User recognition at mid-block crossings via connected vehicle technology:

An evaluation of driver awareness via eye tracking and stated preference data

A Thesis

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APPROVAL SHEET

This thesis is submitted in partial fulfillment of the
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ABSTRACT

Using connected vehicle technologies, pedestrian to vehicle (P2V) communication applications can be installed on smart devices allowing pedestrians to directly communicate with drivers, beyond using body language, by broadcasting discrete safety messages which are received by drivers in-vehicle. This study consists of designing, developing, and deploying a cyber-physical P2V communication system at a mid-block crosswalk to analyze drivers' reactions to in-vehicle advanced warning messages, the impacts of in-vehicle advanced warning messages on driver awareness, and drivers' acceptance of this technology. The application was designed to create a virtual advanced warning system for a mid-block crosswalk through geofencing designated areas in which users will be able to interact with each other via smartphone or tablet.

In testing human subjects with, and without, advanced warning messages upon approaching a mid-block crosswalk, subject reaction, acceptance, and eye tracking data was collected. After analyzing the data from these performance metrics, it was found that the application did in fact increase the rate at which drivers stopped for the pedestrian by 20%. Furthermore, it was found through stated driver observations that 82.5% of participants found the application increased their awareness, 90% of drivers did not find the application more distracting than helpful, and 83.75% of drivers thought that the application was a technology they would like to see deployed in similar GPS navigational systems. Lastly, it was found that, in general, drivers did not look at the pedestrian any more or less during their full exposure to the pedestrian; however, they did look at the pedestrian approximately 15-20% less after having received the message at between the range of 260 to 200 feet away from the crosswalk.

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CHAPTER 1: Introduction

1.1 Purpose

With new technologies being released to the public, the number of incidents involving vehicles and vulnerable road users can be minimized. This research discussed in this thesis describes and analyzes the development and deployment of a pedestrian to vehicle (P2V) connectivity system via cellular technology designed to increase driver awareness of pedestrians at mid-block crosswalks. Throughout this paper, the term 'pedestrian' refers to both people walking on foot and people riding bicycles.

1.2 Scope

Designated mid-block crossings have been modified over time to increase the safety and functionality for pedestrians and motorists. Mid-block crosswalks can incorporate refuge gaps, staggered halves, and curb extensions; however, mid-block crosswalks are not always safe because they can create unpredictable scenarios for both drivers and pedestrians. With the surge of connected vehicle (CV) technology and push for increased alternative modal usage penetration into overall travel mode choice there are more opportunities to connect pedestrians and vehicles and provide road users with increased situational awareness, potentially reducing the number of vehicle-pedestrian incidences.

The scope of this project was to develop a mobile application that both pedestrians and motorists can install on their smartphones or tablets to enable users with the ability to communicate with each other at mid-block crossings via discrete safety messages and analyze the safety impacts and performance metrics of said application. Advanced warning messages differ from currently deployed technologies in vehicles, for example automatic braking, as this technology takes a pro-active approach in preventing incidents rather than a reactive approach. Personalized advanced warning messages sent to drivers inform the driver of the pedestrian's intent to cross, potentially increasing the driver's awareness of the pedestrian as well as the pedestrian's intent at the upcoming crosswalk and limiting the number of incidents observed.

Connected technology such as this application may also help enhance the on-site physical structure's effectiveness by overlaying a virtual environment for pedestrians and motorists to interact. By overlaying a virtual environment over the physical environment, information can more effectively be transmitted to motorists to increase their awareness of the situation. Furthermore, by deploying connected technology that operates over cellular technology, the need to install costly, on-site technologies such as dedicated short-range communications and WIFI is eliminated.

To best understand the effectiveness of this technology, multiple methods of analysis were conducted. Firstly, in an attempt to understand driver awareness, driver's operating the vehicle in testing of the application were analyzed using eye-tracking technology. The goal of eye-tracking was to study where drivers were looking during testing to see if, with the advanced warning message, drivers were looking at the pedestrian more and as to whether or not the message displayed on screen was distracting in any way. Furthermore, driver's reactions were also recorded to see whether more drivers stopped with the advanced warning for a pedestrian at the test site's mid-block crosswalk than without it. During all test runs, driver speed was also recorded to see whether drivers approached the crosswalk at slower speeds with the advanced warning than without it. Finally, drivers were also given a short questionnaire to express their thoughts on the application to understand whether they felt the advanced warning altered their awareness of the pedestrian at the mid-block crossing, whether they found the warning to be more distracting than helpful, and as to whether or not they would desire such types of advanced warnings to be included in GPS technologies.

1.3 The Larger Project

This thesis does not encompass all that may be deemed as pertinent information from the study conducted; however, this thesis serves as a focused analysis of the much larger project which includes application performance testing and kinematic data analysis. In order to execute a project on this scale, multiple researchers worked to take this project from a conceptual idea to a finished and tested product. Primarily, the author of this paper worked alongside Sean Laffey, another student researcher from the University of Virginia, in performing and analyzing the test results.

1.4 Organization of Thesis

The remainder of this thesis is organized as follows:

- Chapter 2: Reviews the literature regarding the safety of mid-block crosswalks and driver acceptance and response to advanced warning messages.
- Chapter 3: Provides a detailed design of the application used to send the advanced warning messages.
- Chapter 4: Details the methodology and technology used in testing the applicants using the mobile phone application.
- Chapter 5: Presents the results of the analysis conducted.

- Chapter 6: Provides a discussion and interpretation of the results as well as recommendations for conducting this research.

CHAPTER 2: Literature Review

While current designs have aided pedestrians in crossing roadways at mid-block crossings, conflicts still arise due to the confusion these designs can cause between pedestrians and motor vehicles *(1)*. Mid-block crosswalks are dangerous for both pedestrians and drivers because communication between the pedestrian and driver is non-verbal and each individual pedestrian decides then it is safe to cross *(2)*. These instances are increased when a designated mid-block crossing is installed at the crossing of a greenway with a roadway due to the higher volume of pedestrians and cyclists crossing. Sometimes these mid-block crossings are across roadways where mid-block crossings are uncommon or unexpected, thus exposing users to an uncomfortable environment.

2.1 Inspiration from Northern Virginia

Turner Fairbank Highway Research Center resides in McClean, Virginia, located in DC Metro area of Northern Virginia. Locally, there are multiple bicycle and pedestrian greenways and trails that cross over many roadways. These roadways range from neighborhood backroads to major roadways servicing high volumes of traffic. In the design of this thesis project, inspiration was drawn from the surrounding areas and trails in an effort to best service pedestrians and drivers.

Figure 1 below shows the Washington and Old Dominion Trail (W&OD) crossing Wiehle Ave in Reston, Va. This mid-block is confusing due its position in relation to the nearby signalized intersection. Wiehle Ave services vehicles and pedestrians wishing to cross the road have trouble communicating with approaching vehicles due to the vehicle’s high approach speed, limited sight distance, and wide crossing width. The minor street approaches have limited sight distance looking to the crosswalk because the mid-block crosswalk is less than 100 feet from the intersection. Providing additional protection, such as advanced driver warnings should make this a more desirable crossing for the pedestrians.

Figure 1 – Wiehle Ave mid-block crossing in Reston, VA *(3)*

Figure 2 below shows a mid-block crossing far from any intersection. The crossing of the W&OD trail in Figure 2 has a refuge area, but the refuge is only protected by pavement markings. Because vehicle speeds on Sunset Hill Road can reach over 50 miles per hour (mph), additional protection at the crossing would make this a more desirable crossing for the pedestrians. Furthermore, there are not advanced warning signs for motorists warning of the approaching mid-block crossing, the only signage for the mid-block crossing is directly at the crossing itself.

Figure 2 – Sunset Hill Road crossing in Reston, VA *(4)*

Multistage mid-block crossings can increase delay because vehicles at all approaches must wait to interpret the pedestrian to non-verbally communicate their desire to cross *(2)*. Communication between the pedestrian and driver becomes more complicated when a mid-block crossing crosses a road with a 3-lane or more cross section because one vehicle at a multi-lane approach can block an adjacent vehicle's view of a pedestrian in the mid-block crossing. Connecting pedestrians and vehicles to provide advanced warnings that anticipate potential collisions should help to eliminate crossing confusion and ambiguities.

Besides visual communication confusion, the balance of existing laws and safety can create confusion at the mid-block crossing. Virginia law requires drivers to yield to pedestrians in the crosswalk; however, along routes such as the W&OD and Mt Vernon Trails, mid-block crossings are signed to such that the pedestrians must stop for traffic. Legally, the drivers are required to stop at the crosswalk should someone be within it; however, it is unclear what to anticipate from drivers as they may yield to pedestrians either expecting them to cross even though pedestrians aren't supposed to stop until no oncoming traffic is approaching or may not yield knowing that pedestrians are supposed to give the right away to all oncoming traffic.

Due to the unique nature of mid-block crossings, the unclear and inconsistent rules of right of way, and the difficulty of establishing visual communication between pedestrian and driver, mid-block crosswalks prove to be confusing and dangerous.

2.2 The Dangers of Mid-Block Crosswalks

Unsignalized mid-block crosswalks pose a unique and confusing scenario for all roadway users as driver and pedestrian communication, or the lack thereof, is paramount in understanding the safety of these designs.

In a FHWA study conducted with data collected throughout the 1990s, it was found that the percentage of pedestrian collisions with absolutely no traffic control was 74.4%, indicating that the majority of pedestrian-motorist collisions can be mitigated with some form of advanced warning *(5)*.

As shown in Table 4, mid-block crossings are the ideal scenario for such situations with over 90% of pedestrian collisions having occurred at mid-blocks with no traffic control for both the 'dart/dash' and 'other' scenarios *(5)*.

The same study conducted by the FHWA found that the majority of the fault of collisions occurring at mid-block crossings was to be placed on pedestrians only, as seen tin Table 5, with 91.6% of collisions being the fault of pedestrians only at mid-blocks in which the pedestrian darts out among traffic and 60.4% of pedestrian collisions being the fault of pedestrians at mid-blocks in general *(5)*.

It would feel appropriate, then, to implement a form of control of pedestrians at these mid-block crossings; however, this is not the case. In order to attempt to combat the unpredictability of pedestrians, the City of St. Louis rewrote their laws requiring all trail users to stop and yield to vehicles at trail-roadway intersections. St. Louis deemed that trail-roadway intersections were not in fact intersections, but simply trail crossings. Thus, in order to control pedestrians at such crossings, St. Louis removed all striping at these crossings and installed stop signs and warning messages along their trails, indicating that it is state law that all trail users stop and yield to vehicles *(6)(7)*. Ultimately, pedestrians operated as usual, with some obeying the signage posted and others ignoring these warning and stop signs and crossing with the assumption that motorists will yield to them as the new state law stated.

A similar case can be seen in Virginia at identical intersection types along the vast network of greenways in Northern Virginia. There are stop signs and warning messages along the trails at intersections with roadways, yet there is still some confusion at such crossings. Whether it be pedestrians ignoring the signs and walking into the roadways with the assumption that they have the right of way or pedestrians stopping as the signage demands, yielding to vehicles, only to encounter vehicles yielding at the crosswalk to pedestrian leaving pedestrians to cross with the assumption that vehicles in adjacent lanes will do the same. Such uncontrolled mid-block crossings foster unpredictable and unsafe situations, leaving all of the decision making to at these intersections in the hands of each individual, thus increasing the potential of possible incidents. With the increased capabilities of connected vehicle technology, it is now possible to connect pedestrians and motorists in a virtual environment, to transmit advanced warnings to drivers when pedestrians are present at mid-block crossings, and to hopefully limit the number of pedestrian crashes.

2.3 Driver Reaction to Advanced Warning Messages

Driver behavior is unpredictable and unique to every driver, thus, introducing a new technology into the in-vehicle environment may have some implications. For this study, the presence of the on-board GPS system is deemed as negligible, as most vehicles and drivers already have a display present whilst they are driving, whether it be part of the vehicle or a smart device mounted on their dashboard. Since this application has both a visual and auditory warning message, the way in which drivers interpret and react to an advanced warning message must be accounted for in order to best test the application for effectiveness. Providing drivers with pertinent information from which they can make a decision sounds like a good thing, but information provided at the wrong time can drastically change driver behavior. Should a message be sent to a driver well before a scenario arises or before the driver has a visual on the scenario, the alert may be considered a false alarm, therefore leading to mistrust in the messaging system; too late and the driver may behave drastically and inappropriately *(8)(9)*. A study conducted in 2016 found that, providing drivers with an advanced warning message of an oncoming collision had the strongest impact in reduced kinetic energy (braking of vehicle) at a lead time of 4 to 8 seconds *(9)*.

2.4 Eye Tracking and Awareness

Defining 'what is driver awareness?' is a difficult task. In his study of the situational awareness of drivers, Leo Gugerty defines situation awareness is 'the updates, meaningful knowledges of an unpredictably-changing, multifaceted situation that operators use to guide choice and action when engaged in real-time multitasking' *(10)*. Gugerty also goes on to describe situation awareness as a type of knowledge and that most drivers have this knowledge in working memory while driving *(10)*. The purpose of this application is to inform drivers of an oncoming situation – a pedestrian attempting to cross the road – therefore, the message the application sends to drivers is considered to be a type knowledge. What remains in question is whether the knowledge being given to drivers is something they are wholly conscious of. Some researchers believe that situation awareness can only be derived from conscious knowledge *(11)*, whereas others believe it situation awareness can be derived from conscious or unconscious knowledge *(12)*. Due to the variability in definitions and understanding of driver awareness, this study asks drivers after their testing of their opinion on how their awareness changed.

The Gugerty study also defines two different ways of understanding visual attention: focal and ambient; however, no direct correlation of how often a driver views a scenario is made to driver awareness is provided *(10)*. Multiple types of tests have been conducted to gather information from drivers pertaining to their awareness of their environment while driving by either asking drivers to report hazardous events while driving *(13)* or measuring driver response time by stopping a situation mid-scenario and asking the driver one or two questions pertaining to the scenario *(14)*. In an effort to understand driver awareness on a quantifiable level, it was determined that eye tracking data was to be collected to discern whether the percent time a driver actively looks at a pedestrian changes between receiving and not receiving an advanced warning message and comparing these results to a driver, self-reported analysis.

CHAPTER 3: Application Design

This project aimed to expand connected vehicle technology to include vulnerable road users in the connected environment. Mid-block crosswalk treatments vary by region and operational needs; often, a mid-block crosswalk is striped but receives no active infrastructure support, such as flashing warning lights, to warn pedestrians and drivers of a potential conflict. The application was designed to create a cyber-physical advanced warning system for a mid-block crosswalk through geofencing – a process of using GPS technology to virtually draw geographic boundaries which allow mobile technologies to trigger a response when within the defined space – designated areas in which users will be able to interact with each other via smartphone or tablet, as seen in Figure 3. The geofenced cellular network delineates three geofenced areas:

- A geofence encompassing the mid-block crosswalk and adjacent sidewalk for the Pedestrian Geofence
- Two geofences adjacent to either side of the mid-block crosswalk for the Vehicle Geofence

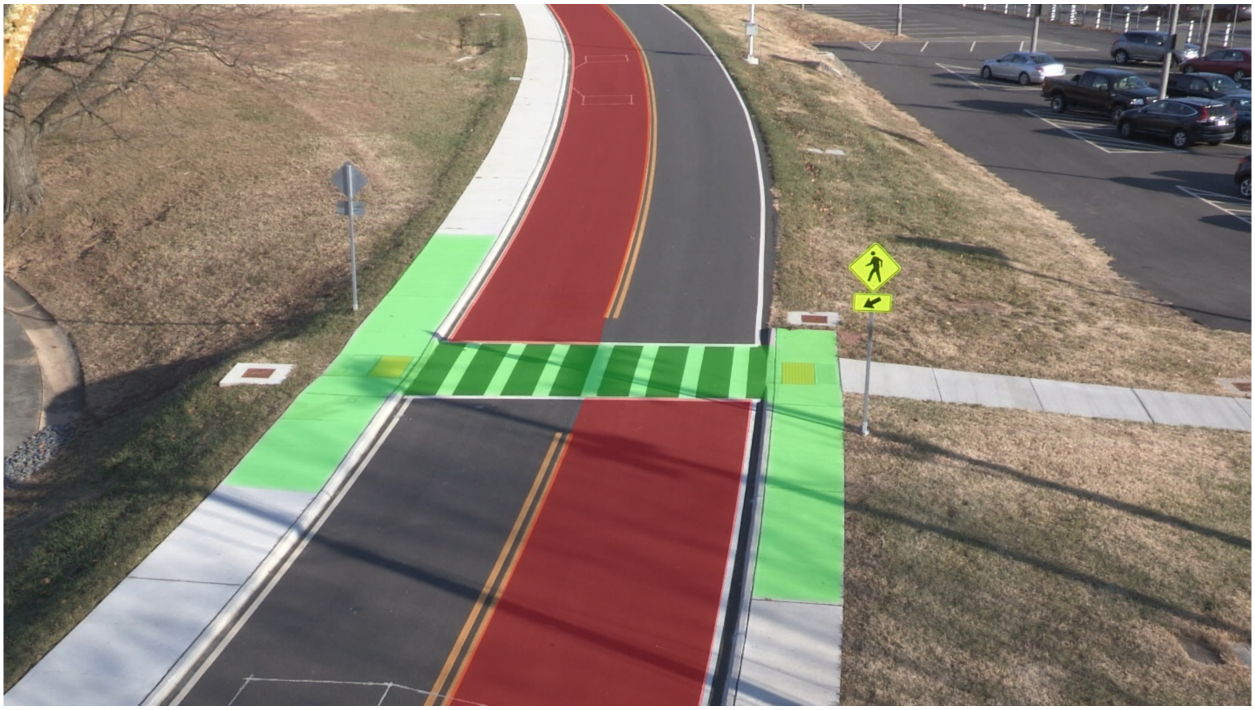

Figure 3 – Geofenced Areas (Pedestrian Geofence in green and Vehicle Geofence in red)

3.1 Concept of Operations

The advanced warning mobile application was designed such that it used wireless communications to create an environment consisting of stagnant virtual midblock crossings, overlapping the existing midblock crossings, which users could interact with. When a pedestrian is in range of the designated crossing, the virtual environment recognizes that a user is present and enables the user to broadcast their presence and intent to cross at the crossing. Drivers need to be equipped with the application so that they may interact with the virtual network, as well. When the driver is within a designated range of the virtual crosswalk and a pedestrian broadcasts a notification of their presence at the mid-block crossing using the mobile application, a visual and audible advanced warning message is transmitted to the driver, warning them that a pedestrian is present.

The proposed application was designed to run as the primary screen on the phone and will serve as a proof of concept. Further development can have the application operate in the background of the smart device or integrated into other GPS technologies, seamlessly allowing users to view their GPS and be alerted from the crossing via visual and audible messaging.

This application needs only standard signage, pavement markings, and cellular signal from two smart devices (one in vehicle and one on the pedestrian's person) in order for proper operation at a midblock crossing. The application was designed so that it would limit the cost and materials needed to operate and maintain active warning technology at mid-block crossings.

3.2 Objective

The primary objective of this study was to build an application designed to increase driver awareness of potential conflicts at mid-block crossings by notifying drivers of pedestrian presence via advanced warning messaging. The goals of this application were to:

- Build an environment to enhance safety at mid-block crossings where adequate safety precautions aren't always present.
- Create a virtual environment to limit the need to install costly equipment at every mid-block crossing.
- Deliver personal messages for drivers warning them of vulnerable users requesting to cross, potentially increasing driver awareness of pedestrians at mid-block crossings.
- Understand driver reaction to advanced warning messages at un-signalized locations.
- Establish a simple, functional application that can be incorporated into the overall CV environment and protocol.

3.3 System Overview

The virtual crossing network was created using localized, designated geospaces (geofenced area), using GPS navigational systems (in this instance, Google Maps) at mid-block crossings. Users in the geospaces have the ability to interact with the virtual crosswalk; the interaction between users and the environment is limited to user request and solely personal-message oriented. Users have the option to define themselves as a Pedestrian or Motorist upon opening the application and are allowed to alter roles between trips. The fundamental data flow for messaging between users is displayed in Figure 4. Furthermore, the detailed system architecture for operations can be found in Figure 5.

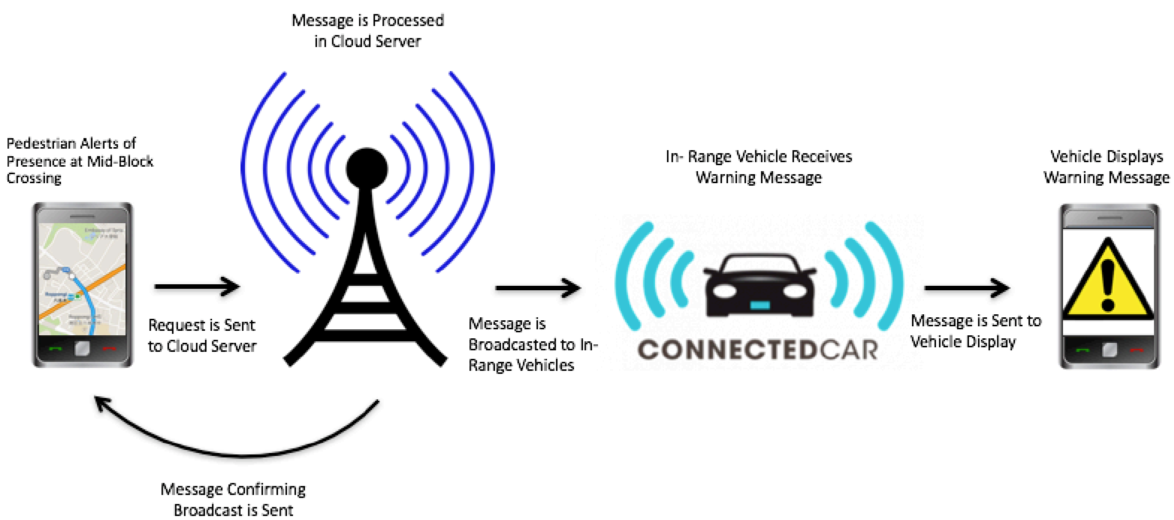

Figure 4 – Message Data Flow

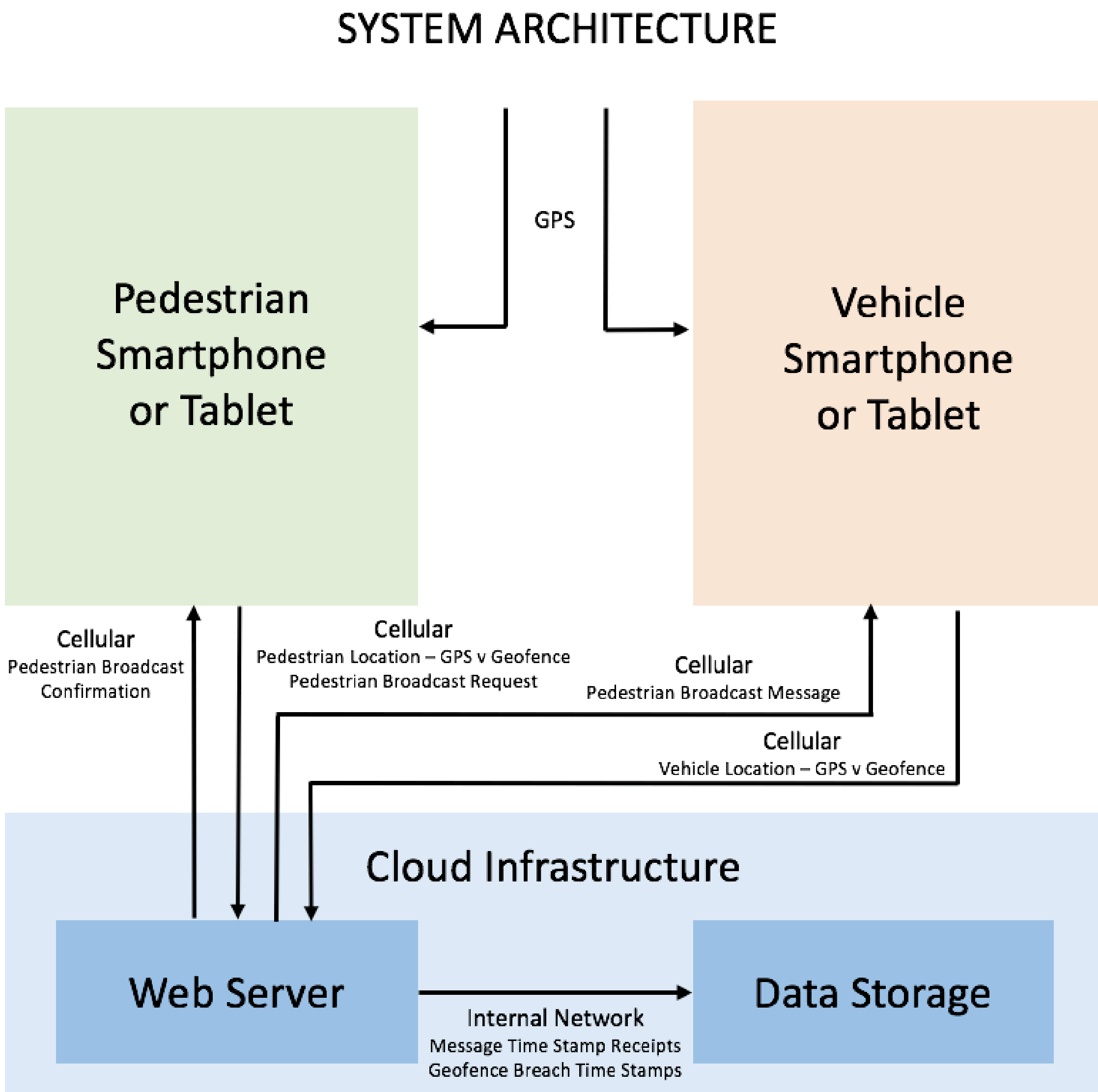

Figure 5 – System Architecture

3.3.1 Pedestrian Driver Interaction Design

The pedestrians and drivers are connected using a cellular phone application that operates using a cellular network. The applications between the drivers and pedestrians will interface when both the driver and pedestrian are in the pre-defined geofenced areas. When a pedestrian is in the Pedestrian Geofence delineating the mid-block crosswalk, the pedestrian will be given the option within the application to notify any drivers within the designated Vehicle Geofence of their presence at the mid-block crosswalk.

3.3.2 Pedestrians

The pedestrians interact directly with the network and application. Pedestrians with the application installed on their cellular device are responsible for physically pressing a button on their screen indicating their presence at the mid-block crossing. Only when the pedestrian signals their presence will the drivers receive an advanced warning message. Once the pedestrian has pressed the button on their screen, they receive a message that their advanced warning message is being broadcasted to motorists within the Vehicle Geofence. The pedestrians do not receive a warning message or any operational message indicating that it is safe to cross as this application is designed to only operate as a situational awareness application and not as a means of enforcing regulation.

3.3.3 Drivers

The drivers with the application installed on their cellular device are automatically connected to the virtual network when inside the geofenced area. It is assumed that drivers have their phone or tablet mounted to their dashboard or windshield, being used as a GPS device. When a pedestrian signals their presence at the crossing, the vehicles in the vicinity of the mid-block crosswalk within the Vehicle Geofence automatically receive a warning message, notifying them of the presence of the pedestrian.

The application requires that localities (city, town, etc.) develop a GPS map layer that the application can access and update as the user travels between localities. The map layer consists of designated, passive geospaces that define the area of operations for the virtual crosswalk.

3.4 User-Oriented Operational Description

Current operations at mid-block crossings are, fundamentally, limited to the interactions between pedestrians and motorists at the mid-block. Often, visual recognition is required to ensure that pedestrians have been seen and are being given the right of way to cross at mid-block as is required by law; however, language is often misunderstood or unclear as yielding to pedestrians is mostly required by law when a pedestrian is within the crosswalk, not at the crosswalk. Due to the large variability of driver and pedestrian behavior at mid-block crosswalks, coupled with variability in signage, marking, and the built infrastructure in place at these locations, safety is of paramount concern.

The introduction of a virtual mid-block crossing application designed to warn drivers of the presence of pedestrians is aimed to increase driver awareness of pedestrians at the sites, thus limiting possible conflicts. The basic requirements for proper interaction between the pedestrian and driver for this application is described in section 3.4.1.

3.4.1 Users and Oder of Operations

<u>Pedestrians</u>

1. Activate application and select user type as ‘Pedestrian’.
2. When at crosswalk, a “button” becomes activatable in the application on the pedestrian’s phone to broadcast the advanced warning message.
3. Message broadcast that a warning should be shown to drivers in proximity zones to crosswalk
4. A confirmation message is sent back to the pedestrian that their message is being broadcasted to all available drivers.

<u>Drivers</u>

1. Activate application and select user type as ‘Vehicle’.
2. The application routinely checks to see if vehicle is in Vehicle Geofence.
3. Once within a Vehicle Geofence while an advanced warning message is being broadcasted, the message is received.
4. The application displays a visual and audio message to the driver of the pedestrian.

CHAPTER 4: Experimental Design

4.1 Test Concept

The goal of the test was to study drivers' reaction to advanced warning messages using the pedestrian midblock crossing application. The advanced warning message indicates that a pedestrian is at a mid-block crosswalk in the test vehicle's current path. The test subjects in the experiment drove the test vehicle, accompanied by a researcher in the rear passenger seat. Another researcher acted as the pedestrian crossing the mid-block crosswalk.

4.2 Test Plan

80 human test subjects operated a test vehicle equipped with a tablet with the capability of displaying a visual and playing an auditory warning to the driver. Originally, the experiment had been designed for 40 test subjects to reach a confidence level of 80% with a 10% margin of error with a 50% response distribution; however, sample size was increased in an attempt to receive more accurate results and account for a loss of data. This increase, with an account for loss of data, allowed for a margin of error of 10% with an 85% confidence level and a 50% response distribution.

For this experiment, the test subjects drove one single lap for approximately 10 minutes total, including both "warm-up" laps and test laps. The test lap was chosen so that the subjects passed a mid-block crosswalk once during each lap. A warm up lap was used so the driver would become comfortable with the vehicle and the test track before the test began. After the warm-up lap was complete, the test laps began. During this test, the drivers completed at least 4 laps around the track, with: the first lap being the warm up lap, the second being a test lap, the third being a 'dead' lap, and the fourth being the final test lap. During one of the test laps, the pedestrian would send an advanced warning message to the driver indicating that the pedestrian wants to cross the mid-block crosswalk. During the other test lap, the pedestrian will be at the mid-block crosswalk and attempt cross the mid-block crosswalk with no advanced warning message being sent to the driver.

4.3 Test Course

The test course for this experiment was determined to be a lap around the Federal Highway Administration's Turner Fairbank Highway Research Center located in McLean, Virginia. The test course is a two-lane cross section, bi-directional road that encircles the research center. There is one mid-block crosswalk present along the course, as indicated by the red square in Figure 6. There are sidewalks leading up to the mid-block crosswalk that the pedestrian utilized for his approach during testing and signalized intersections border both approaches of the midblock crosswalk. The direction that the test subjects drove is indicated by the red arrow in Figure 6. The mid-block crossing that tests were conducted at is shown in Figure 7 from the driver's perspective. The required time to navigate one test lap is approximately 2 minutes, taken at a slow driving pace. During all phases of testing, the signal immediately west of the mid-block crossing, was set to an always green phase for Innovation Drive so as to not impact driver performance when testing (drivers were made aware that the signal would always be green and never change). The perpendicular approaches at this intersection were set to always red.

A small utility marker will be placed approximately 215' from the mid-block crosswalk. This marker indicated the target average distance away from the crosswalk that a message should be sent to the driver. Considering the Wan study, a lead time of 4 to 8 seconds provides the best response from drivers receiving advanced warning messages *(9)*. Since the speed limit on the test roadway is 25 mph, speeds of 30 mph and 20 mph were considered for determining the shortest and farthest distance from the crosswalk, respectively, a message should be sent. The shortest lead time being 4 seconds at 30 mph yields a distance of 176 feet and the farthest lead time being 8 seconds at a speed of 20 mph yields a distance of 235 feet. The average of these two values was found to be approximately 205 feet; however, and extra 10 feet of distance was added to the marked distance to account for pedestrian reaction time in messaging the driver and latency issues that may arise with the application.

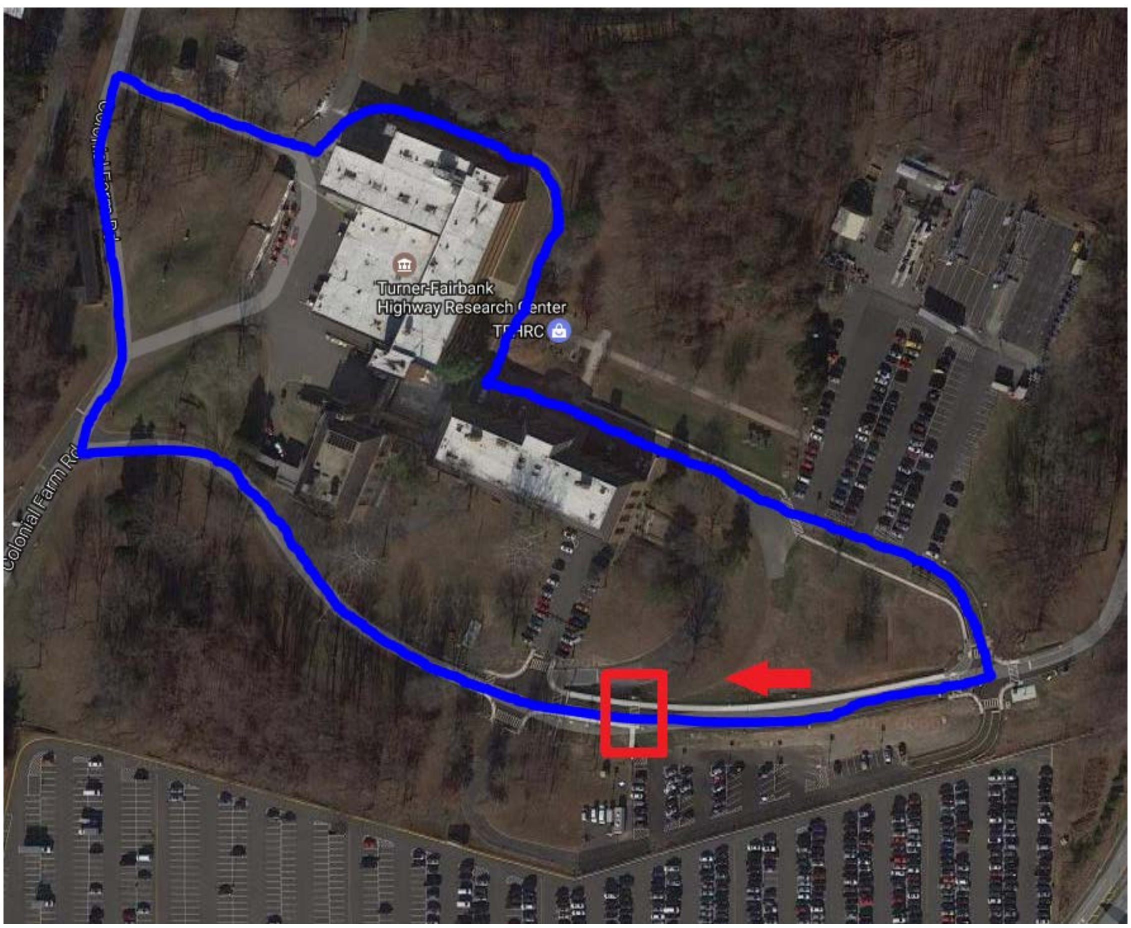

Figure 6 – The designated test lap around Turner Fairbank Highway Research Center *(15)*

Figure 7 – The designated mid-block crossing (with pedestrian present) at approach.

4.4 Cellular Devices

The test vehicle used in this experiment was equipped with a Samsung Tab E tablet with the advanced warning application connected to the Verizon cellular network. The tablet was mounted to the vehicle dashboard, around where the radio would be displayed, as this is where most modern vehicles have screens installed that display GPS information. The pedestrian in this experiment was a researcher using a Samsung Galaxy S7 connected to the Verizon cellular network.

4.5 Test Organization and Preparation

Each test subject was slated for an hour's worth of testing. There were multiple components to this test, so it was imperative that a testing schedule be adhered to as closely as possible for consistent and reliable testing. The minimum viable testing procedure used in this experiment is defined as follows:

- 0:00 – 0:10 – Test Subject Greet and Documentation
- 0:10 – 0:15 – Test Overview
- 0:15 – 0:40 – Subject Eye Calibration & Vehicle Familiarization
- 0:40 – 0:50 – Subject Testing Laps
- 0:50 – 1:00 – Subject Debriefing, Questionnaire, and Payment

Depending on extraneous and/or unanticipated factors, the time spent within each section of the test procedure may have changed and was be allocated to other portions of the test. It should be noted that the allotted times for Subject/Vehicle Familiarization were never reduced to less than 10 minutes as this was the minimum acceptable time suggested by the Human Factors Department at TFHRC to minimize human error due to operating equipment they are unfamiliar with; however, extra time may have been allocated to this portion of the test or to the test runs should there have been a technical failure or malfunction during testing.

In the event of inclement weather, testing was postponed to a later date. Weather conditions such as rain will impact driver sight distance, driving habits, and perception, so it was deemed unfavorable to test in these conditions for accurate and consistent results. Furthermore, all testing was conducted between the hours of 9 AM EST and 5 PM EST to minimize the impacts of daylighting between drivers.

4.5.1 Test Subject Greet and Documentation

Test subjects were asked to meet at TFHRC where they were received by the researcher with whom they drove with for the test. Each subject will be given the appropriate paperwork to complete before testing. No test subjects were exposed to the researcher acting as the pedestrian in the test during this phase.

4.5.2 Test Overview

After the appropriate paperwork was completed for testing, the test subjects were given an overview of the test to be conducted. Each subject was read a script that detailed what the test entailed, what information is to be collected, and what sorts of messages the driver may be exposed to. The driver was informed that eye tracking data was to be collected, though no video footage or pictures were to be taken of the subject to identify them in any manner. The driver was also informed that they would may be exposed to a series of messages while driving; for this test, 4 message types were identified as possible messages to be delivered, 1 of which is the pedestrian mid-block crossing message from the advanced warning application. Furthermore, each subject was told that they were to drive around the facility a few times to familiarize them with the vehicle, and that they would be leaving the facility and driving around McClean for the actual test. Even though this portion of the script was not true and that subjects never left the facility for any testing, subjects were told this so that they were less likely to drive as if being tested and more likely to drive casually (this was a recommendation from the Human Factors Department of TFHRC). The script for the Test Overview was recited in the same fashion to every test subject; this script is detailed in Appendix A.

4.5.3 Eye Tracking Data Collection

Following the Test Overview, each test subject was asked to enter the testing vehicle in the vehicle fleet garage. For this entire experiment the same vehicle was used for every test subject to mitigate operational and user experience factors. Test subjects were asked to adjust seat positioning, seat height, and peripheral mirrors to their liking before the eye tracking calibration was conducted. The eye tracking technology and software used in this experiment was developed by eyesDx and the software packages used were Smart Eye and MAPPS v2017.1. The eye tracking technology consists of multiple, low profile cameras mounted on the dashboard of the test vehicle facing the test subject as well as one low profile forward facing camera. For each participant, the degrees of error for each eye was assumed to be acceptable for tracking if it was under 2 degrees in error; however, not all subjects were able to calibrate this well, so degrees in error up to 10 degrees were sometimes accepted. This difficulty in calibration is reflected in the final eye tracking results as not all of the participant's data was deemed appropriate due to the inaccuracy of their calibration. The process of calibrating each subject took roughly 15 minutes' worth of time for completion due to variances between subject calibrations.

Figure 7 – Smart Eye tracking software eye calibration with researcher posing as test subject

4.5.4 Test Vehicle Specifications

The Field Research Vehicle used in this experiment was an instrumented 2011 Ford Taurus provided by the Human Factors Department often used at TFHRC to collect driver behavior and performance data on actual roadways. The vehicle was equipped with a state-of-the-art eye-tracking system, called Smart-Eye and created by eyesDx, that collected eye tracking data from three infrared cameras mounted on the dashboard and a forward-facing camera (mounted to the left of the rearview mirror). The cameras were small in size and were deemed to have negligible impact on driver behavior, however, it is still entirely possible that they may have added a level of driver stress or awareness to testing. The cameras facing the driver are synchronized to infrared light sources and are used to determine the head position and eye gaze of the driver. The vehicle also records GPS position, vehicle speed, vehicle acceleration, and data input by an experimenter in real time via the on-board CAN bus.

Figure 8 – Test Subject's view in vehicle while driving with the application on the display

4.5.6 Subject Testing Laps

Once the vehicle was moved out of the garage the subject re-entered the vehicle. The accompanying researcher was seated in the backseat of the vehicle and initiated test recording on the testing software that includes both eye tracking data as well as CAN and GPS data. The test subject was told to approach the test track and was given direction by the researcher in the backseat to navigate the testing lap. During this time, the researcher in the backseat was monitoring the vehicle data recording software to ensure that all systems are operational before the test laps are to be conducted.

Once the test subjects had been familiarized with the vehicle they were to continue driving laps around the test track that are designated for usable data collection. Two laps within this portion of data collection were allotted for driver exposure to pedestrian presence at the mid-block crosswalk. Should there have been a scenario deemed to possibly interfere with the test, such as another vehicle driving in front of the test vehicle, the test was aborted and moved to the following lap.

To discern the impacts of the application on driver behavior and awareness at the mid-block crosswalk with pedestrian presence, the 80 subjects were split into two equal sized groups of 40 subjects. Group A was exposed to a pedestrian without the advanced warning during their first test lap; this lap was considered to be the control group. Group B was exposed to a pedestrian with the advanced warning message during their first test lap; this lap was considered to be the best scenario to assess the impacts of the application on driver behavior and awareness. During one of each groups' subsequent test laps, they were exposed to the alternate scenario (with or without the advanced warning message). This methodology was designed to understand driver reaction to pedestrians with or without the advanced warning application as well as their reaction to the pedestrians after exposure to the pedestrian.

4.6 Detailed Driver Test Procedure

The following procedures took place after the test subjects have completed SmartEye calibration and the vehicle has been removed from the garage by the researcher:

1. The researcher is to mount the tablet over the vehicle radio on the mount provided and select to driver role if not already done so, the driver should not witness the role selection map as it may hint at what is being tested. This step should be conducted before eye calibration has initiated, but is mentioned for purposes of detailing order of operations.
2. The test subject is to return to the driver seat and the researcher will sit in the back passenger-side seat where a computer monitor is mounted for initializing testing.
3. The researcher is to initialize the MAPS recording software which will collect the CAN and GPS data as well as initialize the SmartEye recording software.
4. Once data recording has commenced, the researcher will direct the subject to the driving course to begin the subject’s familiarization laps around the testing track.
5. The researcher will monitor the recording software to affirm that all data is being collected, a notebook should be placed in the backseat with the driver to record any anomalies or external factors that can affect the test.
6. The researcher will keep track of how many laps the test subjects are taking.
7. On the first lap after the 3 testing laps, the driver will be exposed to a pedestrian at the mid-block crosswalk. Depending on which group the test subject has been allotted, the mobile application will either alert the driver or not.
8. The driver will react as they determine best in either scenario. Should there be a complication during this test run then the driver will be re-exposed during the second lap of testing. Possible complications include but are not limited to:
    a. A non-test person (NTP) driving in front of the test vehicle

   b. A NTP crossing at the mid-block crosswalk
   c. A NTP conducting work along the test track near the mid-block crossing
   d. Whatever else the researcher in the test vehicle deems possibly unsuitable for reliable test results. This should be noted on the researcher's notepad.

9. After a successful test lap has been conducted, the subject will drive another lap around the test track in which they will not be exposed to any pedestrian or alert, this is considered to be a dead lap.
10. On the lap following the dead lap, the subject will be exposed to a pedestrian again at the mid-block crossing. The subject will be exposed to the alternate test scenario that they didn't experience during their first successful test lap. Should there be complications, a similar procedure will commence as described in item 8.
11. Once the driver has been exposed to both test scenarios, they will be instructed by the researcher to return to the garage, being given directions as needed.
12. The researcher will save and sync all data files according to the test subject's ID # (1-50).
13. The test subject will then be debriefed by the researcher who accompanied them throughout their testing.
14. Following subject debriefing, subjects will be given a short questionnaire regarding the test.
15. Once the questionnaire has been completed, test subjects will be paid for their time and escorted to the front of the building.

4.7 Detailed Pedestrian Test Procedure

Because the experiment did not test the pedestrian, another researcher posed as the pedestrian for each test. The pedestrian was to attempt to indicate to the driver their intention to cross the mid-block crosswalk during each test lap, regardless of whether a message was broadcasted or not.

4.7.1 Experiment Setup

While the test subject (the driver) was undergoing vehicle calibration, the pedestrian set up the experiment in the field. When the subjects arrived, there were multiple steps required for setting up the experiment that the pedestrian will be required to perform:

1. The pedestrian must set up and turn on the video recording camera so the experiment is recorded. The location of the camera should be situated in the southwest corner of the old intersection, location near the red "X" in Figure 10 Below.

Figure 9 – Approximate Camera Location *(15)*

2. The pedestrian must start the application data collection process on the phone before the beginning of the test runs. The pedestrian will note the time the data collection begins.
3. The pedestrian must place a marker approximately 215 feet away from the beginning of the crosswalk, denoting where the vehicle should be when the pedestrian should call for the “pedestrian crossing” signal, seen in Figure 11 below.

Figure 10 – Approximate Location of Marker (215’ from initial crosswalk marking) *(15)*

4. The pedestrian should wear a similar outfit for each experimental run for each test subject. The shirts, pants, and any other clothing accessories should match in color and style.

4.7.2 During the Experiment

While the test laps were being run, the pedestrian was walking on the sidewalk in an eastbound direction. The pedestrian was on the north side of the road, on the sidewalk and walked to the crosswalk approximately 6 seconds before the vehicle arrived, attempting to cross the street in a southbound direction. The pedestrian was not to cross the mid-block crosswalk unless the test vehicle had come to a complete stop.

During the 'dead' lap between the two test laps, the pedestrian was not attempting to cross the road not was the pedestrian visible near the test track. Instead, the pedestrian waited inside the adjacent building to minimize exposure to the driver.

During the experiment, the pedestrian noted which test lap they are testing the crossing with the phone application and without using the phone application. Only when there was no traffic on the stretch of road containing the mid-block crosswalk and when no other pedestrians were present would the pedestrian attempt to run the test. If other vehicles or pedestrians were present, the test lap was aborted.

4.8 Subject Debriefing, Questionnaire, and Payment

Once test subjects had completed their test runs and exited the vehicle, they were debriefed on the experiment conducted. The researcher that was in the vehicle with them during the experiment explained to the test subjects that the cellular phone only displays one advanced warning message: the advanced warning message for the pedestrian. The researchers also explained that the pedestrian crossing is a researcher and the goal of the experiment was to study the driver's reaction to these advanced messages. The script for the debriefing can be found in Appendix B.

Following test subject debriefing, subjects were given a short questionnaire that was designed to analyze the driver's perception of the technology, identifying how much they believed it improved their awareness of the pedestrian, whether they found the technology distracting, and whether or not they would like to see this technology integrated into commonly used GPS routing applications. There was also be space for the test subject to provide feedback on the application should they wish to do so. Responses for each question were provided as a range of answers for the test subjects, ranking driver perception on a scale of 1 to 5, 1 being in strong disagreement, 5 being in strong agreement, and 3 being neutral. The questionnaire that was given to the test subjects can be found in Appendix C.

Once subject debriefing was complete and the questionnaire is filled out, subjects were paid in full for their time and escorted to the reception desk by which they entered.

4.9 Data Collection

The test vehicle, the cellular phones, the eye-tracking software, and the final questionnaire were used to collect experimental data.

4.9.1 Vehicle CAN Data Collection

The data collected from the test vehicle included a variety of information. The vehicle's standard data collection protocol was deemed appropriate as it collected speed (MPH), location (GPS), acceleration rate, deceleration rate, steering wheel angle, and break application (a binary measurement is the brake is pressed or not pressed).

4.9.2 Cellular Device Data Collection

The data collected from the cell phone included a variety of information. The cellular devices were collecting the speed (MPH) and location (GPS) of the driver, which served to validate the vehicle's CAN data. In the vehicle, the tablet was also collecting time stamped information for when the vehicle entered a geofence and when a vehicle exited a geofence as well as a time stamp for when the advanced warning message was displayed, as well as the time the message broadcast was being displayed on screen. The cellular devices were also used to collect pedestrian information, including the time a pedestrian entered a geofence and the time the pedestrian existed a geofence as well as the time the pedestrian sent the advanced warning message and the time the message was being broadcasted properly.

For this test, it was determined that an appropriate frequency of data reporting from the cell phones would be 5 Hz, or one log every 200 milliseconds. Data reporting activities include the pinging of GPS position and recording all of the time stamps as listed above. A series of six application performance test runs were conducted to ascertain whether the devices used in this experiment were capable of meeting the 5 Hz frequency of data reporting and whether the application was stable enough to execute its designed functions. After testing, it was found that, on average, the pedestrian Samsung Galaxy S7 had a latency of 93.391 milliseconds and a log frequency of 199.333 milliseconds while the motorist's Samsung Tab E had a latency of 105.855 milliseconds and a report frequency of 199.333 milliseconds. With the latency being smaller than the reporting frequency of 5 Hz, the devices using the application were deemed acceptable for testing in this experiment.

4.9.3 Eye Tracking Data Collection

The eye tracking software collected the location the driver is looking as a vector in 3-dimensional space. This information was overlaid on the recorded video from the forward-facing camera installed in the vehicle to analyze where the driver was looking during the experiment. The eye tracking data was recorded at a rate of 120Hz which resulted in very accurate detailing when and for how long drivers were looking somewhere. Eye tracking accuracy analysis was conducted by a researcher visually watching a video playback of the scenario with a gaze tracker overlaid on the screen indicating where the driver was looking during the test. Data series were deemed inappropriate for analysis if the gaze tracker seemed unsteady and bounced around the screen often. There are multiple factors that affect the accuracy of the eye tracking data collection, so even if a subject calibrated well with the software before the test began, it was entirely likely that during the test the eye tracking cameras would not track the driver's gaze well enough for accurate results.

To best represent how often the driver was looking at the pedestrian, data collection began at the instant the pedestrian entered the field of vision on the on-board forward-facing camera of which the eye tracking data is recorded and displayed. Data collection ended at two different times depending on the driver's reaction:

- If the driver did not stop for the pedestrian at the mid-block crosswalk, the data collection ended the moment the pedestrian left the field of vision on the forward-facing camera, which is approximately right when the vehicle is crossing the mid-block crosswalk.
- If the driver did stop for the pedestrian at the mid-block crosswalk, the data series ended the moment the pedestrian stepped foot onto the roadway from the sidewalk.

These two instances were chosen as they definitively indicate the drivers' reaction to the pedestrian with and without the advanced warning message; in one instance, the driver is clearly passing the pedestrian with no intent to slam on their brakes at the last minute and in the other, the driver has clearly stopped for the pedestrian to allow him to cross.

Using MAPPS v2017.1, researchers were able to select these time frames to analyze and pull the exact amount of data they needed from the study. To best understand how often the driver was looking at the pedestrian, researchers were able to use a tool in the eyesDx MAPPS software to draw a region of interest on top of the video footage captured by the forward-facing camera around the pedestrian in multiple frames of the test track. The software had the capability to make not of where regions of interest were drawn every few frames apart and interpolate where the region of interest was and how large it was between the frames on which the regions were drawn. Researchers deemed the appropriate number of frames for the region of interest around the pedestrian were drawn when video playback showed the region of interest being interpolated over the pedestrian for the entire course of the test. Furthermore, a static in-vehicle region of interest was drawn over where the mounted tablet was displayed so that the amount of time the driver was looking at the display with the GPS and advanced warning messages could also be recorded. Upon exporting the data, the eye tracking software provided the times and regions the driver was looking during the experiment.

CHAPTER 5: Results

Four tests were conducted during this experiment: Eye Tracking Analysis – to understand how aware drivers were of the pedestrian be analyzing where drivers were looking during the experiment, Driver Reaction – an observation of how drivers reacted to the pedestrian with or without the advanced warning message (did they stop or not stop?), Driver Speed – to understand how drivers changed their speed during their approach to the mid-block crosswalk, and the Questionnaire – to understand the test subjects' response to and acceptance of the advanced warning messages.

5.0.1 Advanced Warning Message Timing

In testing, it was found that the advanced warning message was delivered at an average distance of 215.85 feet from the crosswalk with a standard deviation of 26.05 feet, thus the range in which most messages were received for all 80 test subjects was approximately 189.81 feet to 241.91 feet from the crosswalk.

5.1 Eye Tracking Results

5.1.1 Overall Eye Tracking Results

In an effort to understand driver awareness, eye tracking results were analyzed to understand how often the driver was actively looking at the pedestrian attempting to cross at the mid-block crosswalk. In this analysis, not all eye tracking results were able to be used due to the inaccuracy of tracking of each induvial subject. Of the 80 total subjects, 56 sets (70% data yield) of eye tracking data were deemed acceptable for analysis.

To best comprehend the data provided, it was deemed most appropriate to analyze the results normalized as percentages rather than total time for each participant. Since each driver drove at a different speed on the course, the amount of total time they were exposed to the pedestrian changed from subject to subject, thus, instances in which drivers were driving really slow would possibly show a much longer amount of time spent looking at the pedestrian than someone who was driving at or above the speed limit of the stretch of road.

Below, in Table 1, are the percentages of times that each of the 56 participants spent looking at the pedestrian and the display of the GPS tablet during their first exposure to the pedestrian.

Table 1 – Both Groups' percent time looking at the pedestrian and display from first exposure to pedestrian.

	Group A		Group B	
	% Time Looking at Ped	% Time Looking at Display	% Time Looking at Ped	% Time Looking at Display
	12.59%	0.00%	66.58%	0.00%
	43.73%	0.00%	9.51%	0.22%
	44.18%	0.00%	25.04%	0.00%
	56.78%	0.33%	41.62%	0.07%
	59.22%	0.30%	28.80%	0.00%
	37.27%	0.00%	47.29%	0.00%
	45.83%	0.00%	16.60%	0.00%
	10.84%	0.18%	48.69%	0.05%
	53.44%	0.00%	19.95%	0.00%
	6.91%	0.00%	7.29%	0.00%
	39.80%	0.00%	32.48%	0.55%
	53.05%	0.00%	25.32%	0.00%
	5.98%	0.28%	47.85%	0.00%
	43.87%	0.00%	31.34%	0.00%
	34.43%	0.00%	43.58%	0.00%
	6.53%	0.00%	25.75%	0.00%
	32.10%	0.00%	36.23%	0.17%
	51.14%	0.00%	49.04%	0.00%
	54.45%	0.00%	56.36%	1.05%
	16.75%	0.00%	42.13%	0.00%
	45.33%	0.00%	11.77%	0.05%
	39.26%	0.00%	37.75%	1.86%
	46.88%	0.00%	19.04%	0.13%
	39.11%	0.00%	32.06%	0.85%
	24.02%	0.00%	21.53%	0.07%
	33.54%	0.07%	11.58%	0.00%
	29.02%	0.37%	7.39%	0.12%
	31.51%	0.00%		
	22.63%	0.06%		
Average	35.18%	0.06%	31.21%	0.19%
StdDev	0.16	0.001	0.16	0.004
Variance	0.03	0.000001	0.03	0.000018

From the empirical results, it was found that drivers looked at the pedestrian an average of nearly 4% less with the advanced warning application (Group B) than without it (Group A). A two-sample T-test assuming equal variances was conducted between these two data sets and found the results to be insignificant at confidence levels of 90%, 95%, and 98% with a P-value of 0.357.

Furthermore, it was found that drivers spent very little time looking at the on-board tablet displaying the GPS and advanced warning messages. In Group A, drivers spent an average of .06% of their time looking at the on-board display, whereas in Group B, the group that did receive the advanced warning message, spent an average of .19% of their time looking at the on-board display. Again, a two-sample T-test was conducted between these two data sets not assuming equal variances and found the results to be insignificant at confidence levels of 90%, 95%, and 98% with a P-value of 0.117. Highlighted in red in both the Group A and B data sets are the maximum times per group an individual spent looking at the display.

This analysis, however, assumes that drivers are behaving similarly up until the point along the test course in which they either receive the message or don't. Thus, in analyzing all of the eye tracking data from the instant the pedestrian is visible to the instant the driver's decision is made, half of the data that is assumed to be the same is influencing the results of this t-test. While looking at this data gives a general idea of what to expect from using an advanced warning message, it is necessary to take a closer look at the data from when the message was received until the driver makes a decision.

5.1.2 Overall Eye Tracking Results after Advanced Warning

Table 2 below shows the same analysis conducted between Groups A and B, however, this time the analysis only takes into account all data points collected after 241.91 feet (the average distance plus one standard deviation away from when the advanced warning messages was sent) from the crosswalk and 55 subjects' worth of data.

Table 2 – Both Groups' percent time looking at the pedestrian and display after advanced warning message delivery.

	Group A		Group B	
	% Time Looking at Ped	% Time Looking at Display	% Time Looking at Ped	% Time Looking at Display
	88.70%	0.00%	92.85%	0.00%
	55.10%	0.00%	19.89%	0.17%
	76.50%	0.00%	48.44%	0.00%
	79.56%	0.00%	74.00%	0.00%
	91.03%	0.39%	49.52%	0.00%
	51.19%	0.00%	71.74%	0.00%
	72.09%	0.00%	33.51%	0.00%
	21.11%	0.24%	58.57%	0.10%
	73.55%	0.00%	32.98%	0.00%
	56.97%	0.00%	15.33%	0.00%
	89.13%	0.00%	60.43%	1.20%
	20.85%	0.14%	38.91%	0.00%
	68.71%	0.00%	66.84%	0.00%
	37.04%	0.00%	42.61%	0.00%
	8.80%	0.00%	70.29%	0.00%
	32.10%	0.00%	66.15%	0.00%
	68.72%	0.00%	64.89%	0.41%
	86.71%	0.00%	70.09%	0.00%
	52.61%	0.00%	58.03%	1.88%
	70.06%	0.00%	72.09%	0.00%
	64.05%	0.00%	25.36%	0.11%
	63.78%	0.00%	60.76%	3.75%
	74.15%	0.00%	34.75%	0.29%
	45.21%	0.00%	48.51%	0.99%
	40.56%	0.00%	42.96%	0.00%
	46.79%	0.00%	23.58%	0.00%
	46.54%	0.00%	14.46%	0.00%
	49.71%	0.00%		
Average	58.26%	0.03%	50.28%	0.33%
StdDev	0.22	0.0009	0.21	0.0082
Variance	0.05	0.000001	0.04	0.000067

From the empirical results taken after 241.91 feet away from the crosswalk, it was found that drivers looked at the pedestrian an average of nearly 8% less with the advanced warning application (Group B) than without it (Group A). A two-sample T-test assuming equal variances was conducted between these two data sets and found the results to be insignificant at confidence levels of 90%, 95%, and 98% with a P-value of 0.170.

Again, it was found that drivers spent very little time looking at the on-board tablet displaying the GPS and advanced warning messages. In Group A, drivers spent an average of .03% of their time looking at the on-board display, whereas in Group B, the group that did receive the advanced warning message, spent an average of .33% of their time looking at the on-board display. Again, a two-sample T-test was conducted between these two data sets not assuming equal variances and found the results to be insignificant at confidence levels of 95%, and 98%, but significant at a confidence level of 90% with a P-value of 0.067. Highlighted in red in both the Group A and B data sets are the maximum times per group an individual spent looking at the display.

5.1.3 Detailed Eye Tracking Results

Table 3 displays of the averages of both Groups upon their first exposure to the pedestrian. The length of the test course in which the pedestrian becomes visible until the point at which the vehicle has reached the crosswalk was estimated to be 400 feet in distance, so for this analysis, starting from 400 feet away from the crosswalk, the percentage of time each Group was looking at the pedestrian was averaged per distance away from the crosswalk in 20-foot segments (bins).

Table 3 – Both Groups' percent time looking at the pedestrian per 20ft binned distance from crosswalk.

	Group A		Group B	
Distance	Average	Standard Error	Average	Standard Error
-400	3.40%	1.28%	1.02%	0.36%
-380	13.64%	3.87%	9.96%	2.98%
-360	6.10%	2.34%	15.35%	4.44%
-340	16.87%	3.70%	17.36%	4.26%
-320	21.82%	5.99%	16.94%	4.19%
-300	29.73%	4.53%	20.08%	5.14%
-280	38.31%	6.47%	21.62%	4.86%
-260	38.75%	5.17%	22.38%	5.91%
-240	45.64%	5.90%	27.15%	5.60%
-220	45.61%	7.38%	23.86%	5.03%
-200	54.49%	6.90%	37.88%	6.45%
-180	63.22%	6.74%	48.53%	6.40%
-160	64.80%	6.56%	52.63%	6.48%
-140	59.73%	6.67%	58.83%	6.53%
-120	67.62%	6.46%	62.33%	6.84%
-100	69.34%	6.74%	68.91%	6.61%
-80	48.74%	7.86%	70.33%	6.91%
-60	55.89%	8.77%	50.55%	7.10%
-40	37.80%	13.67%	25.19%	12.23%
-20	36.17%	32.01%	25.64%	18.90%

A graphical representation of the data shown in Table 3 is also shown in Figure 12 to better illustrate the differences in percentage of time looking at the pedestrian in each Group. Figure 12 also includes error bars around each averaged data point indicating the standard error of each Group's average. For each distance bin, the labeled distance indicates all data measurements from the previous bin up until the labeled distance (I.e. distance bin -400 includes all measurements greater than -380 feet up to or equal to -400 feet).

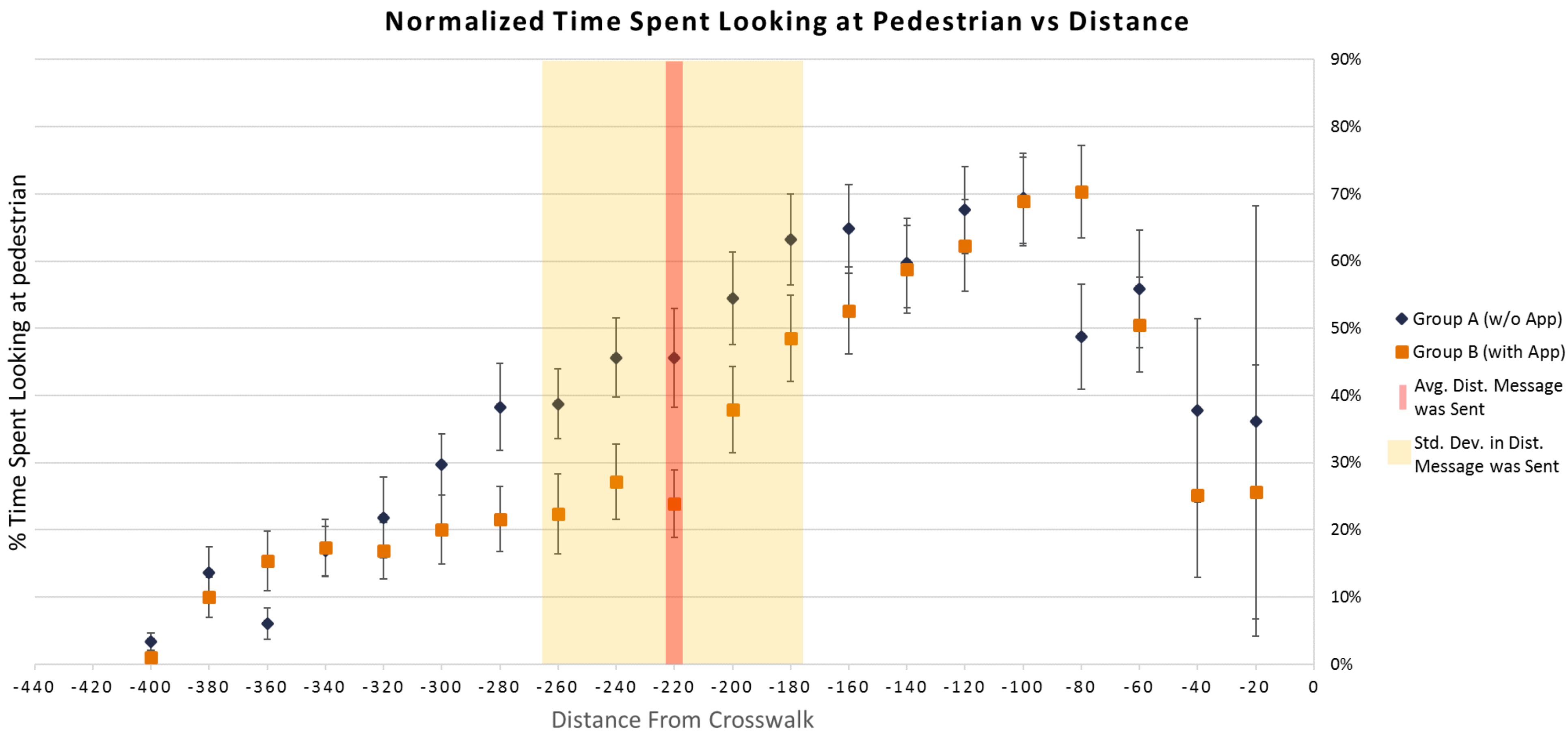

Figure 11 – Normalized percent time spent looking at the pedestrian at the mid-block crosswalk per distance away from crosswalk

As shown in both Table 2 and Figure 12, the standard error of each of the averages of the bins appears to grow dramatically between bins -60 to -20; due to the variability in distance in which drivers who stopped for the pedestrian stopped in distance from the crosswalk, the number of drivers in each bin decreased the closer each bin gets to the crosswalk. This occurs due to the amount of data defined as examinable as listed in Section 4.9.3 of this report. Also shown in Figure 12 are two zones indicating the average distance away the message was delivered to the driver (displayed by the red line) and the average distance away the message was received with respect to the standard deviation (displayed be the yellow box).

Comparing Figure 12 to Table 1, similar results are seen between the generalized analysis and the detailed analysis; however, standard error does not indicate whether results are statistically significant between the two Groups in each bin, thus a two-sample T-test not assuming equal variances was conducted for each individual bin to best understand if at any point after a driver would have or did receive an advanced warning message were statistically significant. The T-test results for each bin can be found in Appendix D.

95% Confidence Level

From the average distance plus one standard deviation away from the crosswalk in which a message was received, bins -260 through -220, and bin -80 were found to have significant results at a 95% confidence level.

90% Confidence Level

From the average distance plus one standard deviation away from the crosswalk in which a message was received, bins -260 through -200, and bin -80 were found to have significant results at a 90% confidence level.

5.2 Driver Reaction

Drivers' reactions were analyzed during this test by recording whether or not the driver stopped for the pedestrian standing at the entrance to the mid-block crosswalk and whether or not the drivers changed their approach speed of the crosswalk, both with and without the advanced warning message. The Results for Group A and Group B are shown in Figure 13 below.

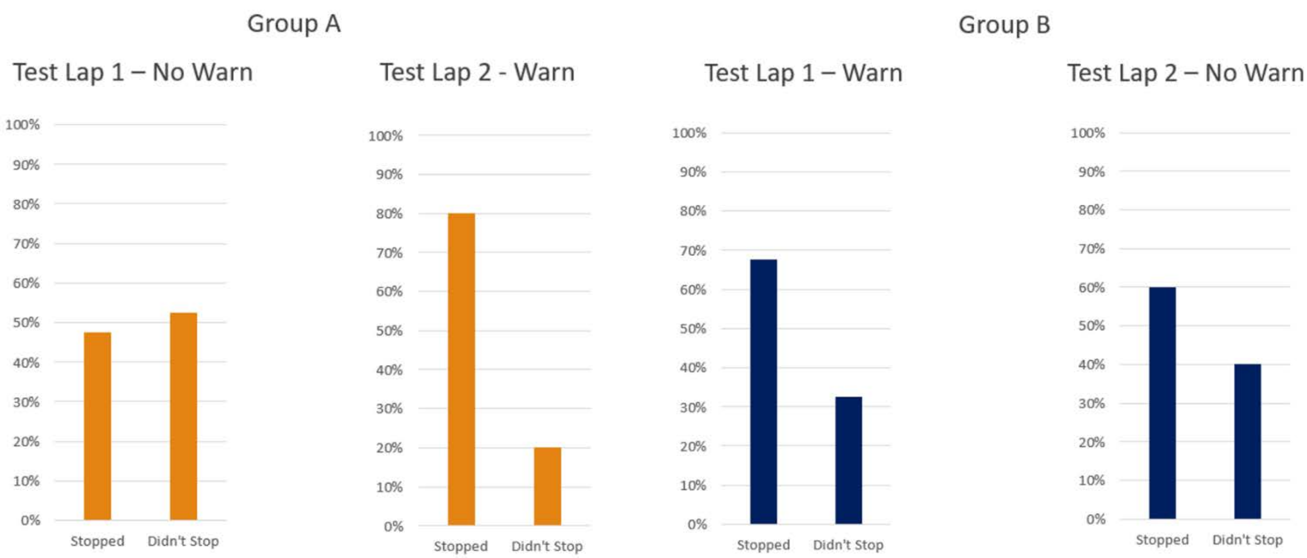

Figure 12 – Driver reactions for both Groups' two test laps.

The most important data sets from these groups are those of Test Lap 1 for both Group A and Group B as this was the driver's first exposure to the pedestrian at the mid-block crosswalk. Without the advanced warning message, 48% of drivers stopped for the pedestrian in Group A; however, in Group B, 68% of drivers stopped for the pedestrian at the midblock crosswalk. Applying an unpaired two sample t-test, the results between these two groups is significant at the 90th percentile, but not at the 95th and 98th percentiles with a P-value of 0.072.

Analyzing driver reaction upon the second exposure to the pedestrian, drivers of Group A stopped for the pedestrian 80% of the time with the application. While this number is approaching double the amount stops for the pedestrian in the first test lap without a warning, it is important to note that the driver is seeing the same exact pedestrian a second time at the crosswalk, so it is likely that the driver may be either more aware of the pedestrian or aware that they are being tested in this scenario.

Driver reaction upon second exposure in Group B also showed a higher rate of stopping, a total of 60%, than those of Group A's first lap without the warning, but less stops than those observed in Group B's first lap with the warning. This indicates that, with driver's having the advanced warning message technology in their vehicle, drivers are more willing to stop for a pedestrian at a mid-block crosswalk because they are expecting the warning application to notify them of the pedestrian, even in the instance that it doesn't. Again, it is important to note that drivers of this scenario are seeing the exact same pedestrian for a second time, thus, results may be influenced.

5.3 Driver Speed

Furthermore, drivers' speed was analyzed as they approached the crosswalk. This thesis does not aim to provide a detailed description of the kinematic data collected during this experiment; however, a representation of driver behavior through the speed graphs provided below serves as a great reference in understanding how drivers behaved with and without an advanced warning message. Three speed graphs are shown in Figure 14 that display drivers' speed in three different scenarios which was obtained through the mobile phone application itself using the cell phones' and tablet's GPS devices. The graph labelled "Lap 1 No Pedestrian" includes all 80 of the subjects' data from the test upon approaching the mid-block crosswalk; this graph is shown to illustrate driver behavior upon approaching the crosswalk. The "Test Lap 1 No Warning" includes the 40 subjects of Group A during their first exposure to the pedestrian with no advanced warning message and “Test Lap 1 With Warning” includes the 40 subjects of Group B during their first exposure to the pedestrian with the advanced warning message.

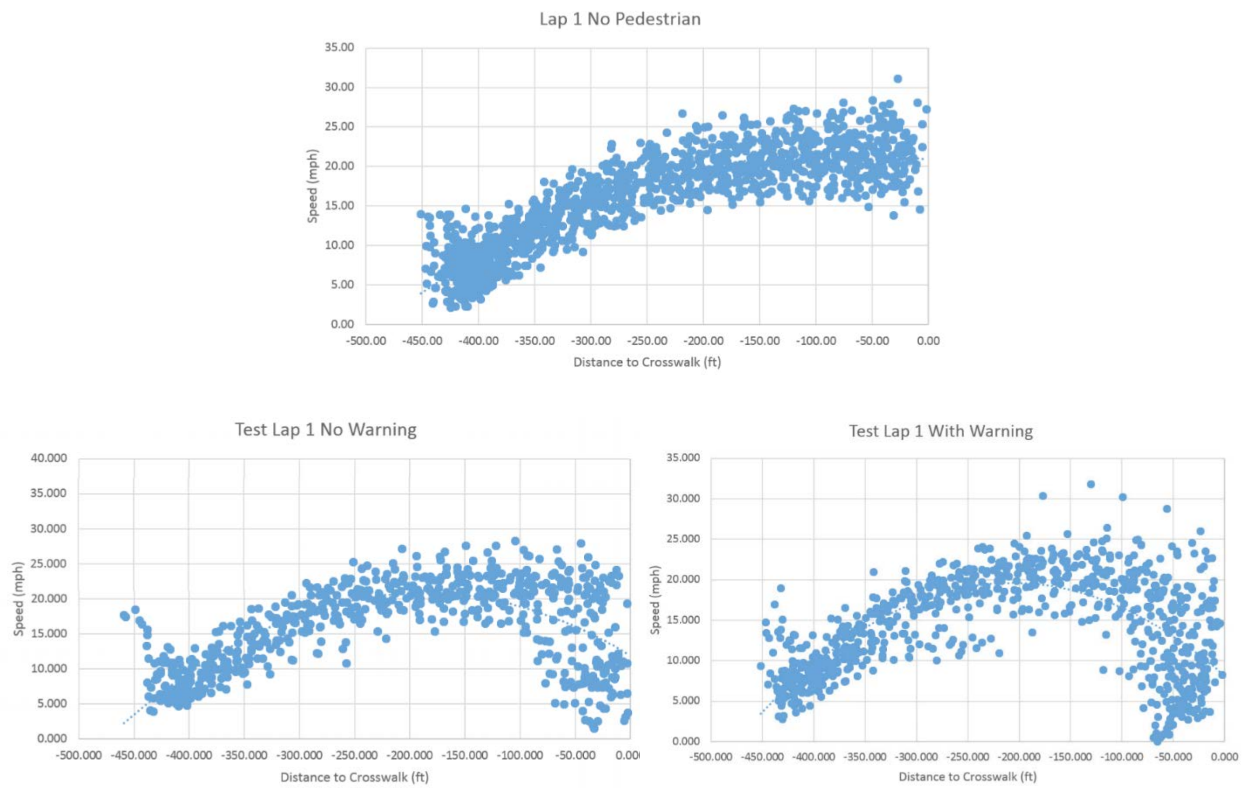

Figure 13 – Driver speed data approaching the mid-block crosswalk for Group A (no warning) and Group B (with warning).

The first graph, “Lap 1 No Pedestrian”, shows all participants behaving rather similarly while driving towards the mid-block crosswalk. It is important to note that at about 450 feet away from the crosswalk, drivers were making a right turn from a stoplight, hence the acceleration shown in each graph from start. The drivers approaching the crosswalk with a pedestrian present and without receiving a warning had an average approach speed of 18 mph with a standard deviation of approximately 6 mph. Drivers approaching the crosswalk with a pedestrian present and having received an advanced warning message approached the crosswalk at an average speed of 16 mph with a standard deviation of approximately 5 mph. Approach speeds were determined by using only data found after the average distance from the crosswalk that the advanced warning message was delivered, which was found to be 216 feet, recorded by the mobile phone application.

5.4 Questionnaire Results

Post-experiment, the participants were asked to complete the short questionnaire that consisted of three questions targeted to understand user-technology acceptance, but also as a gauge to better understand driver awareness. The results from this survey are found in Figures 15 and 16.

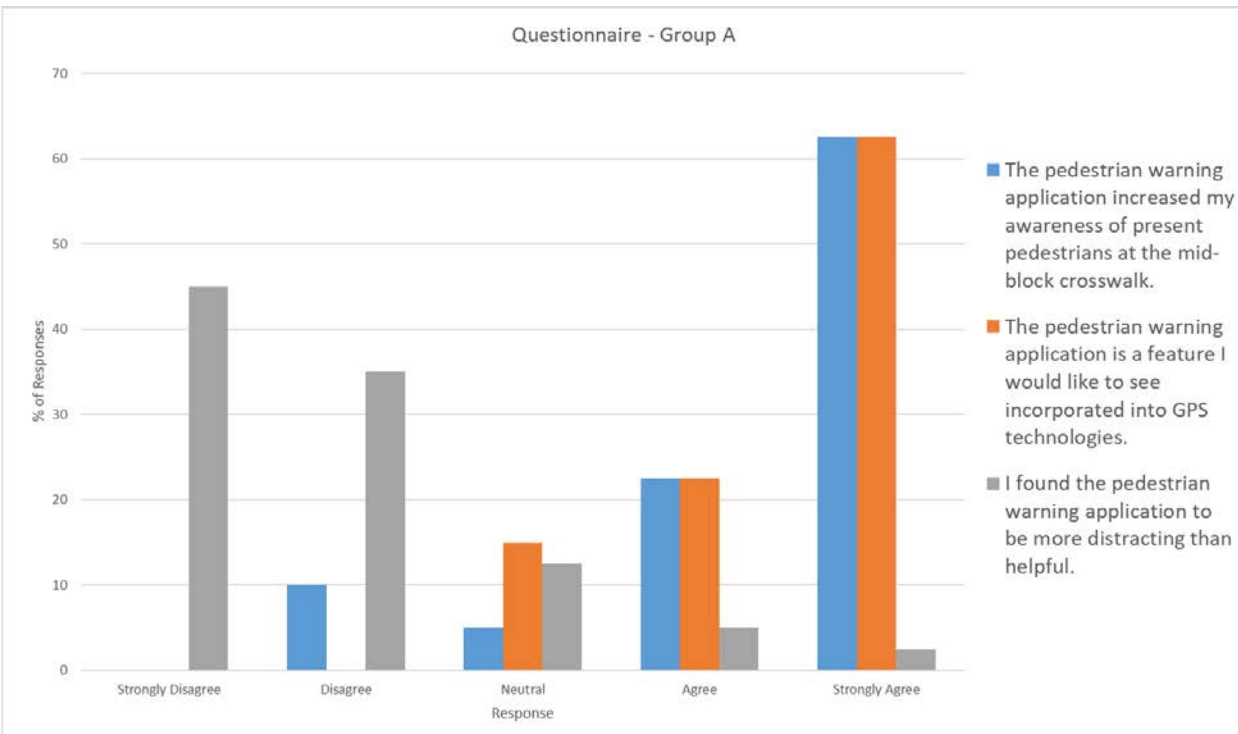

Figure 14 – Group A Questionnaire results.

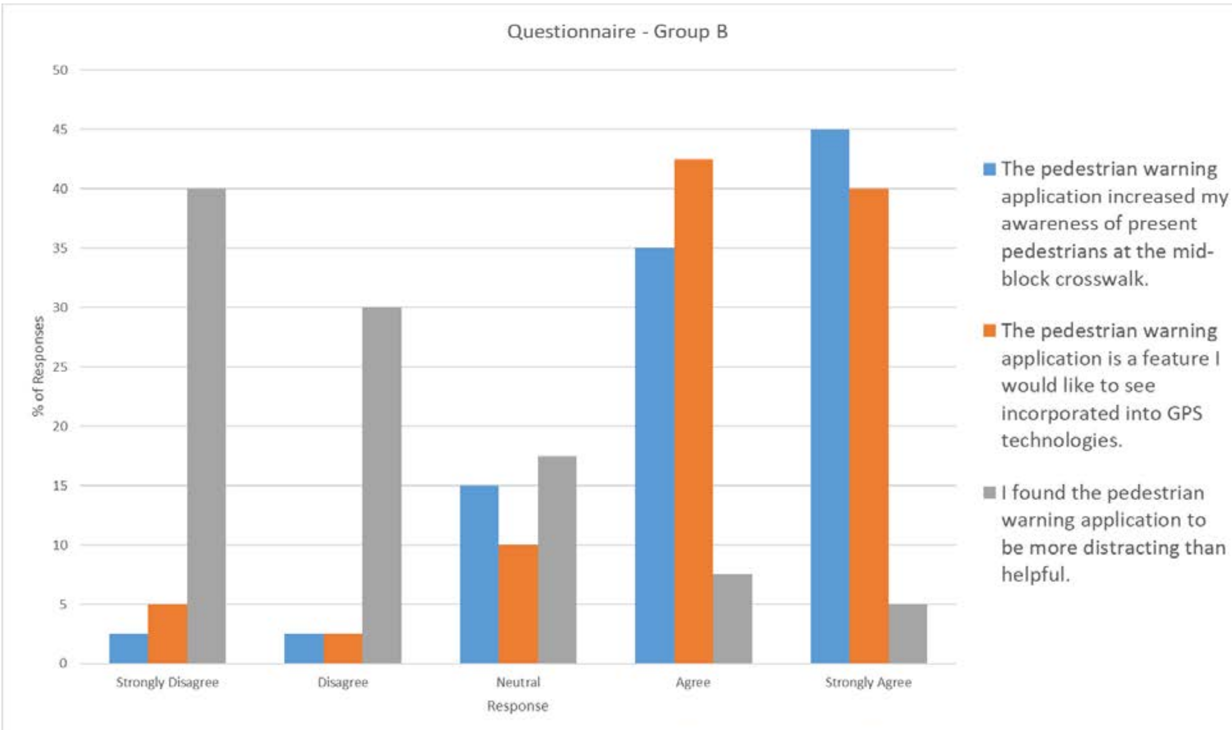

Figure 15 – Group B Questionnaire results.

The first statement of the questionnaire regarding user awareness showed an overwhelming response from both Group A and Group B in drivers' agreement. 85% of drivers from Group A and 80% of drivers from Group B responded that they agreed or strongly agreed with the statement "the pedestrian warning application increased my awareness of present pedestrians at the mid-block crosswalk. Furthermore, a total of 62.5% of the respondents of Group A strongly agreed with this statement (roughly three quarters of the Group A population in agreement with this statement) whereas only 45% of Group B strongly agreed (approximately half of the Group B population in agreement with this statement).

The second statement of the questionnaire yielded nearly identical responses as the first. Again, 85% of respondents from Group A either agreed or strongly agreed that "the pedestrian warning application is a feature [they] would like to see incorporated in GPS technologies". Group

B's responses were similar, showing a total of 82.5% in agreement. Again, Group A showed a more opinionated response whereas Group B's responses between 'Agree' and 'Strongly Agree' options were split nearly evenly.

The last statement regarding user's stated-perception of distraction yielded fairly positive responses as well. Group A shows that 80% of drivers did not "find the advanced warning application to be more distracting than helpful". Group B showed similar results with 70% or respondents in general disagreement.

Looking at the data collectively, it was found that 82.5% of respondents found the applications to increase their awareness of the pedestrian, 83.75% of respondents would like to see similar technology deployed in other GPS systems, and that 90% of drivers did not find the application to be more distracting than helpful.

CHAPTER 6: Interpretation of Results & Future Work

The outcomes of this study proved to be incredibly insightful in understanding user reaction and acceptance of advanced warning messages while also raising some interesting questions.

6.1 Eye Tracking & Driver Awareness

At a glance, the eye tracking experimentation yielded counter-intuitive results. Many of the survey responses stated that drivers believed they were more aware of the pedestrian, yet there were no statistically significant results for the overall analyses of the experiment. There were, however, a few bins in the detailed results of the eye tracking data that suggest, once a message is received, drivers behave differently in where they are looking. As seen in Figure 12, the percentage of time looking at the pedestrian appears to be similar between the two Groups at the beginning of the test course, but then diverge around when the message would be received showing Group B looking at the pedestrian less, and then converge a short distance after. The initial thought would be that the warning application sent to drivers in Group B is distracting and that many of drivers must have looked at the display when they received the advanced warning message, thus the decrease in their average percentage times looking at the pedestrian. This seems fairly unlikely however, as the percentages of time drivers in Group B spent looking at the display was so small that, even though there was a statistically significant difference between Group A and B in time looking at the display, it was deemed negligible in the overall exposure time to the pedestrian after 241.91 feet; furthermore, most of the drivers also stated that they felt the application to not be distraction, coinciding with this observation.

Considering the results from this experiment, it may be that eye tracking is a poor way to understand driver awareness. Recording the active viewing of the pedestrian by the driver may not necessarily capture how aware the driver is of the pedestrian's presence at all. While this test clearly shows that both the drivers' focal and ambient vision are focused on the pedestrian as defined by the Gugerty study described in section 2.4, it is not uncommon for drivers to zone out while behind the wheel, distracted by one's thoughts while still handling the vehicle appropriately. While visual information is being processed while a driver is zoned out, this doesn't necessarily mean that the driver is engaged by their surroundings and knowingly reacting to them. It could be that, while driving, most drivers focused on the pedestrian during the test along the testing section of the course simply because the pedestrian is the only moving being in the immediate vicinity, so the driver unconsciously fixates on them. While this scenario is entirely possible, there is no strong connection between the described scenario and the questionnaire results as drivers felt their awareness of the pedestrian had increased significantly, indicating that they were actively aware of the pedestrian and not zoned out staring at the pedestrian absentmindedly.

Instead, it may be the case that, since the driver is being notified of the pedestrian's intent, they feel it is less important to look at the pedestrian and more important to look at the road. The advanced warning message is designed to notify drivers of the pedestrian's intent to cross, so, by receiving the advanced warning message, drivers are being warned in vehicle via an auditory and visual warning. With such a high percentage of drivers indicating that they felt the advanced warning message increased their awareness of the pedestrian, it appears that driver awareness may coincide best with personal report rather than eye tracking data. If such is the case, then the decreases seen in drivers viewing of the pedestrian with the message comparted to without the message may be interpreted as highly beneficial; being notified of the pedestrian's presence and knowing the pedestrian's intent before reaching the crosswalk possibly enhance the driver's awareness of the oncoming situation and allow the driver to more actively look at the rest of the road and environment instead of being focused more on the pedestrian and trying to anticipate what the pedestrian is going to do next. This notion seems to be the most likely scenario as it coincides best with the questionnaire results as well as the increase in the amount of times drivers stopped for the pedestrian.

6.2 Driver Reaction

Driver reaction showed strong distinction between amount of times drivers stopped for the pedestrian with and without the advanced warning application. Having such a strong correlation, it can be concluded that, with the advanced warning message, drivers are more likely to stop for pedestrians than without.

The reasoning behind this conclusion is, however, up for interpretation and entirely dependent on the individual. Drivers may have felt that, by receiving the advanced warning message, they should react accordingly. The advanced warning message was designed so that is wasn't a regulatory message, such as "Yield for Pedestrian", but it was an informative warning message.

It is also entirely possible that drivers felt the need to stop for the pedestrian more so than normal because they were in a testing environment. Even though drivers were told that testing was to be conducted off site, drivers were still operating a federally owned vehicle on federal property in visual sight of the Central Intelligence Agency. It is certainly noted that these factors may well have increased driver behavior in receiving a message regarding a possible safety concern and reacted in the manner they felt most appropriate.

6.3 Driver-Stated Perception and Acceptance

Another big takeaway from this study comes from the questionnaire; it can be concluded that drivers would like to see this technology incorporated into GPS technologies. With such a high percentage of driver's indicating that, not only did the application increase their awareness of the pedestrian, but that they would also, essentially, feel comfortable with this sort of advanced warning message being broadcasted and delivered to them, it appears that advanced messaging information via CV technology may possibly enhance the way drivers perceive and understand upcoming scenarios while on the road.

6.4 Future Work

While this experiment yielded many insightful results, it also posed a few questions that, answered, would further help in understanding the effects of advanced warning messaging and driver awareness at mid-block crosswalks.

In examining the results from this experiment with respect to the detailed eye tracking analysis, it may be of benefit to examine more test subjects for a higher data yield. With the eye tracking data proving to be statistically significant in a few bins with P-values less than .05, a few more test subjects may prove other bins to be just as significant.

Another potentially beneficial route of future work would be to deploy this application in a pilot test so that results are more naturalistic and less influenced by environmental factors such as having an experimenter in the backseat or driving on federally owned property in a federally owned vehicle. While driver reaction and stated perception were statistically significant in a controlled environment, they may prove less, or even more so, significant in everyday driving scenarios when the driver isn't expecting to be tested or to receive a warning message.

Another alternative would be to conduct this test during nighttime hours. As described in Chapter 2, many incidents at mid-block crossings occur during dark conditions when pedestrians aren’t easily visible. It may be the case that drivers end up looking at the pedestrian more with the advanced warning when it is dark outside than without the application simply because they didn’t or couldn’t see the pedestrian at all without being notified of their presence.

Lastly, to better understand driver awareness, one or two more questions could be added to the questionnaire that would help in clarifying why test subjects answered questions the way they did. Along with asking whether or not the application increased their awareness of the pedestrian, it may have also been beneficial to ask whether or not the application increased the drivers understanding of the pedestrian’s intent at the mid-block crosswalk. Furthermore, it may have been beneficial to ask the subjects whether or not they felt more obligated to stop for the pedestrian with the warning application than without to better understand if drivers viewed the advanced warning as a more regulatory message than informative.

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Appendices

Appendix A Test Overview Script

Welcome to Turner-Fairbank Highway Research Center and thank you for your participation in this study. Today, you will be operating a test vehicle from our fleet equipped with the capability of providing drivers with auditory and visual notifications. Possible notifications that you may receive during vehicle operation in this test are:

1. Construction Ahead Warning
2. Pedestrian Ahead Warning
3. Curve Speed Warning
4. Pothole Ahead Warning

During this test, you will be monitored using the eye tracking technology within the test vehicle. GPS and vehicle operational data will also be collected during this test. Before you drive the vehicle, we will calibrate you to the eye tracking technology. No video recording will be conducted that will allow us or anyone else to identify you as a driver, nor will any in vehicle auditory recording be conducted during this experiment. I will accompany you within the test vehicle and guide you through the test course. We will first drive around the facility to familiarize you with the test vehicle, after we will leave the facility for the test. Should you have any questions or concerns during the test please feel free to ask me at any time. Once the test is complete, I will instruct you to return to the garage and you will be given a short questionnaire. Once complete, you will be paid for your time here. All data from this test will be made public, however, none of the data collected will in any way, shape, or form, identify you as having been a test subject. Do you have any questions for me before we begin calibration and testing?

Appendix B Test Debrief Scrip

Thank you for participating in this study. During this test, we monitored your reactions to a pedestrian within the mid-block crossing along the test track with, and without, a visual and auditory warning message from the pedestrian mid-block crossing application installed on the tablet in the test vehicle. The message you received in vehicle was broadcasted by the pedestrian using their smartphone and the same application. The application is designed to notify drivers of pedestrian presence and intent to cross at mid-block crossings. The last portion of this test involves a questionnaire regarding your perception of this application. Once complete the test will be complete. Do you have any questions?

Appendix C Post-Test Questionnaire

Questionnaire

1. The pedestrian warning application increased my awareness of present pedestrians at the mid-block crosswalk.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

2. The pedestrian warning application is a feature I would like to see incorporated into GPS technologies.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

3. I found the pedestrian warning application to be more distracting than helpful.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

4. Provide any suggestions you would like to see done better or included.

Appendix D Two Sample T-Tests for Binned Eye Tracking Results per Distance

-400 TO -380

Two-Sample T-Test and CI: C2, C3
Method

μ_1: mean of C2

μ_2: mean of C3

Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C2	27	0.0340	0.0667	0.013
C3	28	0.0102	0.0193	0.0036

Estimation for Difference

Difference	95% CI for Difference
0.0238	(-0.0034, 0.0511)

Test

Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$
Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
1.79	30	0.084

-380 TO -360

Two-Sample T-Test and CI: C4, C5
Method

μ_1: mean of C4

μ_2: mean of C5

Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C4	27	0.136	0.201	0.039
C5	28	0.100	0.158	0.030

Estimation for Difference

Difference	95% CI for Difference
0.0368	(-0.0613, 0.1350)

Test

Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$
Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
0.75	49	0.454

-360 TO -340

Two-Sample T-Test and CI: C6, C7

Method

μ_1: mean of C6

μ_2: mean of C7

Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C6	27	0.061	0.121	0.023
C7	28	0.154	0.235	0.044

Estimation for Difference

Difference	95% CI for Difference
-0.0925	(-0.1939, 0.0089)

Test

Null hypothesis	$H_0: \mu_1 - \mu_2 = 0$
Alternative hypothesis	$H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
-1.84	40	0.073

-340 to -320

Two-Sample T-Test and CI: C8, C9

Method

μ_1: mean of C8

μ_2: mean of C9

Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C8	27	0.169	0.192	0.037
C9	28	0.174	0.225	0.043

Estimation for Difference

Difference	95% CI for Difference
-0.0049	(-0.1181, 0.1083)

Test

Null hypothesis	$H_0: \mu_1 - \mu_2 = 0$
Alternative hypothesis	$H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
-0.09	52	0.932

-320 to - 300

Two-Sample T-Test and CI: C10, C11
Method

μ_1: mean of C10

μ_2: mean of C11

Difference: $\mu_1 - \mu_2$
Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C10	27	0.218	0.311	0.060
C11	28	0.169	0.222	0.042

Estimation for Difference

Difference	95% CI for Difference
0.0488	(-0.0983, 0.1959)

Test

Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$
Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
0.67	46	0.508

-300 to -280

Two-Sample T-Test and CI: C12, C13
Method

μ_1: mean of C12

μ_2: mean of C13

Difference: $\mu_1 - \mu_2$
Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C12	27	0.297	0.235	0.045
C13	28	0.201	0.272	0.051

Estimation for Difference

Difference	95% CI for Difference
0.0965	(-0.0409, 0.2339)

Test

Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$
Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
1.41	52	0.165

<u>-280 to -260</u>

Two-Sample T-Test and CI: C14, C15

Method

μ_1: mean of C14

μ_2: mean of C15

Difference: μ_1 - μ_2

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C14	27	0.383	0.336	0.065
C15	28	0.216	0.257	0.049

Estimation for Difference

Difference	95% CI for Difference
0.1668	(0.0041, 0.3296)

Test

Null hypothesis H_0: $\mu_1 - \mu_2 = 0$

Alternative hypothesis H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
2.06	48	0.045

<u>-260 to -240</u>

Two-Sample T-Test and CI: C16, C17

Method

μ_1: mean of C16

μ_2: mean of C17

Difference: μ_1 - μ_2

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C16	27	0.388	0.269	0.052
C17	28	0.224	0.313	0.059

Estimation for Difference

Difference	95% CI for Difference
0.1638	(0.0061, 0.3214)

Test

Null hypothesis H_0: $\mu_1 - \mu_2 = 0$

Alternative hypothesis H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
2.08	52	0.042

-240 to -220

Two-Sample T-Test and CI: C18, C19
Method

μ_1: mean of C18

μ_2: mean of C19

Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C18	27	0.456	0.307	0.059
C19	28	0.272	0.296	0.056

Estimation for Difference

Difference	95% CI for Difference
0.1849	(0.0216, 0.3482)

Test

Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$
Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
2.27	52	0.027

-220 to -200

Two-Sample T-Test and CI: C20, C21
Method

μ_1: mean of C20

μ_2: mean of C21

Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C20	27	0.456	0.383	0.074
C21	28	0.239	0.266	0.050

Estimation for Difference

Difference	95% CI for Difference
0.2175	(0.0378, 0.3973)

Test

Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$
Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
2.44	46	0.019

<u>-200 to -180</u>

Two-Sample T-Test and CI: C22, C23

Method

μ_1: mean of C22

μ_2: mean of C23

Difference: μ_1 - μ_2

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C22	27	0.545	0.359	0.069
C23	28	0.379	0.341	0.064

Estimation for Difference

Difference	95% CI for Difference
0.1660	(-0.0235, 0.3556)

Test

Null hypothesis	H_0: μ_1 - μ_2 = 0
Alternative hypothesis	H_1: μ_1 - μ_2 ≠ 0

T-Value	DF	P-Value
1.76	52	0.085

<u>-180 to -160</u>

Two-Sample T-Test and CI: C24, C25

Method

μ_1: mean of C24

μ_2: mean of C25

Difference: μ_1 - μ_2

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C24	27	0.632	0.350	0.067
C25	28	0.485	0.339	0.064

Estimation for Difference

Difference	95% CI for Difference
0.1469	(-0.0397, 0.3334)

Test

Null hypothesis	H_0: μ_1 - μ_2 = 0
Alternative hypothesis	H_1: μ_1 - μ_2 ≠ 0

T-Value	DF	P-Value
1.58	52	0.120

-160 to -140

Two-Sample T-Test and CI: C26, C27
Method

μ_1: mean of C26

μ_2: mean of C27

Difference: μ_1 - μ_2

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C26	27	0.648	0.341	0.066
C27	28	0.526	0.343	0.065

Estimation for Difference

Difference	95% CI for Difference
0.1218	(-0.0633, 0.3068)

Test

Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$
Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
1.32	52	0.193

-140 to -120

Two-Sample T-Test and CI: C28, C29
Method

μ_1: mean of C28

μ_2: mean of C29

Difference: μ_1 - μ_2

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C28	27	0.597	0.347	0.067
C29	28	0.588	0.345	0.065

Estimation for Difference

Difference	95% CI for Difference
0.0089	(-0.1784, 0.1962)

Test

Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$
Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
0.10	52	0.924

-120 to -100

Two-Sample T-Test and CI: C30, C31

Method

μ_1: mean of C30

μ_2: mean of C31

Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C30	27	0.676	0.336	0.065
C31	27	0.623	0.355	0.068

Estimation for Difference

Difference	95% CI for Difference
0.0529	(-0.1360, 0.2417)

Test

Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$
Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
0.56	51	0.576

-100 to -80

Two-Sample T-Test and CI: C32, C33

Method

μ_1: mean of C32

μ_2: mean of C33

Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C32	26	0.693	0.344	0.067
C33	26	0.689	0.337	0.066

Estimation for Difference

Difference	95% CI for Difference
0.0044	(-0.1854, 0.1941)

Test

Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$
Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
0.05	49	0.963

-80 to -60

Two-Sample T-Test and CI: C34, C35
Method

μ_1: mean of C34

μ_2: mean of C35

Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C34	22	0.487	0.368	0.079
C35	19	0.703	0.301	0.069

Estimation for Difference

Difference	95% CI for Difference
-0.216	(-0.428, -0.004)

Test

Null hypothesis $H_0: \mu_1 - \mu_2 = 0$

Alternative hypothesis $H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
-2.06	38	0.046

-60 to -40

Two-Sample T-Test and CI: C36, C37
Method

μ_1: mean of C36

μ_2: mean of C37

Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C36	18	0.559	0.372	0.088
C37	14	0.505	0.266	0.071

Estimation for Difference

Difference	95% CI for Difference
0.053	(-0.177, 0.284)

Test

Null hypothesis $H_0: \mu_1 - \mu_2 = 0$

Alternative hypothesis $H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
0.47	29	0.639

-40 to -20

Two-Sample T-Test and CI: C38, C39

Method

μ_1: mean of C38

μ_2: mean of C39

Difference: μ_1 - μ_2

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C38	10	0.378	0.432	0.14
C39	10	0.252	0.387	0.12

Estimation for Difference

Difference	95% CI for Difference
0.126	(-0.261, 0.513)

Test

Null hypothesis H_0: $\mu_1 - \mu_2 = 0$

Alternative hypothesis H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
0.69	17	0.501

-20 to 0

Two-Sample T-Test and CI: C40, C41

Method

μ_1: mean of C40

μ_2: mean of C41

Difference: μ_1 - μ_2

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C40	3	0.362	0.554	0.32
C41	5	0.256	0.423	0.19

Estimation for Difference

Difference	95% CI for Difference
0.105	(-1.078, 1.288)

Test

Null hypothesis H_0: $\mu_1 - \mu_2 = 0$

Alternative hypothesis H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
0.28	3	0.795