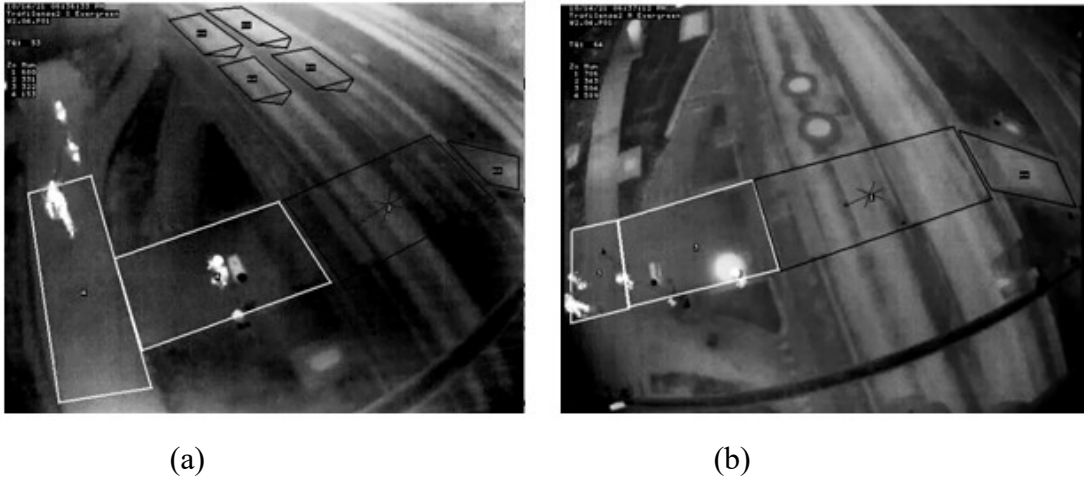


Figure 9- Thermal Detection Zones: (a) South Side and (b) North Side

3.3.1 Field Implementation and Calibration

System development, bench testing, and laboratory evaluation was conducted by Polera and Intelight with Washington County in Spring 2021. Once an initial controller software design was developed and tested, field implementation and testing was conducted in June and July 2021. The first two field tests revealed minor flaws in the system logic, which were addressed in the field. The third field test revealed an “edge case” problem with smaller pedestrians being hidden by the pedestrian pole, causing the call to drop. Twelve-inch pedestrian button extenders were installed to direct pedestrians further into the detection zone. The pedestrian cancelation and extension system went live in August 2021.

3.4 Variables of Interest

Several variables were selected to determine the efficiency of the Pedestrian Call Extension and Cancelation System. Variables are separated into five (5) categories: pedestrian behavior, vehicular delay, waiting behavior, crossing phase, and auxiliary data. The post-installation data also includes cancelation and extension information.

3.4.1 Pedestrian Conditions and Actions

For the purpose of understanding how different user types interacted with the crosswalk, each observation was categorized as one of four (4) groups: Walk, Run, Bike, or Other. These categories were chosen to determine if faster-moving pedestrians, such as runners or cyclists, may choose to jaywalk if cross traffic allows minimizing momentum loss. In many cases, “other” classification typically consisted of various forms of micromobility or pedestrians assisted with mobility aids, such as wheelchairs.

Several pedestrian actions were recorded. Each observation noted if the pedestrian pressed the pushbutton or not. While the Pedestrian Call Cancellation and Extension System performs some functions without human input, it still requires pushbutton activation to place a call for service. After entering the curb zone, pedestrian delay was recorded. Timing began when a user pressed or was adjacent to the pushbutton. It ended when they continued forward, either with the onset of the pedestrian phase or if the user chose to jaywalk after some amount of waiting. In the case of a trial user waiting outside the curb zone or behind others, pedestrian delay began when they stopped and ended when they started the crossing movement.

3.4.2 Vehicular Stop Time Delay

To evaluate the potential time savings with the implementation of the cancellation function, vehicular stop time delay was also recorded. In the context of this study, stop time delay is recorded as the delay of the first vehicle to arrive at the crosswalk during the crossing interval. This captured the longest waiting time for the queued vehicles during the cycle. Vehicles traveling in both directions were considered. Total delay for all vehicles in the queue was not observed in the field. Stopped time delay for the first vehicle to arrive at the crosswalk served as the vehicular delay measurement.

3.4.3 Waiting Behavior

The curb waiting zone extends from the edge of the sidewalk to the edge of the roadway. This detection zone plays a key role in the pedestrian cancelation function. As a result, the waiting behavior of all pedestrians were recorded. Actions before crossing were divided into five (5) categories: waited in curb zone, waited outside curb zone, moved in and out of curb zone, did not stop, and jaywalked. The jaywalking category was combined with any other waiting categories if the user waited for a period of time before walking.

3.4.4 Crossing Phase

The crossing phase, during which the pedestrian began crossing the roadway was recorded. The phases are categorized as Walk, Flashing Don't Walk, Solid Don't Walk, and Did Not Cross. Beginning to walk during the SDW indication is considered as jaywalking and therefore corresponds with the Jaywalking category in the Waiting Behavior observations.

3.4.5 Auxiliary Data

Several other crossing characteristics were noted in the data transcription process. Each observation indicated if the pedestrian stopped in the median or not. This was particularly important for pedestrians who chose to jaywalk. Time in the median was also recorded, when applicable. If the median pushbutton was pressed, usage was noted.

Additional observations were collected regarding environmental conditions. This includes the weather condition (e.g., clear, cloudy, rain), surface condition (e.g., dry, wet) and lighting (e.g., sunny, dawn, dusk). These observations were most useful in the post-installation data collection for interpreting malfunctions or inaccuracies.

In the case of uncommon observations, additional notes were recorded. These often included the number of pedestrians in a group, number of pushbutton presses, or length of time spent waiting in the median.

3.4.6 Post-Installation Data

In addition to the data observed in the pre-installation period, the post-installation transcription consisted of pedestrian phase cancelation- and extension-specific observations. For both scenarios, the reasoning for the action was recorded. For a canceled call to occur, reasons include Jaywalked, Decided Not to Cross, Left the Detection Zone, or System Malfunction. Researchers recorded whether or not a pedestrian pushed the pushbutton again after a cancelation. Post Call Cancelation actions were recorded as Jaywalked, Waited in Curb Zone, Waited Outside Curb Zone, Moved In/Out of Curb Zone, or Abandon Curb Zone.

Reasons for a pedestrian extension to occur were categorized into four (4) groups: a slow-moving pedestrian who started crossing during the Walk interval, a slow-moving pedestrian who started crossing during the FDW interval, and a normal-to-fast moving pedestrian who started crossing during the FDW interval. Other conditions, such as large groups crossing, were also noted.

3.5 Data Collection and Transcription

As a longitudinal, before-after study, three time periods were identified to observe pedestrian behavior at predetermined intervals after exposure to the system. Video footage of the study location was collected for seven days from 7 AM to 7 PM. Each observation period consisted of 84 hours of video data. The before condition occurred between April 26, 2021 and May 2, 2021. The two post-installation data collection periods occurred 2 weeks (August 28, 2021 – September 3, 2021 and September 12, 2021) and 2 months (October 9-15, 2021) after the

official installation. Each observation period consisted of four video angles (as shown in Figure 4), recordings of each FLIR camera, and the controller log outputs. All observations were made with video footage.

3.5.1 Transcription Template and Guide

To gather the necessary data for evaluating the accuracy and effectiveness of the Pedestrian Call Extension and Cancellation System, two (2) transcription templates were created to standardize the procedure: one for before and one for after conditions. The post-installation template includes information regarding pedestrian call extension and cancellation occurrences. Each observation consists of one crossing movement. Multiple pedestrians in the same group crossing together were considered a single observation. The transcription template was refined during the first two observation periods by the research team. All team members participating in the transcription process reviewed the transcription procedure with the senior researcher. Transcription data was reviewed to ensure consistency and clarity in completed observations. This included ensuring a consistent definition of “jaywalking” was implemented throughout all observations (i.e., all jaywalkers crossed during the SDW interval) and rounding all pedestrian and vehicular stop time delays to the nearest tenth. Comments were reviewed for irregularities or special cases, and the videos available for these observations were visually inspected by the senior researcher if any additional questions remained. The post-installation periods were cross-referenced with the controller logs provided by the county to ensure an accurate count of cancellations and extensions.

3.5.2 Transcription Procedure

Video files were provided by the video contractor on an online cloud interface that allowed researchers to download the files. These files were transferred to external hard drives for distribution to members of the research team participating in the transcription process.

Each day consisted of four video files—one for each camera angle. The SE camera was chosen as the baseline because it has the best view of the trail. With the videos downloaded, researchers viewed the SE videos in 10 second intervals until a pedestrian arrived. The video was then paused, and the other three video angles were fast-forwarded to the corresponding time. As pedestrians arrived on either end of the crosswalk, initial observations including time, pedestrian type, and pushbutton usage was recorded. Video was paused when the pedestrian pressed the pushbutton, and pedestrian delay was recorded when video resumed. Waiting behaviors and crossing phase are recorded after the pedestrian delay was determined. The vehicular stop time delay was determined using the SW and NE camera angles, which show the vehicle travel lanes and traffic signals. Timing began upon the arrival of the first vehicle during the pedestrian phase, from either eastbound or westbound approaches. The maximum stop time delay for each pedestrian crossing was recorded.

The post-installation video transcription required controller logs to confirm pedestrian phase cancelation and extensions. Video timestamps and transcribed data were cross-referenced with controller logs to ensure an accurate count of extensions and cancelations. Corresponding video footage from the thermal detection FLIR cameras were used to track pedestrian location during extension or cancelation periods. The FLIR cameras also assisted in confirming zone occupancy in “edge cases” in which logging or field errors occurred.

4.0 RESULTS

This section presents the outcomes of the study. The cancelation and extension results are followed by an analysis of vehicular stop time delay and pedestrian delay. A multiple linear regression (MLR) model was developed to estimate pedestrian and vehicular stop time delay at the crossing.

4.1 Sample Breakdown

The data was collected over three observation periods. The existing-condition observation period (Before) occurred from April 26, 2021 to May 2, 2021. The first after-condition observation period (After 1) occurred two weeks after installation, between August 28, 2021 and September 3, 2021. Due to camera failure on Sunday, replacement data for August 29 was also collected on September 12, 2021 for this period. The second after-condition observation period (After 2) occurred two months after the system installation, from October 9, 2021 to October 15, 2021.

One observation is defined by a pedestrian/pedestrians or bicyclist/bicyclists that cross the street at or near the defined crosswalk. Users may or may not enter the curbside waiting zone or use the entire crosswalk (e.g., a bicyclist entering the crosswalk at the median from the traffic lane). A group was determined to be together if they entered a waiting zone at the same time and appeared to have common origins and destinations. If a trail user entered the wait zone after another and waited several feet behind the lead pedestrian, these were considered two separate observations, as shown in **Figure 8**. Pedestrians or bicyclists waiting at opposite curbside zones at the same time were recorded as two observations. The pre-installation observation period yielded 1649 unique observations. The two post-installation observation periods yielded 1772 and 1230 observations, respectively. Due to the second after condition occurring in early Fall with colder, wetter weather, fewer observations were collected. Each data collection period

recorded 84 hours of video, resulting in a total of 252 hours of data. Data transcription occurred as data became available and was completed in November 2021. In total, the data took approximately 300 hours to transcribe.

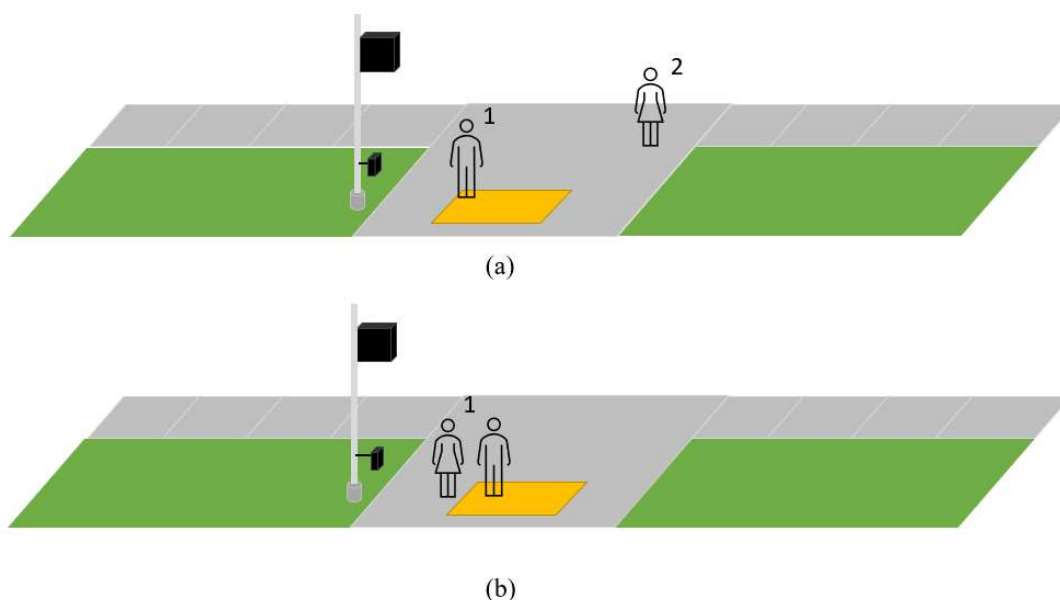


Figure 10- Example of (a) Two Individual Observations and (b) One Observation

The Rock Creek Trail is largely used for recreational purposes. As a result, non-motorized traffic includes walkers, runners, bicyclists, and other modes. In most cases, “Other” corresponds to scooters, skateboards, or wheelchairs, both electric and manually powered. Walkers were the most frequent users across all observation periods, followed by bicyclists. **Table 1** shows the distribution of pedestrian types across all three observation periods.

Table 1: Distribution of Pedestrian Types During Each Observation Period

| Pedestrian Type | Before | After 1 | After 2 |
|-----------------|-------------|-------------|-------------|
| Walk | 49.8% (821) | 44.3% (745) | 48.6% (598) |
| Run | 19.4% (319) | 19.5% (345) | 22.5% (277) |
| Bicycle | 28.6% (472) | 33.9% (600) | 27.6% (340) |
| Other | 2.2% (36) | 2.4% (42) | 1.2% (15) |

The large proportions of jaywalking at this location are hypothesized to be a result of the recreational usage of the trail, the presence of acceptable gaps between the conflicting vehicular movements, and the presence of the refuge island allowing for two-stage crossings. Jaywalking rates, which correspond to crossing during the SDW interval, range from 36.5% (After 2) to 40.9% (After 1) across the three observation periods. Of the jaywalking events observed after installation, 19.9% occurred during the weekday peak periods. Of those who did not cross, 71.4% Before and 69.2% After pressed the pushbutton. Most did not remain in the curb zone while waiting. **Table 2** shows the distribution of crossing phases for each data collection period.

Table 2: Distribution of Crossing Departure Phase During Each Observation Period

| Crossing Phase | Before | After 1 | After 2 |
|----------------------------|-------------|-------------|-------------|
| Walk | 56.5% (931) | 52.4% (929) | 57.6% (708) |
| Flashing Don't Walk | 5.9% (98) | 6.3% (112) | 5.5% (68) |
| Solid Don't Walk (Jaywalk) | 37.2% (613) | 40.9% (724) | 36.5% (449) |
| Did Not Cross | 0.4% (7) | 0.4% (7) | 0.4% (5) |

4.2 Cancellation Results

The Pedestrian Call Extension and Cancellation System aims to reduce vehicular delay by canceling calls for service after a pedestrian jaywalks, decides not to cross, or otherwise leaves the waiting zone. During After 1, 204 cancelations (12.3% of observations) occurred throughout the observation period. During After 2, 133 cancelations (10.8% of observations) occurred throughout the observation period. Results are presented in **Table 3**. As shown in **Figure 11**, 50.0% and 45.5% of these cancelations were caused by walkers during After 1 and After 2, respectively. Runners caused 24.0% of cancelations in After 1 and 30.3% of cancelations in After 2.

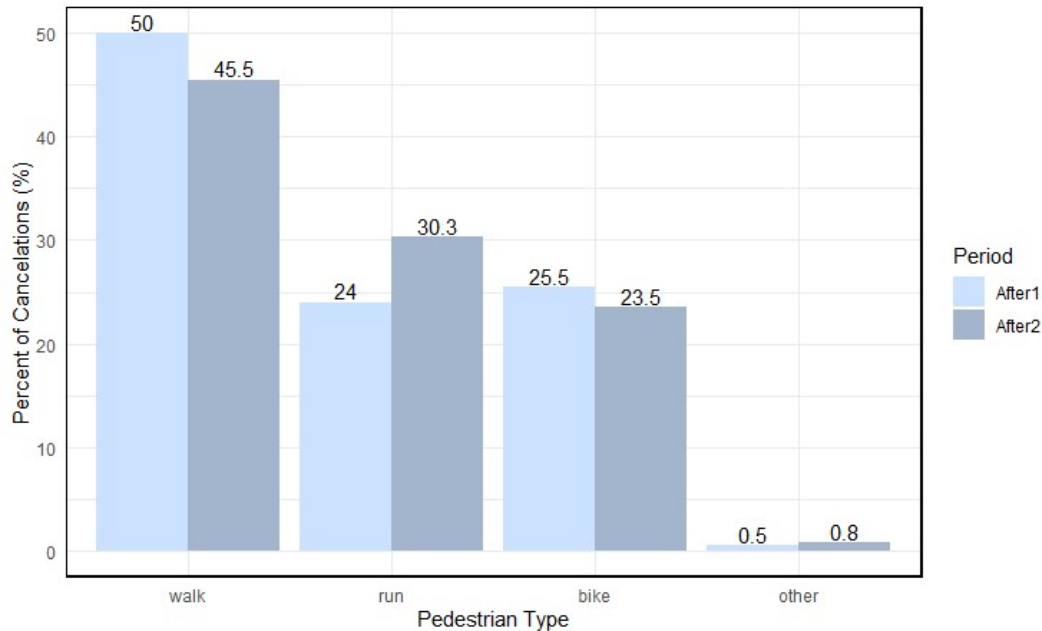


Figure 11- Cancellations by User Type Distribution

Four (4) scenarios for a cancellation exist: the user jaywalks, the user leaves the waiting zone, the user walks away and does not cross, or a malfunction occurs. Jaywalkers caused the majority of cancellations with 77.5% and 87.9% in After 1 and After 2, respectively. Malfunctions, however, accounted for 12.7% and 7.6% of cancellations in After 1 and After 2, respectively. Results are shown in **Figure 12**. Between After 1 and After 2, a total of 36 malfunction-caused cancellations occurred. Of these malfunctions, 24 (66.7%) occurred at the southside wait zone, and 32 (88.9%) pressed the pushbutton after the call was canceled. Each malfunction is described in detail in Appendix B- Edge Cases.

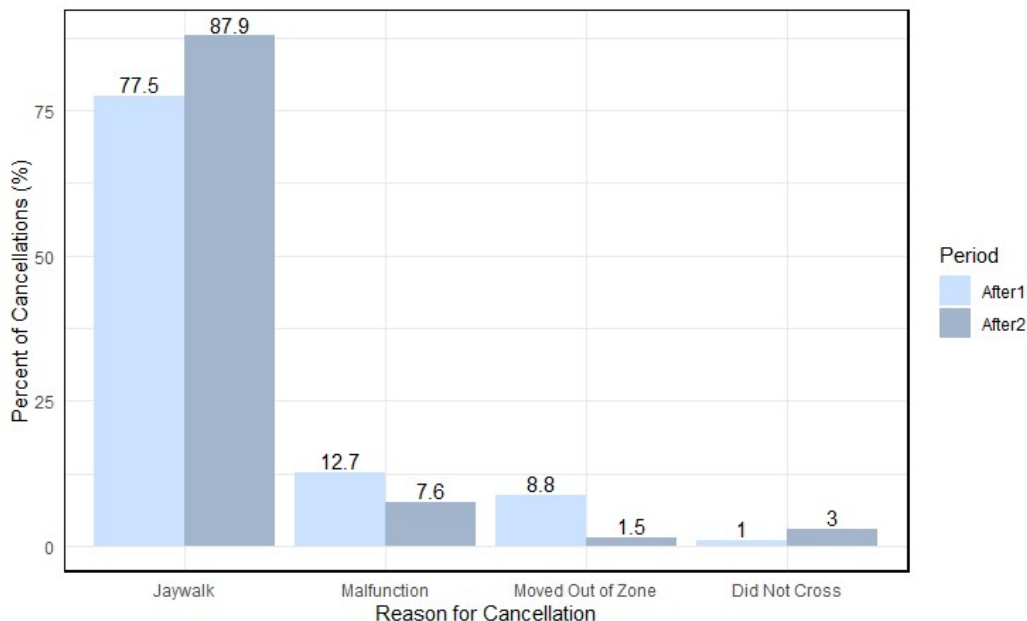


Figure 12- Cancellation Cause Distribution

After a call is canceled, an audible message plays to inform pedestrians of the cancellation and prompts users to return to the waiting zone and press the pushbutton again to reinstate the call for service. The message plays in English and Spanish. Ideally, after a call cancels, pedestrians return to the waiting zone and wait for the pedestrian phase after pressing the button again. However, only 22.1% and 13.6% of pedestrians reinstated the call for service by pressing the pushbutton again after a cancellation in After 1 and After 2, respectively. This indicates there may not be clear understanding of this feature and the message by users.

The cancellation system provides a safety buffer (i.e., red revert) in the instance of a pedestrian beginning to cross during the vehicular yellow change interval. The red revert condition shows vehicles a circular red indication for five seconds, but the pedestrian indication remains an SDW. The call is recorded as a cancellation in the controller logs. Ideally, the red revert condition does not occur during peak hours to avoid increasing vehicle delay in the coordinated condition. Of the 73 red reverts that occurred during After 1, eight occurred during

the weekday peak periods. None of the 41 red reverts during After 2 happened during peak hours. Overall, 22.6% of the cancelations occurred during the weekday peak periods. These results are displayed in **Table 3**.

Table 3- Cancelation Counts

| Action | After 1 | | After 2 | |
|-------------------------|---------|---------|---------|---------|
| | Count | Percent | Count | Percent |
| Calls Canceled | 204 | 12.3 % | 132 | 10.7 % |
| Red Revert | 73 | 35.7 % | 41 | 31.6% |
| Call Reinstated | 45 | 22.1 % | 18 | 13.6 % |
| Peak Period Cancelation | 48 | 23.5 % | 28 | 21.2 % |

4.3 Extension Results

The Pedestrian Call Extension and Cancelation system extends the SDW buffer if a pedestrian is detected in the crosswalk at the end of the FDW interval. During this interval, vehicles continue to see the circular red while pedestrians are shown the SDW. A total of 76 extensions occurred during the study period, with 47 during After 1 and 29 in After 2. Of these extensions, 13 in After 1 and nine in After 2 occurred during the peak hours in which the signal is coordinated.

Ideally, this function provides slower-moving pedestrians (e.g., older populations and people with strollers or small children) additional time to cross safely. Extensions were caused for four (4) reasons: normal-to-fast paced pedestrians beginning to cross on the FDW interval (Norm Ped- FDW), slow pedestrians beginning to cross on the Walk interval (Slow Ped), slow pedestrians beginning to cross on the FDW interval (Slow Ped- FDW), and False Extension. A vast majority of extensions were caused by normal-to-fast moving pedestrians (i.e., pedestrians moving at, above, or around the average pedestrian walking speed) crossing during the FDW interval. As seen in **Figure 13**, this occurred for 78.7% and 72.4% of all extensions in After 1 and After 2, respectively. Slower moving pedestrians crossing during the green indication, for

which the system is designed for, only account for 17.0% and 20.7% in After 1 and After 2, respectively. One false extension occurred when a pedestrian pressed the median pushbutton while crossing. Although no one was present in the crosswalk when the pedestrian phase was served, the call was recorded as a one-second extension.

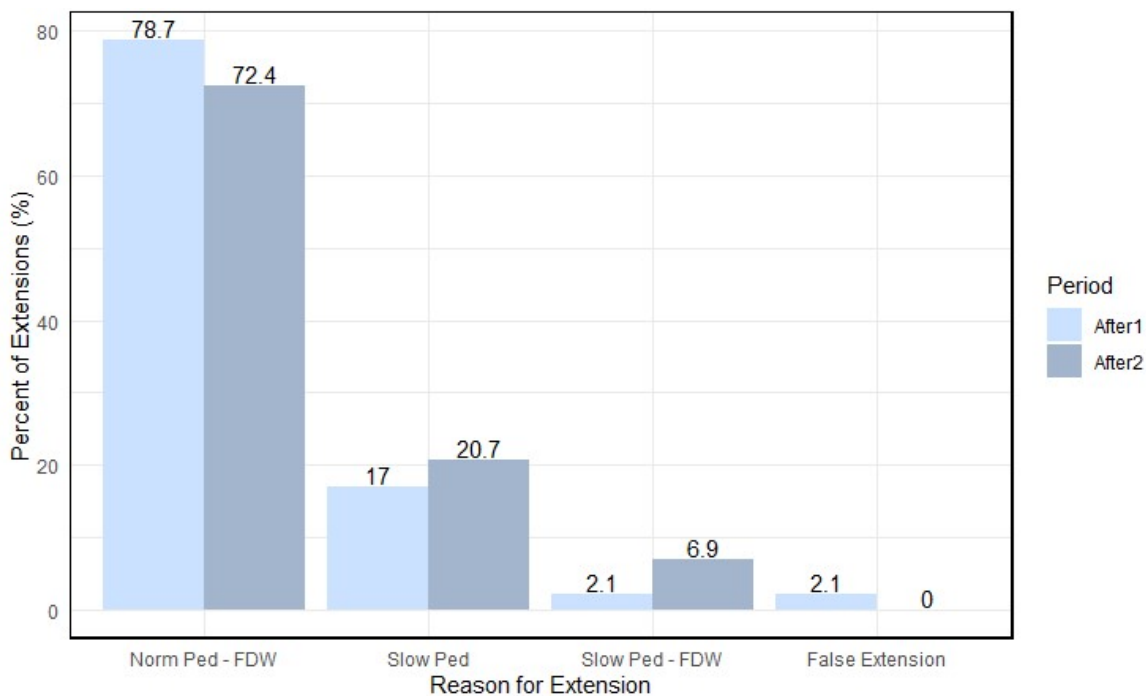


Figure 13- Distribution of Extension Causes

Calls are extended between one and 10 seconds, depending on a pedestrian's location within the crosswalk and speed. The average extension length in After 1 was 2.4 seconds with a standard deviation of 1.4 seconds. The average extension length in After 2 was 2.8 seconds with a standard deviation of 1.4 seconds. Generally, pedestrians only need a couple of seconds to complete a crossing maneuver, even if entering during the FDW phase. All extensions were between one and five seconds. A distribution of extension duration is shown in **Figure 14**.

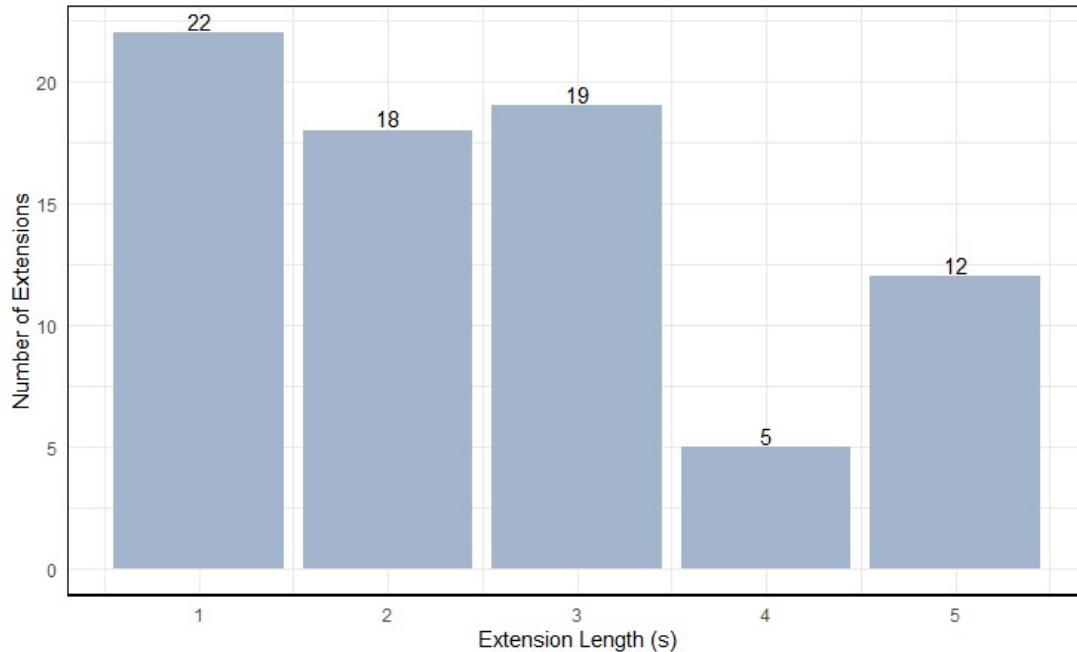


Figure 14- Frequency Distribution of Extension Durations

4.4 Pedestrian Behavior

The excessive jaywalking observed presents a potential safety issue at the trail crossing. To better understand the pedestrian behavior at the crosswalk before and after the Pedestrian Call Extension and Cancellation System was installed, three (3) levels of response were characterized and are summarized below.

- Correct Response:** Pedestrian presses the pushbutton and waits for the Walk indication, or the pedestrian crosses during the Walk indication without pressing the pushbutton because they saw someone else push it, coincidentally arrived during the priority indication, were waiting behind another group, etc.
- Partially Correct Response:** Pedestrian presses the pushbutton and may or may not wait for some time before crossing during the SDW interval, or the pedestrian does not cross in the defined crosswalk.

- **Incorrect Response:** Pedestrian does not press the pushbutton and crosses during the SDW or the FDW interval or the pedestrian did not cross.

The correct pedestrian response at the crosswalk accounts for 56.5%, 52.4%, and 57.5% during the Before, After 1, and After 2 observations, respectively. These results indicate that just over half of pedestrians followed the commonly accepted simple messages conveyed by the traffic control devices at the crosswalk location by pressing the pushbutton and/or waiting for the Walk indication to cross. The remaining pedestrians failed to properly comply. The distribution of pedestrian responses is displayed in **Table 4**.

Table 4- Distribution of Pedestrian Level of Response

| Response | Before | | After 1 | | After 2 | |
|-----------|--------|------------|---------|------------|---------|------------|
| | Count | Percentage | Count | Percentage | Count | Percentage |
| Correct | 931 | 56.5% | 929 | 52.4% | 708 | 57.6% |
| Partial | 235 | 14.3% | 243 | 13.7% | 161 | 13.1% |
| Incorrect | 483 | 29.3% | 600 | 33.9% | 361 | 29.3% |

It is important to note that a pedestrian must press the pushbutton for the Pedestrian Call Extension and Cancellation system to function. However, pushbutton use accounted for 64.7%, 60.3%, and 65.9% of the observations in Before, After 1, After 2, respectively. Conducting a proportion test comparing the Before and three aggregations of After periods (After 1, After 2, and Overall-After) provides evidence of a difference in pushbutton use between Before and After 1. However, there is no evidence that pushbutton use is different between Before and After 2 and Overall-After. Results are shown in **Table 5**.

Table 5- Proportion Tests for Pushbutton Use

| Comparison | Proportion 1 | Proportion 2 | Alt. Hypothesis | p-value |
|--------------------------|--------------|--------------|----------------------------|---------|
| Before vs After 1 | 0.648 | 0.603 | $\hat{p}_1 \neq \hat{p}_2$ | <0.01 |
| Before vs. After 2 | 0.648 | 0.659 | $\hat{p}_1 \neq \hat{p}_2$ | 0.541 |
| Before vs. Overall After | 0.648 | 0.626 | $\hat{p}_1 \neq \hat{p}_2$ | 0.15 |

Jaywalking accounted for 37.2%, 40.9%, and 36.5% of all observations during the Before, After 1, and After 2, respectively. The Before period proportion of jaywalking was compared to that After 1, After 2, and Overall After. There is strong evidence of a difference between jaywalking proportions in Before and After 1. However, there is no evidence that the proportion of jaywalkers differs with Before and After 2 and Overall After. The increase in jaywalking indicates that jaywalking behaviors initially worsened after installing the Pedestrian Call Extension and Cancellation System. However, jaywalking rates returned to Before-like conditions two months after installation. It can be concluded that jaywalking proportions overall remained the same after installation, and that jaywalking behavior did not change after increased exposure to the Pedestrian Call Extension and Cancellation System. Results are shown in **Table 6.**

Table 6- Proportion Tests for Jaywalking

| Comparison | Proportion 1 | Proportion 2 | Alt. Hypothesis | p-value |
|--------------------------|--------------|--------------|----------------------------|---------|
| Before vs After 1 | 0.372 | 0.409 | $\hat{p}_1 \neq \hat{p}_2$ | 0.023 |
| Before vs. After 2 | 0.372 | 0.365 | $\hat{p}_1 \neq \hat{p}_2$ | 0.741 |
| Before vs. Overall After | 0.372 | 0.391 | $\hat{p}_1 \neq \hat{p}_2$ | 0.214 |

Most jaywalkers failed to press the pushbutton across all observation periods. In Before, After 1, and After 2, only 38.3%, 33.6%, and 35.8% of jaywalkers pressed the pushbutton, respectively. Conducting proportion tests between Before and After 1, After 2, and Overall-After

revealed a slight change in the percent of pushbutton usage among jaywalkers after installation. Results are shown in **Table 7**.

Table 7- Proportion Tests for Jaywalker Pushbutton Usage

| Comparison | Proportion 1 | Proportion 2 | Alt. Hypothesis | p-value |
|--------------------------|--------------|--------------|----------------------------|---------|
| Before vs After 1 | 0.383 | 0.336 | $\hat{p}_1 \neq \hat{p}_2$ | 0.079 |
| Before vs. After 2 | 0.383 | 0.359 | $\hat{p}_1 \neq \hat{p}_2$ | 0.447 |
| Before vs. Overall After | 0.383 | 0.344 | $\hat{p}_1 \neq \hat{p}_2$ | 0.115 |

The lack of change in pedestrian behavior is further demonstrated by looking at pedestrians pressing the pushbutton again after a cancelation. In After 1, 44 of 204 (21.6 %) and in After 2, 18 of 133 (13.5 %) canceled calls were reinstated with a second pushbutton activation. Conducting a two-sided proportion test reveals no difference in proportions between the two after periods (p-value = 0.086). In the case of cancelations caused by jaywalking, many examples show pedestrians pushing the button and crossing when an acceptable gap is presented rather than waiting for the Walk indication. If a pedestrian began crossing at the onset of the yellow clearance interval, the Red Revert condition often occurred. Calls were reinstated by the original pedestrian after another pedestrian jaywalked and caused a cancelation, by other pedestrians pushing the button after the original pedestrian jaywalked, when pedestrians left the waiting zone to the left, right, or trail-end of the waiting zone, or when the detection dropped occupancy from a malfunction. There were no examples of pedestrians beginning to jaywalk and turning around to push the button again and wait for the Walk indication after the audio message played.

In general, pedestrian behavior did not change with increased exposure to the Pedestrian Call Extension and Cancelation System. Pushbutton use was found significantly different between Before and After 1 but returned to similar rates in After 2 and Overall-After. Jaywalking

was also found significantly different between Before and After 1, although the jaywalking rate increased during After 2. After two months and overall, jaywalking rates remained the same as Before. Jaywalking pushbutton usage had no significant difference from Before in both after data collection periods.

4.5 Pedestrian Delay

Pedestrian waiting time, which equates to the amount of time a pedestrian waited before beginning to cross, was recorded for each observation. Delay was recorded from the time the pedestrian pressed the pushbutton or arrived at the waiting zone area adjacent to the button if the pushbutton was not activated (National Academies of Sciences Engineering and Medicine 2022). Average pedestrian delay in the Before, After 1, and After 2 periods were 12.7, 14.9, and 15.1 seconds, respectively. The boxplot in **Figure 15** shows the distribution of pedestrian delay across observation periods.

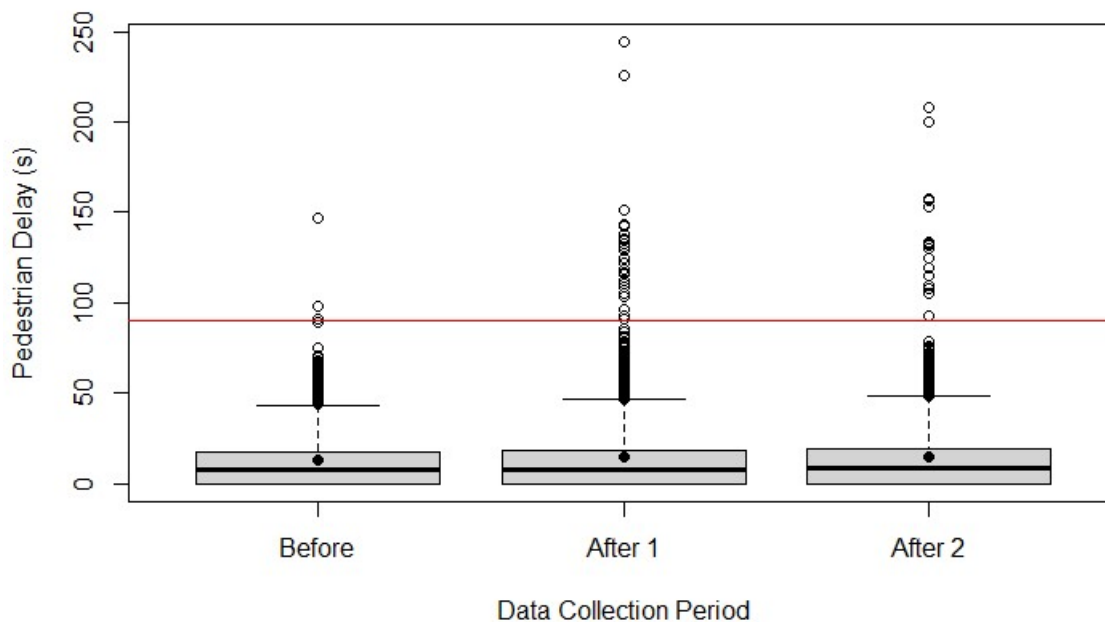


Figure 15- Boxplot of Pedestrian Delay with Outlier Reference

As shown in **Figure 15**, all three observation periods include several data points with pedestrian delay beyond the maximum value determined by Interquartile Range (IQR). According to the Interquartile Range Rule, outliers are defined by one and a half times the third quartile of the IQR. However, this method results in different outlier thresholds for each observation periods and eliminated 286 (83 from Before, 126 from After 1, 77 from After 2) observations that potentially represent valuable insights into system operations under high volume periods. To better fit the data and crosswalk signal timing, outliers are defined as observations with pedestrian delay above 90 seconds. This corresponds with the location at which IQR-defined outliers begin to visually begin to separate from each other, as seen in **Figure 15**. It also corresponds with the signal's cycle length during peak hours.

Although pedestrian delay above 90 seconds is considered an outlier, several interesting observations occur in scenarios with such high wait times that are worth noting. The three outliers in the Before period represent two instances of a pedestrian pushing the pushbutton upon arrival. The pushbutton is pressed again in both scenarios. In the first scenario, a NB pedestrian pushed the button and waited 30.3 seconds before pressing the button again. A SB pedestrian arrived shortly after the first and did not press the pushbutton at all. The pedestrians in this scenario waited in opposite zones for 97.8 and 91.2 seconds before receiving the Walk symbol. In the second scenario, a NB pedestrian pushed the button and jaywalked after waiting 89.0 seconds. A SB bicyclist pushed the opposite button after the first party jaywalked and waited for a total of 147.1 seconds before receiving the green indication. These two situations demonstrate a potential source of error in the data. Data collection relied on visual inspection and observing pedestrian behavior. While it appears these pedestrians pushed the buttons correctly, a call for

service may not have been initially placed. Not pressing the button hard enough or system malfunctions in calling for service may have lead to excessive wait times in the Before period.

Examples of excessive pedestrian delay also occurred after the Pedestrian Call Extension and Cancellation System was installed. For example, a SB pedestrian pressed the north-side pushbutton upon arrival, and a NB pedestrian pressed the south-side pushbutton and exited the waiting zone as the circular yellow was initiated. The call was canceled and red reverted. The SB pedestrian pushed the button after the NB pedestrian jaywalked. Despite the red revert clearly occurring, a cancelation was not recorded in the controller log. The first pedestrian to arrive experienced a total of 135.7 seconds of delay. In another instance, a SB pedestrian pressed the pushbutton, and a NB pedestrian arrived and pushed the opposite button. Both pedestrians pressed their respective buttons several times while waiting. The south-side waiting FLIR zone dropped and regained occupancy twice; however, a cancelation was not recorded. Pedestrian delay was 129.9 seconds for the SB pedestrian and 119.4 and 115.1 seconds for NB pedestrians. These scenarios both demonstrate pedestrian misuse or possible malfunctions in the detection, cancelation algorithm, and controller logging, all of which may lead to occasionally high pedestrian wait times.

4.5.1 Pedestrian Delay Results

As demonstrated, several atypically high pedestrian wait times occurred after the installation of the Pedestrian Call Cancellation and Extension system. To attempt to understand how the system functions on a regular basis, the observations with pedestrian delay above 90s were removed for analysis. Doing so resulted in an average pedestrian delay of 12.5, 13.1, and 13.5 seconds in the Before, After 1, and After 2 observation periods, respectively. To determine any significant differences between these values, several two-sample t-tests were conducted.

Both one-sided and two-sided tests were conducted depending on the defined research questions. The null hypothesis states there is no difference between means in all tests. The alternative hypothesis in the two-sided t-test states that the difference between means is different than zero. The alternative hypothesis in the one-sided tests states that the first mean is less or greater than the second. A 95% confidence interval was used for all tests, indicating that p-values greater than 0.05 showed no significant difference between means. If a p-value below 0.05 was obtained, a significant difference between means is concluded.

Pedestrian delay was first compared across both post-installation observation periods. The two-sided t-test indicates no significant difference between the mean pedestrian delay in After 1 and After 2 (p-value = 0.4693). As a result, the After 1 and After 2 datasets were combined for the following analysis with an Overall After condition mean pedestrian delay of 13.3 seconds. Conducting a two-sided t-test between the Before condition and Overall After resulted in a p-value of 0.101. This suggests there is no significant difference between the mean pedestrian delay before and after installation. As a result, it can be concluded that the Pedestrian Call Extension and Cancellation system does not affect pedestrian delay across observation periods.

Reflecting on the Research Questions 2 and 3, the cancellation system is hypothesized to increase pedestrian delay, and the extension system is hypothesized to reduce pedestrian delay. As a result, a one-sided t-test was conducted to compare pedestrian delay between observations with a cancellation vs. no cancellation in the Overall After period. Average pedestrian delay for observations with a cancellation was significantly higher than that for observations without a cancellation. A one-sided t-test was also conducted to compare pedestrian delay during

extensions vs. no extensions. Pedestrian delay was significantly lower during an extension compared to observations without an extension. **Table 8** presents the results.

Table 8- Pedestrian Delay Comparisons

| Comparison | Average 1 (s) | Average 2 (s) | Alt. Hypothesis | p-value |
|-----------------------------------|---------------|---------------|--------------------|---------|
| After 1 vs. After 2* | 13.1 | 13.5 | $\mu_1 \neq \mu_2$ | 0.469 |
| Before vs. Overall After* | 12.5 | 13.3 | $\mu_1 \neq \mu_2$ | 0.101 |
| Cancellation vs. No Cancellation* | 17.1 | 12.8 | $\mu_1 > \mu_2$ | <0.01 |
| Extension vs. No Extension* | 6.3 | 13.4 | $\mu_1 < \mu_2$ | <0.01 |

*Outliers removed

While the Pedestrian Call and Extension system increases pedestrian delay during cancellations, it decreases pedestrian delay during extensions, as expected. However, due to the high proportion of extensions caused by normal-to-fast paced pedestrians crossing during the FDW interval, most extensions were not initiated by the same person who originally pressed the pushbutton. As a result, delay needs to be considered separated for two (2) different cases: pedestrian delay for the person who pressed the button for the original call for service and pedestrian delay of the person actually causing the extension. The average pedestrian delay shown in **Table 8** represents that of the pedestrians causing the extension. In comparison, the average pedestrian delay of the people initiating the call for service that was extended was 22.6 seconds, with outliers removed.

Eight extensions also correlate with a canceled call, although one had a pedestrian wait time of 126.4 seconds and is not considered in the comparison above. The average pedestrian delay for the remaining seven calls was 38.3 seconds for the pedestrians who initiated the call. A total of 22 extensions occurred during peak periods with an average pedestrian delay of 30.8 seconds for pedestrians who pressed the pushbutton to initiate the call canceled.

4.6 Vehicular Stop Time Delay

To understand how the Pedestrian Call Extension and Cancellation system effects vehicle delay on Evergreen Parkway, vehicular stop time delay was measured for each observation. Stop time delay began when the first vehicle to arrive at the crossing came to a complete stop and ended when the vehicle began moving again. This represents the maximum wait time for each observation. In cases which multiple parties were crossing, stop time delay was recorded only for the first pedestrian to press the push button. The average stop time delay for the first vehicle in the standing queue in the Before, After 1, and After 2 conditions were 12.6, 10.7, and 12.3 seconds, respectively. The boxplot displayed in **Figure 16** shows the distribution of vehicular stop time delay across the three observation periods.

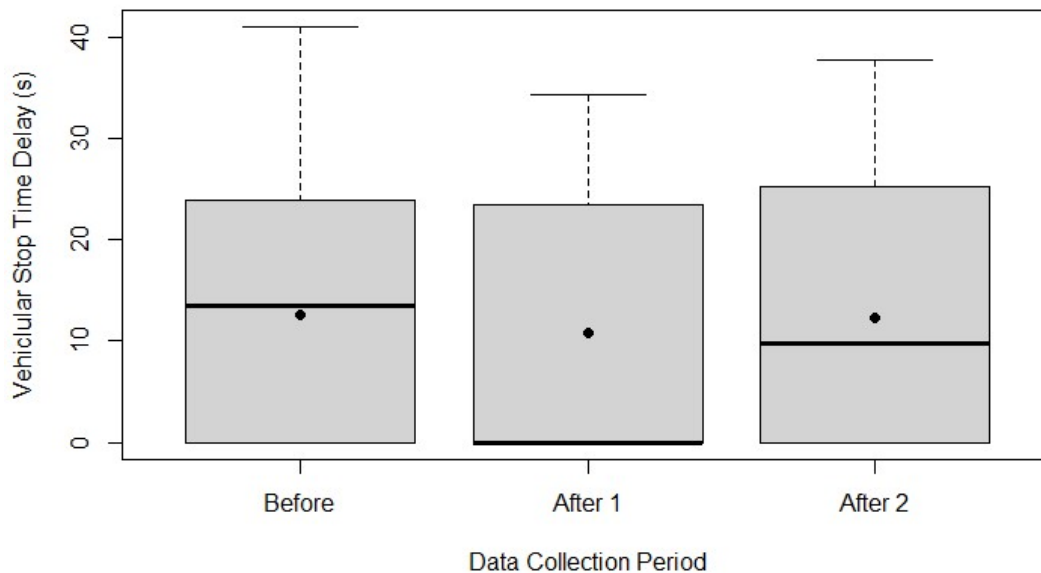


Figure 16- Boxplot of Vehicular Stop Time Delay

Unlike pedestrian delay, the vehicular delay data do not indicate any outliers when considering the Interquartile Range Rule. As a result, no outliers were removed from the dataset to analyze stop time delay.

4.6.1 Vehicular Stop Time Delay Results

As shown in **Figure 16** average vehicular delay initially decreases after the Pedestrian Call Extension and Cancellation System installation and increases again by the second after observation period. One-sided t-tests were conducted to compare mean vehicular stop time delay between After 1 & After 2 and Before and the three After conditions (After 1, After 2, and Overall After). Doing so shows there is convincing evidence that the mean vehicular delay between After 1 & After 2, Before & After 1, and Before & Overall After are significantly different. There is no evidence that there is a difference in the mean stop time delay between Before & After 2. This may be due to the higher percentage of cancellations observed in After 1 than in After 2. Overall, it can be concluded that vehicular stop time delay decreased after installation. Results are displayed in **Table 9**.

Table 9- Vehicular Stop Time Delay Comparisons

| Comparison | Average 1 (s) | Average 2 (s) | Alt. Hypothesis | p-value |
|----------------------------------|------------------|------------------|--------------------|---------|
| After 1 vs. After 2 | 10.7 | 12.3 | $\mu_1 \neq \mu_2$ | <0.01 |
| Before vs. After 1 | 12.6 | 10.7 | $\mu_1 \neq \mu_2$ | <0.01 |
| Before Vs. After 2 | 12.6 | 12.3 | $\mu_1 \neq \mu_2$ | 0.53 |
| Before vs. Overall After | 12.6 | 11.4 | $\mu_1 \neq \mu_2$ | <0.01 |
| Cancellation vs. No Cancellation | 4.6 | 12.2 | $\mu_1 < \mu_2$ | <0.01 |
| Extension vs. No Extension | 20.5 | 11.1 | $\mu_1 > \mu_2$ | <0.01 |

The Pedestrian Call Extension and Cancellation System was predicted to affect vehicular delay, similarly to pedestrian delay. The extension system was estimated to increase stop time delay, while the cancellation was hypothesized to reduce stop time delay. As a result, two one-sided t-tests were conducted to compare the cancellation & no cancellation, and extension & no extension mean vehicular delay across all post-installation observations. The results present

convincing evidence that the cancelation system reduced vehicular delay while the extension system increased vehicular delay. These results are also shown in **Table 9**.

4.7 Statistical Modeling

Due to the continuous nature of the pedestrian and vehicular stop time delay variables, multiple linear regression (MLR) was used to further analyze and estimate delay at the crossing.

The general form of both models is shown in **Equation 1**:

$$\text{Equation 1: } \mu\{Y_i | X_1, X_2, \dots, X_n\} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n$$

where Y_i is the vehicular stop time delay or pedestrian delay for any observation i , X_n is the independent variable affecting the delay, and β_n is the estimated regression coefficient for each independent variable. Positive coefficients represent an increase in delay whereas negative coefficients indicate a decrease in delay. The results of the MLR models are presented in **Table 10**.

Table 10- MLR Results for Pedestrian and Vehicular Stop Time Delay

| Pedestrian Time Delay | | | | |
|------------------------------|----------|------------|---------|--|
| Variable | Estimate | Std. Error | P-value | |
| Intercept | 21.32 | 1.83 | <0.01** | |
| Peak Hour | 2.45 | 0.54 | <0.01** | |
| Call Canceled | 8.30 | 1.07 | <0.01** | |
| Call Extended | -1.65 | 2.16 | 0.45 | |
| Period A1 | 1.96 | 0.61 | <0.01** | |
| Period A2 | 1.20 | 0.66 | 0.07* | |
| Crossing Phase- SDW | -7.37 | 0.66 | <0.01** | |
| Crossing Phase- FDW | -4.83 | 1.31 | <0.01** | |
| Pedestrian Type- Walk | -2.52 | 1.81 | 0.17* | |
| Pedestrian Type- Run | -2.66 | 1.87 | 0.15* | |
| Pedestrian Type- Bike | -1.73 | 1.83 | 0.34 | |
| Pedestrian Did Not Stop | -14.58 | 0.72 | <0.01** | |
| Lighting- Dawn | -5.94 | 5.01 | 0.24 | |

| Vehicle Stop Time Delay | | | |
|--------------------------------|----------|------------|---------|
| Variable | Estimate | Std. Error | P-Value |
| Intercept | 2.77 | 1.82 | 0.13* |
| Peak Hour | 0.32 | 0.24 | 0.19* |
| Call Canceled | -12.00 | 0.52 | <0.01** |
| Call Extended | 15.38 | 0.98 | <0.01** |
| Period A1 | 0.06 | 0.28 | 0.82 |
| Period A2 | 0.43 | 0.30 | 0.15* |
| Crossing Phase- SDW | -3.17 | 1.81 | 0.08* |
| Crossing Phase- FDW | -1.58 | 1.88 | 0.40 |
| Crossing Phase- W | 0.97 | 1.81 | 0.59 |
| Pushbutton Utilization | 16.06 | 0.33 | <0.01** |
| Lighting- Dawn | -4.21 | 2.27 | 0.06* |

Significance levels: **at 95% *at 80%

As shown in **Table 10**, two MLR models were developed. The first estimates pedestrian delay as a function of peak hour, call cancelations and extensions, observation period, crossing phase, pushbutton activation, and lighting. The results in **Table 10** indicate that the peak periods (i.e., 7:00-8:30 AM and 3:30-6:30 PM) have a significant effect on pedestrian delay with an increase of 2.5 seconds of wait time. Concurrently, vehicular stop time delay is estimated to only increase by 0.3 seconds during the peak periods. Because vehicular traffic is prioritized during these hours to reduce delay, pedestrian delay increases as they wait for the cycle to time out rather than a gap in traffic.

The MLR models further demonstrate that the Pedestrian Call Extension and Cancellation System works as hypothesized. In the case of a cancelation, pedestrian delay is estimated to increase by 8.3 seconds while vehicular stop time delay is estimated to decrease by 12.0 seconds. The goal of the cancelation system is to decrease vehicular stop time delay for the “ghost” calls when pedestrians are absent from the crosswalk while the pedestrian phase is active. In many cases, canceled calls occurred due to jaywalking. Several malfunctions also occurred that

severely increased pedestrian wait time, especially in cases where one pedestrian chose to jaywalk, and another chose to wait for the Walk” symbol. In some cases, pedestrian delay reached above 200 seconds.

The extension system serves the users in an opposite fashion, in which pedestrian delay decreases and vehicular stop time increases. Extended calls are estimated to see vehicular stop time delay increase by 15.4 seconds. Pedestrian delay is estimated to decrease by 1.6 seconds. Although the average extension was 2.6 seconds, the average vehicular stop time delay for extended calls was 20.5 seconds. Additionally, 76.6% of extensions were caused by normal-to-fast paced pedestrians entering the crosswalk during the FDW interval. These pedestrians experience no delay because traffic is already stopped for the pedestrian who initiated the call, therefore reducing overall delay for extended calls.

Observation period was also taken into consideration when estimating pedestrian and vehicular stop time delay. In relation to the Before period, pedestrian delay increases in After 1 and After 2 by 2.0 and 1.2 seconds, respectively. This follows the general trend of increased pedestrian delay with the installation of the Pedestrian Call Extension and Cancellation System. Especially when considering the unusually long wait times observed due to system malfunctions, these increases are expected. Vehicular delay is estimated to increase in After 1 and After 2 by 0.1 and 0.4 seconds, neither of which represent a significant change in relation to the Before observation period. Unlike pedestrian delay, which is highly variable, vehicle delay is largely dictated by the length of the pedestrian phase. With cancellations decreasing the number of unnecessary stops and extensions increasing vehicular length for an average 2.6 seconds over 76 observations, vehicular delay is estimated to be minimally effected during the After periods.

Crossing phase is particularly important in estimating delay for both pedestrians and vehicles. In this study, a pedestrian crossing during the SDW interval indicates the pedestrian jaywalks. Whether a pedestrian pressed the button or waited in the detection zone for some time, the delay they experience is less than if they wait for the green Walk indication. Crossing during the FDW interval indicates a pedestrian enters the wait zone late and crosses the street with minimal delay. According to the model, a pedestrian crossing during the SDW interval is estimated to experience 7.4 seconds less delay than a pedestrian who did not cross or crossed during the Walk interval. Alternatively, pedestrian delay for those who crossed during the FDW interval is estimated to decrease by 4.8 seconds. Pedestrians crossing during these intervals also decreases vehicular delay. When a pedestrian crosses during the SDW interval, the Pedestrian Call Extension and Cancellation System cancels the call, thus preventing unnecessary vehicular delay. Pedestrians crossing during the FDW interval are also estimated to decrease vehicular stop time delay by 1.6 seconds. Although extensions are possible in this situation, the amount of delay necessary for another complete cycle for the same pedestrian to stop and wait far exceeds that of a short extension. As expected, pedestrians crossing during the Walk interval are estimated to increase vehicular delay by 1.0 second. This includes vehicular delay from pedestrians who pushed the button and pedestrians who crossed during the Walk interval but may not have initiated the call for service.

User types Walk, Run, and Bike were all found to decrease pedestrian wait time as compared to the Other classification. Although none were found to be significant, likely due to the small sample of Other pedestrian types, runners are estimated to have the largest decrease of wait time at 2.6 seconds. Vehicular delay was deemed unaffected by non-motorized road user type. Lighting in the early morning (i.e., dawn) was found to decrease both pedestrian and

vehicular delay. Fewer pedestrians and vehicles were present at these times, so fewer interactions between the two occurred. This lighting condition only occurred in After 2, which was recorded in October when the days were notably shorter than other observation periods.

The final pedestrian behaviors that had significant impacts on pedestrian and vehicular stop time delay are the pedestrian not stopping before crossing and pushbutton use, respectively. In the case of pedestrians failing to stop, delay is estimated to decrease by 13.7 seconds. This includes pedestrian not pausing in the wait zone when presented the SDW, FDW, and Walk indications. This also considers pedestrians who pressed the pushbutton but crossed immediately without waiting. Pushbutton use is estimated to increase vehicular delay by 16.1 seconds. This considers if pedestrians jaywalked or waited for the Walk indication to be displayed and accounts for canceled calls. In general, pressing the pushbutton implies that a pedestrian interval will occur, therefore pausing vehicular traffic, if present.

5.0 DISCUSSION

This chapter discusses the necessary considerations for successful implementation of the Pedestrian Call Extension and Cancellation System at mid-block crosswalks. It includes insight on the edge cases observed that present opportunities for potential system improvements. User benefits are also considered along with discussion regarding recommendations and additional considerations.

The Pedestrian Call Extension and Cancellation System is a novel traffic control device designed to reduce delay and increase safety for all road users. Although other mechanisms exist to serve similar purposes, the extension and cancellation features are novel. The mid-block trail crossing also provides a unique setting with mostly recreational users and high jaywalking rates. However, the system deserves additional research at different locations that may benefit users in different ways.

5.1 Edge Cases

In preparation for analysis, 88 “edge cases” were identified within the dataset. All edge cases occurred after the Pedestrian Call Extension and Cancellation System was installed and account for 2.9% of the post-installation observations. These cases represent scenarios in which logging errors, malfunctions, or unexplained calls occurred during the observation periods. Two main patterns were identified. First, 27 observations were recorded as canceled although the pedestrian interval was served, which may represent a false positive condition or a logging error. Of these, 22 occurred when the pedestrian began crossing during the vehicular yellow change interval, four occurred when the pedestrian crossed during the Walk interval, and one occurred when the pedestrian jaywalked. These 27 observations were not recorded as cancellations for subsequent analysis. The second pattern consisted of 14 pedestrians pressing the pushbutton,

jaywalking, and the call appearing to be canceled. These may represent a false negative condition or a logging error. However, these calls were not recorded as cancelations in the controller logs. They were considered canceled for subsequent analysis.

Thirty-six cancelations were recorded as malfunctions, 24 of which occurred at the southside waiting zone. In total, malfunctions account for 10.7% of the cancelations observed, not including the potential logging errors described above. Although the FLIR videos are unavailable for many of these observations, the videos available reveal the waiting zone dropping occupancy if the pedestrian was very still or was hidden by the pedestrian signal head. Of the 36 malfunctions recorded, 32 of the pedestrians pressed the pushbutton again. These account for 50.8% of the total number of calls reinstated. As a result, in the case of a malfunction, the audio message appears effective in prompting pedestrians to call for service again.

The remaining edge cases were not associated with a common observation. A complete list of the identified edge cases with a description of each scenario is located in Appendix A.

5.2 User Benefits

The Pedestrian Call Extension and Cancelation System offers several benefits to all users at the Rock Creek Trail crossing. Average vehicular stop time delay experienced the most notable improvement with a 1.2-second reduction between Before and Overall After. A total of 11.5% of calls observed after installation were canceled. Overall, 22.6% of cancelations occurring during the peak hour, and 77.6% of these observations did not press the button again. These cancelations represent instances in which vehicles previously would have to had to stop for an empty crosswalk. As a result, the cancelation function improves efficiency in the system by minimizing unnecessary stops at the crosswalk. It simultaneously reduces the number of

potential exposures to rear-end-crashes and decreases the amount of emissions released from idling due to fewer stops.

While the extension system is intended to serve slower moving, late entering pedestrians, any person that causes an extension benefits. Pedestrians who crossed during the FDW interval and extended the call experienced no delay upon arriving at the crosswalk, thus reducing pedestrian delay during extensions. The extension also ensures a longer all-red clearance interval in which vehicles are not permitted to continue until the pedestrian has completed their crossing maneuver. As a result, the risk of a vehicle-pedestrian conflict is also reduced. The effects of the extension system are also reflected in the MLR models for pedestrian and vehicular delay. For pedestrian delay, extensions were estimated to have minimal impact, whereas vehicular delay is estimated to significantly increase. However, the low frequency of extensions that occur have minimal impact overall, and the safety benefits for pedestrians far outweigh the additional vehicular stop time delay.

5.3 Additional Considerations

As observed throughout the data, extensions occur infrequently and are mostly caused by normal-to-fast moving pedestrians beginning to cross during the FDW interval. While the extension system minimizes the risk of conflicts with vehicular traffic by providing additional time to cross, the system is not necessarily designed for this purpose. Ideally, the extension is designed to assist people who are older, people with mobility limitations, people with children/strollers, and groups of people by adding extra time to the all-red SDW buffer. While 17% and 20.7% of extensions were caused by slow pedestrians departing on the Walk indication, any case in which an extension prevents pedestrians in the crosswalk at the onset of the conflict green indication is a safety benefit. Additional research is required to determine the optimal

application and duration of the extension system. All extensions were less than or equal to five seconds, indicating that the maximum extension may be shorter than ten seconds. It may provide greater benefit at locations with higher volumes of older pedestrians, such as those near retirement communities, or in areas with more younger children, such as in school zones.

In general, the high rates of pedestrians noted to partially or entirely fail to comply to the crosswalk laws may be concerning. As previously noted, jaywalking rates remained the same before and after the installation of the Pedestrian Call Extension and Cancellation System. Pushbutton use increased during the After 1 but returned to Before-like conditions in After 2. These observations suggest that pushbutton use did not change with increased exposure to the system. A majority of the observed jaywalkers failed to press the pushbutton before crossing, and the audio message appears to have been ineffective in getting pedestrians to return to the wait zone after a cancellation. Since the system requires a button push to call for service, this lack of change is expected due to deviation in normal user behavior.

The cancellation system introduces several benefits for vehicular traffic and overall safety. However, pedestrian delay was observed to be higher during canceled calls versus non-canceled calls. This is also reflected in the MLR models. Several factors may contribute to the increased pedestrian delay during canceled calls. For example, several cancellations occurred after a pedestrian waited for a duration of time and decided a gap in traffic was acceptable to cross, therefore causing a cancellation. This was particularly true in cases where the pedestrians sought refuge in the median during a two-phase crossing, especially during the peak hour when overlapping gaps in both directions may be less likely to occur. As mentioned previously, 36 cancellations were recorded as malfunctions. These typically occurred when the pedestrian stood very still or was obstructed by the pedestrian signal head. As a result, the detection zone dropped

occupancy and the call canceled, leading to higher pedestrian wait times. A majority of these pedestrians pressed the button again and waited for the Walk indication.

Pedestrian delay was higher during the peak hour, in comparison to when the signal is running free, likely due to higher traffic volumes. However, nearly 30% of the observed extensions also occurred during the peak hour. Because the signal is running on coordinated 90 second cycles, pedestrians arriving at the crosswalk must wait for the cycle rather than traffic flow, which may result in longer wait times. Additional pedestrians may arrive during this wait time or during the active pedestrian interval. For the latter case, pedestrians typically chose to cross during the FDW interval to avoid having to wait for the next Walk interval, thus causing an extension instead.

6.0 CONCLUSION

This study presents the user benefits of a Pedestrian Call Extension and Cancellation System. The following section summarizes these findings while considering limitations and potential sources of error. Ideas for future work are also discussed.

6.1 Primary Findings

The results of this study indicate no change in jaywalking, pushbutton use among jaywalkers, or pedestrian delay. Jaywalking and pushbutton use both changed between Before and After 1 but returned to initial rates in After 2 and overall. In general, pedestrian behavior did not change with increased exposure to the system. While pedestrian delay did not significantly change overall, cancellations tend to increase wait time while extensions decrease delay. However, vehicular delay significantly decreased overall after installation. Stop time delay decreases in the case of a cancellation and increases during extensions. A majority of the cancellations were caused by jaywalkers. The audible message informing pedestrians of a cancellation appeared ineffective overall but was successful at prompting pedestrians to reinstate the call after a malfunction. The majority of extensions were caused by normal-to-fast moving pedestrians crossing during the FDW interval.

6.2 Limitations and Sources of Error

The primary limitation, and potential source for error, was visual data collection. Visual data limited the certainty that someone actually pressed the pushbutton and initiated a call for service. It is possible that a pedestrian appeared to push the button but failed to apply enough pressure to call for service. This may be the case in situations with extraordinary wait times and observations that appear to have canceled but are not recorded in the controller logs.

6.3 Future Work

An opportunity for future work lies in testing the Pedestrian Call Extension and Cancellation System in other locations with different traffic patterns and pedestrian types. The extension system may yield greater benefits in areas with an overrepresentation of older or school-aged pedestrians. The cancellation system may further decrease vehicular delay at four-way intersections where pedestrians may call for service in two directions.

Another opportunity for future work involves testing various methods of communicating the occurrence of a cancellation to the pedestrian. While the audio message is effective for getting pedestrians to push the button again after a malfunction, few pedestrians reinstated the call after a cancellation. Additional research in signing or audio messaging may decrease jaywalking, and therefore cancellation rates, and further increase safety. Other methods beyond pushbutton activation, such as an automatic call for service via pressure plate or waiting zone occupancy, may be worthwhile to decrease jaywalking rates.

Additional work may be necessary in addressing the malfunctions for pedestrians standing very still or obstructed by the signal head. Adjusting camera angles or installing pushbutton extension arms may be necessary to reduce such malfunctions.

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8.0 APPENDIX

8.1 Appendix A- Edge Cases

*Observations logged as cancelations, but pedestrian interval was served

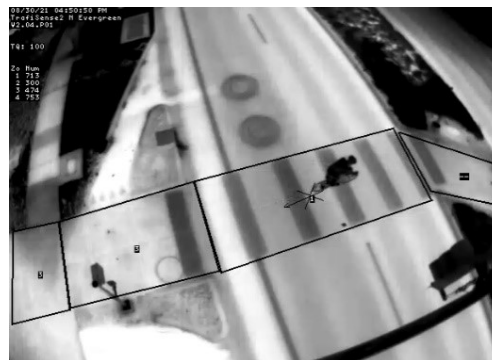
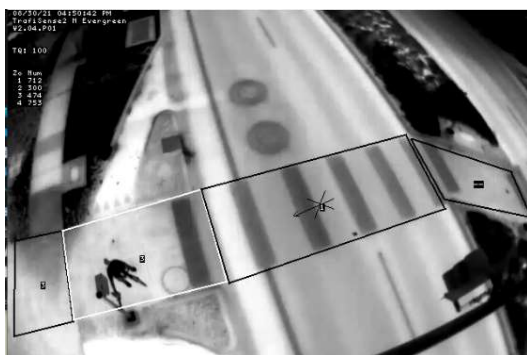
**Observations where the pedestrian pushes the button, jaywalks, and call appears canceled but is not recorded in the controller logs as a cancelation

***Cancelation occurred due to malfunction

AFTER 1:

1. *** **August 28, 14:55**: SB Pedestrian pressed pushbutton upon arrival. As NB pedestrian entered waiting zone and pressed the button; vehicular yellow occurs, call cancels, and red reverts. NB pedestrian left waiting zone by jaywalking immediately after pressing button. SB pedestrian pushed button again after the NB pedestrian finished jaywalking. Not recorded as cancelation in the controller logs.
2. *** **August 28, 15:43**: NB Pedestrian pushed button, waited in curb zone. Pedestrian stepped into the center after pushing the button, and then stepped closer to the button and waited very still next to it. Call was recorded as canceled. The pedestrian pushed the button again and crossed when they received the Walk symbol. No FLIR available for southern wait zone during this observation period. Sunny conditions.
3. *** **August 28, 16:00**: NB pedestrian pushed button upon arrival and waited in the curb zone. Pedestrian and dog moved around a little bit but became still near the button after a few seconds. Call was recorded as canceled. The pedestrian pushed the button again and crossed when they received the Walk symbol. No FLIR available for southern wait zone during this observation period. Sunny conditions
4. *** **August 28, 16:04**: NB recumbent bicycle pressed pushbutton upon arrival and waited in the curb zone without moving. Call was recorded as canceled, the pedestrian pushed the button again, and crossed when they received the Walk symbol. No FLIR available for the southern waiting zone during this observation period. Sunny conditions.
5. *** **August 28, 18:09**: SB bicycle pressed pushbutton upon arrival and waited in the curb zone, using the pushbutton sign for balance. FLIR camera dropped occupancy and the call canceled. Pedestrian pushed the button again and crossed at the Walk symbol. Sunny conditions with some shadows.

6. * **August 30, 12:19:** Call was recorded as canceled, but pedestrian interval was served. Pedestrians began crossing during yellow change interval.
7. ** **August 30, 13:49:** Pedestrian jaywalked, and call appears canceled. Not recorded in the call logs as a cancellation.
8. **August 30, 16:50:** Pedestrian interval was served a minute after pedestrian jaywalked but should have canceled. Detection zone occupancy was dropped after the pedestrian crossed.



9. *** **August 30, 17:19:** NB Pedestrians pressed pushbutton and waited in pedestrian zone. Call canceled and red reverted. Pedestrians pushed button again after red revert and then jaywalked when they received an acceptable gap. One pedestrian moved in place while the other stood still. No FLIR available for southside waiting zone for this observation period. Cloudy conditions, no shadows.
10. * **August 30, 17:46:** Call was recorded as canceled, but pedestrian interval was served after crossing. Pedestrian had crossed and was in opposite waiting zone when yellow change interval occurred.
11. * **August 30, 17:59:** Call was recorded as canceled, but pedestrian crossed on onset of pedestrian interval. FLIR video for the southside wait zone unavailable for this observation period.
12. ** **August 30, 18:25:** Pedestrian jaywalked, and the call appears canceled, but is not recorded in the call logs as a cancellation.
13. *** **August 30, 18:36:** NB Group of bicycles arrived over a period of several seconds. First bicycle (appears to be a child) pressed the button and waited close to the pushbutton, relatively still. Call was recorded as a cancellation, and the pedestrians pushed the button a second time. Group crossed when they received the Walk symbol and also initiated an

extension. No FLIR for southside wait zone for this collection period. Cloudy conditions, no shadows.

14. * **August 30, 18:49**: Call was recorded as canceled, but the pedestrian interval was still served, and pedestrian crossed on green.
15. ** **August 31, 14:51**: Pedestrian jaywalked, and the call appears canceled, but it is not recorded in the call logs as a cancelation.
16. *** **August 31, 17:58**: NB pedestrian pressed pushbutton upon arrival and stood very still within arm's reach of button. Call canceled and red reverted. Pedestrian pushed button again and jaywalked when an acceptable gap in traffic occurred. Pedestrian interval was served approximately one minute later. No FLIR for southside wait zone for this collection period. Sunny conditions with some shadows.
17. **September 1, 11:11**: Pedestrian interval was served with no pedestrians. Pedestrian who crossed previously had pressed the median pushbutton while crossing during the pedestrian interval. Unknown if calls placed in the median have the ability to cancel.
18. *** **September 1, 12:53**: NB Pedestrian pressed pushbutton upon arrival and waited in the curb zone, moving around within a little bit. Call canceled and red reverted. Pedestrian pushed button after initial cancelation and crossed when they received the Walk symbol. No FLIR for southside wait zone for this collection period. Sunny conditions, no shadows.
19. *** **September 1, 13:27**: SB bicyclists, 4 in total, pressed pushbutton upon arrival and waited in curb zone next to the button. One pedestrian waited in the curb zone in the sidewalk. The sidewalk curb zone dropped occupancy first (standing very still) and then the remainder of the curb zone dropped occupancy. Pedestrians pushed button again and crossed on Walk indication. Sunny conditions, no shadows.
20. *** **September 1, 16:04**: NB bicyclists, 2 in total, pressed the pushbutton upon arrival and waited side-by-side in curb zone within arm's reach of the pushbutton, staying in place. Call was recorded as a cancelation, and the pedestrians pushed the button again. They crossed during the Walk indication. No FLIR available for southside wait zone during this observation period. Sunny conditions, no shadows.
21. *** **September 1, 16:41**: NB pedestrian pushed button upon arrival, standing very close to the pushbutton, not moving. Call was recorded as a cancelation, and the pedestrian

pressed the pushbutton again and crossed on the Walk symbol. No FLIR for southside wait zone for this observation period. Sunny conditions, wait zone in shadows.

22. *** **September 1, 16:52**: NB pedestrians, two in total, pushed button upon arrival and moved forward in the wait zone between the button and the edge of the curb, standing very still. Call was canceled, and the pedestrian pushed the button again and crossed on the Walk symbol. No FLIR for southside wait zone for this observation period. Sunny conditions, wait zone in shadows.
23. * **September 1, 17:06**: Call was recorded as canceled, but pedestrian interval was served. Pedestrians began crossing during yellow change interval.
24. *** **September 1, 17:25**: NB pedestrian pushed button upon arrival and waited slightly behind the button in the waiting zone, very still. Call was recorded as a cancelation and the pedestrian pushed the button again and crossed on the Walk symbol. No FLIR for southside wait zone for this observation period. Sunny conditions, wait zone in shadows.
25. *** **September 1, 17:45**: NB bicycle pressed pushbutton upon arrival and waited in curb zone. Pedestrian moved a bit in place (reached for water bottle, etc.). Call was recorded as canceled and the pedestrian pushed button and crossed on the Walk symbol. No FLIR for southside wait zone for this observation period. Sunny conditions, wait zone mostly out of shadows.
26. ** **September 2, 8:28 & 8:31**: Pedestrians pushed the button, jaywalked, and calls appear canceled, but are not recorded in the call logs as cancelations.
27. * **September 2, 9:39**: Call was recorded as canceled, but pedestrian interval was served. Pedestrian began crossing during yellow change interval.
28. *** **September 1, 10:38**: NB bicycle pressed pushbutton upon arrival and stood very still next to the pushbutton. Call was recorded as a cancelation and pedestrian pushed button again and crossed during the Walk interval. No FLIR for southside wait zone for this observation period. Sunny conditions, wait zone in shadows.
29. **September 1, 11:09 - 11:11**: Four SB pedestrians pressed pushbutton and crossed on Walk interval. Halfway through, one of these pedestrians pressed the median pushbutton. At 11:11, this call was served. Call was recorded in the controller logs as an extension, although no pedestrians were present. No FLIR available for the southside wait zone for

this observation period- unknown if crosswalk detection zone was falsely occupied.

Sunny conditions, part of crosswalk and southern detection zone in shadows.

- 30. * September 2, 10:50:** Call was recorded as canceled, but pedestrian interval was served. Noted that waiting zone was in shadow. Pedestrian began crossing during yellow change interval. No FLIR available for southside wait zone for this observation period.



- 31. * September 2, 10:54:** Call was recorded as canceled, but pedestrian interval was served. Pedestrians began crossing on green—did not jaywalk.
- 32. * September 2, 13:47:** Call was recorded as canceled, but pedestrian interval was served. Pedestrian began crossing during yellow change interval.
- 33. *** September 2, 16:14:** NB bicyclist pressed pushbutton upon arriving and waited near the edge of the wait zone (possibly one foot out), relatively still. Call was recorded as cancelation and pedestrian pushed the button again and crossed on the Walk symbol. No FLIR available for southside wait zone for this observation period. Sunny conditions, no shadows.
- 34. September 2, 17:49-17:51:** SB pedestrian pressed button and waited 244.1 seconds before being served. FLIR zone maintained occupancy throughout. Two other NB pedestrians, at separate times, pressed pushbutton (one in median) and jaywalked. First pedestrian reactivated call after cancelation. Unclear if northside canceled due to NB jaywalkers or malfunction. No cancelation recorded in the controller logs.
- 35. *** September 2, 18:14:** NB pedestrian pressed pushbutton upon in the wait zone. A runner came up behind them and moved in and out of the wait zone and eventually jaywalked. Call was recorded as cancelation and pedestrian pushed the button again and

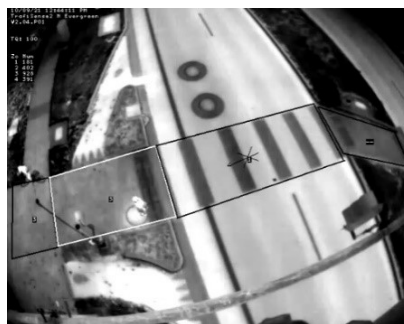
crossed on the Walk symbol after waiting 225 seconds. No FLIR available for southside wait zone for this observation period. Sunny conditions, no shadows.

36. * **September 2, 18:34**: Call was recorded as canceled, but pedestrian interval was served. Pedestrian began crossing during yellow change interval.
37. * **September 3, 11:11**: Call was recorded as canceled, but pedestrian interval was served. Pedestrian was in median during yellow change interval.
38. * **September 3, 12:27**: Call was recorded as canceled, but pedestrian interval was served. Pedestrians began crossing during yellow change interval.
39. * **September 3, 12:55 & 12:56**: Two NB children ran ahead, pressed button, then exited wait zone to run back to adults. The pedestrian interval was served, rather than canceling, and everyone crossed during FDW. 2 of 5 pedestrians in the group stopped and waited in median instead of crossing all the way. Pressed median pushbutton then jaywalked. Pedestrians who crossed all the way also pressed southside pushbutton while waiting for others in the median. Both calls were recorded as cancelations, but both pedestrian intervals were served.
40. * **September 3, 14:04**: Call was recorded as canceled, but pedestrian interval was served. Pedestrian began crossing during yellow change interval.
41. *** **September 3, 14:08**: NB pedestrian pressed pushbutton upon in the wait zone and waited very still. Call red reverted and pedestrian pushed the button again and crossed on the Walk symbol. No FLIR available for southside wait zone for this observation period. Cloudy conditions, no shadows.
42. *** **September 3, 15:04**: NB pedestrians entered waiting zone and pressed pushbutton upon arrival. One pedestrian wandered around the waiting zone, while the other stayed put. They both eventually stopped moving and the call canceled. Pedestrian pushed the button again and then jaywalked. No FLIR available for southside wait zone for this observation period. Cloudy conditions, no shadows.
43. **September 3, 15:21 – 15:22**: Three pedestrians pressed pushbutton (two NB, one SB), but no pedestrian intervals were served. All three eventually jaywalked. No cancelations recorded, and the northside FLIR was occupied throughout the duration of delay. No FLIR available for southside waiting zone. Possible problem with controller software. All three are recorded as cancelations in data reduction.

44. *** **September 3, 16:44**: NB pedestrian pressed pushbutton upon entering and stood still next to the pushbutton. Call canceled and red reverted. Pedestrian pushed button again and crossed at the Walk indication. No FLIR for southside wait zone for this observation period. Cloudy, no shadows.
45. *** **September 3, 17:32**: SB pedestrian pressed pushbutton upon entering and stood very still next to the pushbutton. NB pedestrian, who did not press the button, jaywalked. FLIR dropped SB wait zone occupancy and the SB pedestrian pushed the pushbutton again. Sunny, wait zone in shadows.
46. ** **September 12, 9:25**: Pedestrian jaywalked, and call appears canceled, but it is not recorded as a cancellation in the control logs.
47. * **September 12, 10:09**: Call was recorded as canceled, but pedestrian interval was served. Pedestrian began crossing during yellow change interval.
48. * **September 12, 13:48**: Call was recorded as canceled, but pedestrian interval was served. Pedestrians began crossing on pedestrian green—did not jaywalk.
49. * **September 12, 14:32**: Call was recorded as canceled, but pedestrian interval was served. Pedestrians began crossing during yellow change interval.
50. * **September 12, 15:28**: Call was recorded as canceled, but pedestrian interval was served. Pedestrian began crossing during yellow change interval.
51. **September 12, 16:25**: NB and SB pedestrians pushed button around same time. The system immediately red reverted. Another SB pedestrian approached and jaywalked without waiting after red revert. Jaywalker pressed median pushbutton and reinstated call. Both original NB and SB recorded as cancellation in data reduction
52. *** **September 12, 17:04**: SB pedestrian pushed button upon arrival and stood very still. Call was recorded as a cancellation and red reverted. Pedestrian pushed the button again and crossed during the Walk interval. Sunny conditions, no shadows.
53. * **September 12, 17:12**: Call was recorded as canceled, but pedestrian interval was served. Pedestrian began crossing during yellow change interval
54. **September 12, 17:27**: Call was recorded as extended, but no pedestrians were present at the termination of pedestrian interval. No FLIR for southside wait zone, but pedestrians left the zone after crossing. Possible that FLIR held occupancy.

AFTER 2:

55. * **October 9, 10:32:** Call was recorded as canceled, but pedestrian interval was served. Pedestrian began crossing during yellow change interval.
56. *** **October 9, 11:41:** SB pedestrian pressed button upon entering wait zone. Stood still texting for a few seconds, standing in line with the pedestrian signal head, and the wait zone dropped occupancy. The pedestrian moved forward again and the FLIR picked up occupancy again. Call canceled, and pedestrian pushed the button again and crossed on the Walk symbol. Cloudy conditions, no shadows.
57. ** **October 9, 12:10:** Pedestrian jaywalked, and the call appears canceled, but is not recorded in the call logs as a cancelation.
58. **October 9, 12:43:** Two pedestrian arrived at same time, on opposite sides of street. Both pressed pushbutton, NB pressed multiple times. The pedestrian who had previously crossed stopped at the edge of the northside wait zone, and the FLIR eventually dropped occupancy for this section (see below). Call canceled with 132 second ped delay.



59. *** **October 9, 15:30:** NB pedestrian pressed pushbutton upon arrival. Stood very still in the wait zone, and the call canceled. Pedestrian pushed the button again and eventually jaywalked. No FLIR available. Sunny conditions, no shadows in wait zone.
60. ** **October 9, 15:44:** Pedestrian jaywalked, and the call appears canceled, but is not recorded in call logs as a cancelation.
61. ** **October 9, 17:18:** Pedestrian jaywalked, and the call appears canceled, but is not recorded in call logs as a cancelation.
62. * **October 10, 17:28:** Call was recorded as canceled, but pedestrian interval was served. Pedestrian began crossing during yellow change interval.

- 63. * October 10, 17:46:** Call was recorded as canceled, but pedestrian interval was served. Pedestrian began crossing during yellow change interval.
- 64. * October 11, 8:49:** Call was recorded as canceled, but pedestrian interval was served. Pedestrians began crossing during yellow change interval.
- 65. *** October 11, 9:46:** NB pedestrian pushed button upon arrival and stood still next to the pushbutton. Call canceled and red reverted. Vehicles stopped at the red revert, and the pedestrian crossed on the SDW symbol. No FLIR available. Sunny conditions, wait zone completely in shadows.
- 66. * October 11, 10:23:** Call was recorded as canceled, but pedestrian interval was served. Pedestrians began crossing during yellow change interval.
- 67. *** October 11, 12:31:** NB Pedestrian pressed pushbutton upon arriving to wait zone and behind the pedestrian signal head. FLIR occupancy turned on and off. Call canceled and the pedestrian pushed the button again and crossed on the Walk symbol. Sunny conditions, no shadows. Screenshot of FLIR below.



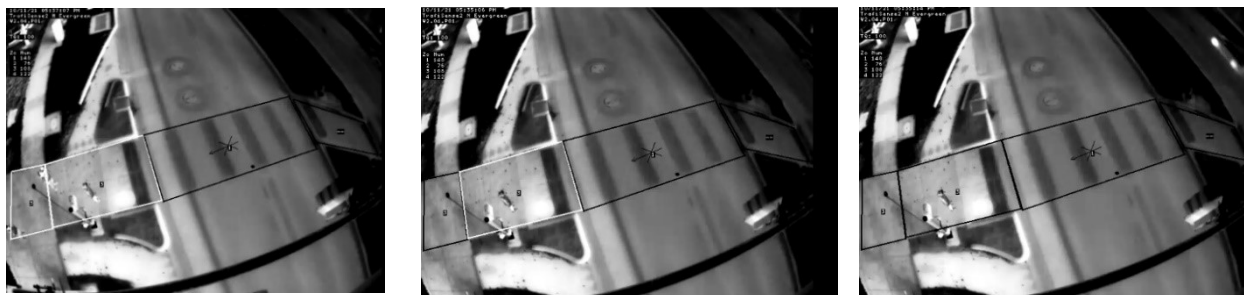
- 68. * October 11, 12:39:** Call was recorded as canceled, but pedestrian interval was served. Pedestrian began crossing during yellow change interval.
- 69. *** October 11, 13:** NB bicycle pressed pushbutton upon arrival to wait zone. FLIR dropped occupancy after pedestrian stood still for a few seconds. Call canceled, and the pedestrian pushed the button again and crossed on the Walk symbol. Cloudy conditions, no shadows. Screenshot of FLIR below.



70. *** **October 11, 16:23**: SB bicyclist pressed pushbutton. Another pedestrian approached and stood in line with the pedestrian signal head. The two appear to talk for several seconds, after a while the FLIR occupancy drops, and the call cancels. The second pedestrian walked away, and the original pedestrian pushed the button again and crossed on the Walk symbol. Wait zone never regained occupancy after the second pedestrian walked away.



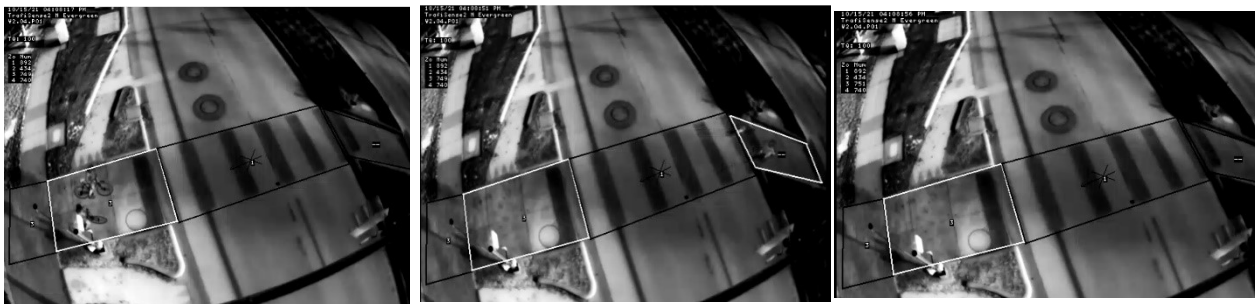
71. *** **October 11, 17:40:** SB Pedestrian pressed button and stood in wait zone very still. Occupancy dropped and reactivated by NB pedestrians. Pedestrian interval served 6 seconds after NB ped pushed button. SB pedestrian did not push button again. No shadows. Possible SB pedestrian (runner) did not hear audible message- wearing headphones possibly.



72. ** **October 12, 9:50:** Pedestrian jaywalked, and the call appears canceled, but is not recorded in the call logs as a cancelation.
73. **October 12, 13:03:21:** Pedestrian pushed button and walks away (does not cross) but pedestrian interval is served. Pedestrian moves out of waiting zone during yellow clearance interval. Not recorded as a cancelation in controller logs.
74. * **October 12, 13:24:** Call was recorded as canceled, but pedestrian interval was served. Pedestrians began crossing during yellow change interval.
75. ** **October 13, 16:40:** Pedestrian jaywalked, and the call appears canceled, but is not recorded in the call logs as a cancelation.
76. **October 13, 17:24:** SB pedestrian jaywalked, and the call appears canceled, but is not recorded in the call logs as a cancelation. FLIR zone maintained occupancy throughout wait time.
77. ** **October 14, 8:59:** Pedestrian jaywalked, and the call appears canceled, but is not recorded in the call logs as a cancelation.
78. * **October 14, 17:30:** Call was recorded as canceled, but pedestrian interval was served. Pedestrian began crossing during yellow change interval.
79. **October 14, 17:46 & 17:46:** SB ped pressed button and immediately walks around signal pole, leaving waiting zone. Pressed button again after circling pole. NB ped waited for a while, pressed the button, then jaywalked. SB ped paced in and out of waiting zone and

eventually jaywalked. Pedestrian interval was never served. One, if not both, appear to be canceled.

- 80. ** October 15, 8:47:** Pedestrian jaywalked, and the call appears canceled, but is not recorded in the call logs as a cancelation.
- 81. * October 15, 9:35:** Call was recorded as canceled, but pedestrian interval was served. Pedestrian began crossing during yellow change interval.
- 82. ** October 15, 10:20:** Pedestrian jaywalked, call canceled and red reverted, but is not recorded in the call logs as a cancelation.
- 83. *** October 15, 12:55:** NB bicycle pressed pushbutton upon arrival. Pedestrian waited very still, somewhat blocked by pedestrian signal head, and FLIR dropped occupancy. Regained occupancy after second button push. Crossed on Walk symbol.
- 84. October 15, 14:55 & 14:55:** First pedestrian (NB) did not press pushbutton and jaywalked. Second pedestrian (SB) pressed pushbutton and waited for green. NB pedestrian waited in median until pedestrian interval was served. Call was recorded as canceled on the North side, but pedestrian call was served.
- 85. October 15, 16:08:** Pedestrians jaywalked, and pedestrian interval was served after crossing. Call should have canceled, but waiting zone remained occupied after the pedestrian jaywalked.



- 86. *** October 15, 16:47-16:48:** SB Pedestrian arrived and pressed pushbutton. Approx. 10 seconds later, NB pedestrian arrived and pushed button. South-side wait zone lost occupancy, and the NB pedestrian pushed button again, regained occupancy, and lost it again. SB pedestrian pressed button several times. No cancelation recorded in controller logs.

- 87. October 15, 17:26:** NB pedestrians arrived and pressed button. SB pedestrians arrived and pressed pushbutton after NB group jaywalks. A second NB pedestrian waited in curb zone then jaywalked after first group and waited in median and presses median pushbutton. Pedestrian interval was served after median and north-side buttons are pressed. No cancelation recorded in call logs, however the previous call at 17:25 was recorded as canceled. These calls were within the cancelation lock-out period.
- 88. *** October 15, 17:59:** SB bicycle pressed pushbutton when arriving to pushbutton. Stood still while waiting and FLIR dropped occupancy. Pedestrian pushed button again and crossed during Walk symbol. FLIR never regained occupancy. Cloudy conditions, no shadows.