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Enhancing Intersection Safety for the Blind and Visually Impaired (BVI) Pedestrian Using Device-to-Infrastructure Communication

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ENHANCING INTERSECTION SAFETY FOR THE BLIND AND VISUALLY IMPAIRED (BVI) PEDESTRIAN USING DEVICE-TO-INFRASTRUCTURE COMMUNICATION

by

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Visually impaired pedestrians have limited mobility options, where they rely heavily on walking and transit for their transportation needs. One of the major issues facing these pedestrians is intersection crossing. Accessible Pedestrian Signals (APS), as a means of helping their intersection crossings, were introduced in the United States as early as 1920 but were not included in the Manual on Uniform Traffic Control Device (MUTCD) until 2000. The most recent type of APS is the beaconing APS which has shown improvements in road crossing abilities of blind pedestrians though it has many downsides to it. This study developed a cane to enhance safety and crossing abilities of visually impaired pedestrians at wide and complex intersections. The cane, named Smart-Cane, is composed of three subsystems: the veering adjustment system using RFID technology where device-to-infrastructure (D2I) communication is established; driver alert system through the cloud (LTE) where device-to-vehicle (D2V) communication is established and vehicle-to-infrastructure (V2I) communication through DSRC is established; and the green time system where connection is established through WiFi with the signal controller and device-to-infrastructure (D2I) communication is established. Three scenarios (A, B & C) were proposed to study the improvements of the Smart-Cane over APS. Findings state that the Smart-Cane proved feasibility and practicability over APS.

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Mohammad Sayyah Al-Akash

DEDICATION

To my father who taught me how to face obstacles
with persistence and strength,
To my mother, the kindest woman in the world,
who without her continuous support,
I would not be here,
To my caring and supportive sisters
I dedicate this work to you all with respect and love!

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CHAPTER I

INTRODUCTION

According to the data from the United States Census Bureau (Brault, 2012), difficulty seeing is defined as experiencing blindness or having difficulty seeing words and letters in ordinary newsprint even when wearing glasses or contact lenses. Those lacking the ability to see words and letters constituted about 8.1 million people that are 3.3 percent of the 241.7 million population aged 15 years and older in the United States in 2010. The primary modes of transportation for the Blind and Visually Impaired (BVI) are walking or public transit. To improve accessibility and the level of confidence for the BVI pedestrians, it is essential to remove both physical and mental barriers that might obstruct their mobility.

Visually impaired pedestrians have difficulties maneuvering through intersections and require information on intersection geometry, signal timing, and traffic. To complete crossing safely, BVI pedestrians need to perform certain tasks, among which are street detection, locating crosswalk, alignment, specifying an appropriate time to cross, and maintain a straight heading while crossing intersections (Guth & Rieser, 1997; Hill & Ponder, 1976; Jacobson, 1993; LaGrow & Weessies, 1994; Willoughby & Monthei, 1998).

The first appearance of the audible pedestrian signals in the United States is dated back to 1920. Nevertheless, it was not included in the Manual on Uniform Traffic Control Devices (MUTCD) until 2000. In the mid-1990's, audible pedestrian signals were equipped with pushbuttons and improvements were made on audible pedestrian signals to tackle some of the shortcomings they had. The improved audible signals included a pushbutton with a locator tone incorporated within that repeats at 1Hz to provide BVI pedestrian with information about the location of the pushbutton.

At intersections equipped with Accessible Pedestrian Signals (APS), a pushbutton is required to be triggered. Barlow, Bentzen, & Bond (2005) studied blind pedestrian behavior in three cities and concluded that 27% of all the crossings that did not involve outside assistance were completed after the beginning of perpendicular traffic stream. Furthermore Barlow, Bentzen, & Bond (2005) pointed out that 42% of crossings ended outside the crosswalk.

Research Problem

Pedestrian veering occurs due to the minor difference in length of the human legs (Guth, 1990). Without guidance, humans tend to veer. The amount of veering depends on the personal physical characteristics of pedestrians and is different from one pedestrian to another (Guth & LaDuke, 1995). In addition, the extent of veering might be slightly increased when crossing quiet and wide intersections.

Ninety-seven percent of the Orientation and Mobility (O&M) trainers that responded to a survey conducted by Bentzen, Barlow, & Franck (2000) indicated that their students veered when crossing streets where there is no acoustic guideline (parallel traffic) to follow across the wide street. Furthermore, 66% of the O&M trainers claimed that their students had difficulties in knowing where the destination corner was.

On one hand, the shape and development of APS have effectively solved some of the crossing issues faced by BVI. On the other hand, APS has certain drawbacks. Among which are repeating tone adds 5 decibels of noise within 6 to 12 feet, no standard location for the pushbutton, and requirement of additional stubs for installing pushbutton station (Liao, Rakauskas, & Rayankula, 2011). Furthermore, the cost of installing an APS system is around 6,000 dollars in addition to labor costs. Bentzen, Barlow, & Franck (2000) examined other issues with APS, such as the volume of the audible messages, not knowing which street has the 'WALK' phase and that BVI pedestrians confused signal tones with traffic. Moreover, respondents to a survey (NCHRP 117) conducted by Tauchi, Sawai, Takato, Yoshiura, & Takeuchi (1998) uncovered problems associated with "keeping direction while walking in the crosswalk" even with an APS; additionally, the acoustic signals were often confusing. Wall, Ashmead, Bentzen, & Barlow (2004) indicated that when two parallel crossings have audible walk signals at the same time, interference might occur across signals, where blind pedestrians might be drawn towards the intersection. In the case where BVI pedestrians are present at different approaches and triggering the audible beaconing, confusion may be caused and might lead BVI pedestrians to the wrong beacon and, eventually, to the wrong destination which could affect their safety.

Surveys conducted by the American Council of the Blind (ACB) and the Association for Education and Rehabilitation of the Blind and Visually Impaired (AER) in 1998 indicated that blind pedestrians are sometimes not able to localize sounds from APS to use for guidance in street crossing. Eighty-five percent of ACB survey respondents reported that they were sometimes confused by surprising features such as medians or islands. The broadcasted sound from speakers mounted on pedestrian signal head seemed not to provide usable directional information.

To meet BVI pedestrians' needs at intersections, an integrated system has been suggested to improve safety, crossing performance, and mobility of pedestrian crossing at intersections, and the main technology used for this system is the Radio Frequency Identification (RFID). The system is comprised of three subsystems which work together to increase convenience and safety of pedestrians' intersection crossing, yet each subsystem can be implemented separately, giving it more flexibility. This system is integrated on a cane and is called the Smart-Cane, which is connected wirelessly to a handheld mobile device.

The first subsystem, which is the main concept of this research, is the blind pedestrian veering adjustment system which can be used by Blind and Visually Impaired to help them in their crossing maneuvers and prevent veering outside the crosswalk, minimize crossing time, and increase self-confidence and independence. It has the potential to be a decent and comfortable application for BVI in a sense that it could give them the adequate perception they need to identify their location relative to the crosswalk when crossing intersections. This can be accomplished through text-to-speech or tactile (vibrations) warnings. In addition, it provides helpful information about the intersection through an application installed on the mobile phone; this would make crossing experience easier and more convenient. Moreover, this system may be further improved to include roundabouts and un-signalized intersections in future developments.

The second subsystem is the driver alert system. This system, which alerts drivers approaching, yielding, and idling at intersections to the presence of pedestrians within crosswalks, helps increase the safety of pedestrians and minimize conflicts between vehicles and crossing.

The third subsystem is the green time system which is mainly designed to extend pedestrians' signal green time to the maximum in the case where crossing time is insufficient to complete crossing safely, and this system can be activated by pressing a button on the mobile phone.

As transportation engineering progresses over time, what once was just a thought is becoming a reality. As nations compete in the implementation of smart cities, technologies are suggested, researched, tested, and then employed to meet the requirements of smart cities. And as we are one step closer to implementing Connected Vehicles (CV) technology which one day might be an essential part of our everyday life, this research may contribute to the future of transportation in one or more fields such as Device-to-Infrastructure (D2I) communication through the Smart-Cane connection to intersection infrastructure and Vehicle-to-Device (V2D) communication through the driver alert system suggested. At the end of the day, this could hopefully lead to more livable communities that are safer to non-motorized road users, especially to those with disabilities.

The current research is intended to address the following question:

Does the suggested Smart-Cane help the blind and visually impaired pedestrians

- improve their road crossing abilities,
- maintain their heading,
- minimize their veering,
- decrease their crossing time,
- and increase their independence and self-confidence,

at wide, unfamiliar, and complex intersections with high noise levels, where audible beaconing might fail to provide guidance and assistance in crossing?

Objective

The objective of this study is to assist blind pedestrians to make their crossing easier and safer by aiding them in maintaining heading while crossing (wide, unfamiliar, complex) intersections. Furthermore, ending their crossing within the crosswalk, decreasing crossing time, increasing their independence on other cues while crossing, increasing self-confidence and making crossing behaviors of BVI pedestrians safer. The Smart-Cane may contribute to developing more livable and safer communities where pedestrians with disabilities can exercise their right of making use of this technology to move from one place to another conveniently and easily.

Scope of Study

The main scope of this research is to study the improvements and implications that the Smart-Cane can have on the crossing abilities of the BVI pedestrians at intersection locations. It subsidizes to some extent to the development of new technologies that will constitute futuristic smart cities, eventually, ending up in creating safer, more livable communities especially for those with visual disabilities.

CHAPTER II

LITERATURE REVIEW

The literature review is divided into three sections. The first section reviews studies conducted on the concept of the veering problem and its measurements as well as the history of blind pedestrians veering. The second section takes into account the history of Accessible Pedestrian Signals and studies conducted on measuring the effectiveness of APS. The third section discusses the history of Radio Frequency Identification (RFID) technology developed for blind people. RFID applications to help Blind and Visually Impaired (BVI) pedestrians' navigation, wayfinding and road crossing behaviors are also investigated.

Blind and Visually Impaired Pedestrians' Veering

A bulk of research has studied causes of human veering, ways to quantify and measure the veering tendency, and ways to minimize and prevent veering for pedestrians since the 1800s. Most studies investigated the veering behavior of the BVI pedestrians and its implications mainly from a safety, accessibility, and mobility perspectives.

Most studies have come up with similar definitions of the veering behavior. For example, Guth (2008) defined veering with respect to straight-line locomotion as the deviation of a person from the intended straight-line path. Furthermore, he stated that in case of vague sources of guidance, veering can mostly be compulsory. It is almost impossible to maintain a straight heading while walking without any external visual or audible cues. Kallie, Schrater, & Legge (2007) identified veering as the tendency to deviate from the intended route while maneuvering in a cue-less environment.

Veering can be dangerous, especially, for blind pedestrians in that it creates hazardous situations such as veering into the stream of traveling vehicles in a parallel direction as claimed by Jacobson (1993). Various training sessions were held by Orientation and Mobility (O&M) specialists to help blind pedestrians recover from veering, but few strategies prevent the initiation of a veering behavior (Guth & LaDuke, 1994). Moreover, Hill & Ponder (1976) suggested efficient strategies that can help recover someone after discovering that s/he has veered outside the path of travel, keeping in mind that one has to differentiate between initial misalignments and veering even though both might have the same outcomes but are not similar (Guth, Hill, & Rieser, 1989). Misalignment is the incorrect initial alignment or arrangement of the pedestrian before initiating walking with respect to the physical cue by which s/he follows to maintain correct alignment, whereas veering is the action of going off track or changing a direction while crossing or walking.

Veering can be avoided through utilization of various information offered by the physical and acoustic features of the blind pedestrians' surroundings (Guth & LaDuke, 1994). While walking on a sidewalk in a city, blind pedestrians often use walls, storefronts, sidewalk edges, or grass lines as guidelines by employing their canes or hands as a means of maintaining physical contact with these physical cues (Jacobson, 1993). Another method used to avoid veering is through maintaining auditory contact via the sounds that the surfaces emit when they come into physical contact with. In cases where a blind pedestrian tries to cross a signalized intersection, s/he depends on the parallel street surge of traffic as their auditory cue. In cases where an intersection is equipped with an Accessible Pedestrian Signal (APS), blind pedestrians sometimes tend to depend on the audible beaconing to reach the correct corner and maintain heading while crossing (Peck, 1990).

Physical cues, which were previously mentioned, are often not available when crossing intersections. Auditory cues are often discontinuous and confusing especially at major intersections that lack traffic during the day. Furthermore, auditory cues that can be useful for BVI pedestrians may be concealed in a noisy environment. In such situations, it appears that joint and muscle cues that can help self-movement are inadequate to detect veering (Guth & LaDuke, 1994). When attempting to judge whether a curved path with a 42-foot radius was straight or curved by blind and blindfolded sighted pedestrians, it was found that the subjects acted at chance levels (Cratty & Williams, 1966).

There have been several ways to measure and quantify veering. One method was to draw approximate travel paths (Schaeffer, 1928). From arcs marked in the grass, the angular deviation was measured for blind pedestrians with respect to their initial walking direction (Rouse & Worchel, 1955) which is another way of measuring veering. Another method used to measure veering is by comparing initial walking direction with later walking direction, (Klatzky, et al., 1990). Cratty & Williams (1966) measured veering as the perpendicular displacement from an ideal straight-line path.

Accessible Pedestrian Signals (APS) and Blind Pedestrians

The Manual on Uniform Traffic Control Devices (MUTCD) defines Accessible Pedestrian Signals (APS) as a device that communicates information about pedestrian timing in nonvisual formats such as audible tones, verbal messages, and/or vibrating surfaces. According to the Draft Guidelines on Accessible Public Rights-of-Way (Draft PROWAG), an APS is a device that disseminates information regarding the “Walk” phase in audible and vibrotactile formats. The main difference between the MUTCD definition and that of the Draft PROWAG is that the former states that an APS provides information in either audible or vibrating surfaces, while the latter states that the APS provides information in both audible and vibrotactile formats.

Numerous designations such as Acoustic, Audiotactile, Audible Pedestrian, Audible Traffic, and Audible Pedestrian Traffic Signals were given to APS in different countries. APS can provide information to pedestrians. Information includes pushbutton that activates the "Walk" phase, beginning of the walk interval, the direction of the crosswalk, location of destination curb, intersection street names in braille, raised print, or speech messages, intersection signalization with a speech message, and intersection geometry through tactile maps and diagrams or through speech messages.

Audible pedestrian signals were reported to exist in the United States as early as 1920, but they have not been incorporated in the MUTCD until 2000. In the mid-1970s, mass marketing of APS was originally based on a Japanese system that emanated sound from an overhead speaker during the "Walk" phase only. The overhead speaker was placed at the opposite end of the crosswalk.

Various studies, which examined the benefits of APS, found that APS improves the crossing actions of blind pedestrians. Moreover, research proved that APS devices allow more accurate judgments of the onset of the walk interval, reduce the number of crossings beginning during "Don't Walk" phase, reduce delay, and result in more crossings completed before signal phase changes (Harkey, Carter, Barlow, & Bentzen, 2007).

Studies on complex intersection crossing by blind pedestrian before and after installation of APS and again after installation of innovative device features in two cities were conducted by Scott, Barlow, Bentzen, Bond, & Gubbe (2008). The findings proved that numerous improvements in pedestrian performance were observed in both cities, with no negative impacts of the installation of APS. Perhaps, the most significant improvements occurred with timing measures and some improvements took place in orientation and wayfinding. The researchers' observations of participants indicate that when the audible beacon was called in the city of Portland, it was difficult to hear the "Walk" indication at the waiting location due to the incorrect direction that the speakers aimed at. In addition, the audible beacon did not seem to improve the "ending within the crosswalk" behavior of participant as expected. In the event that participants did not align accurately, they often veered outside the crosswalk. Another study that targeted blind pedestrians' complex intersection crossing behaviors before and after installation of APS was made by Barlow, Scott, & Bentzen (2009). The results indicated that less than 50% of crossings were completed within the crosswalk in Charlotte, and no improvements in starting within the crosswalk were noticed. Furthermore, the study indicated that, while APS provided information about the status of the pedestrian signal, APS generally did not provide good wayfinding information, especially, in the case where the sound was emitted from both ends of the crosswalk.

Barlow, Scott, Bentzen, Guth, & Graham (2013) compared the effect of three treatments: standard APS (no beaconing), prototype beaconing APS, and raised guide strip on their ability to assist in establishing and maintaining a correct heading for blind pedestrians while crossing streets. It was found that almost 60% of the participants' crossings were performed outside the crosswalk in the standard APS condition. With regard to the prototype beaconing APS and the raised guide strips, the results indicated that the performance of the participants in crossing within the crosswalk had improved. In the standard APS treatment case, more than half of the time participants were outside the crosswalk by six feet or more, exposing them to danger by being available in the path of through or idling traffic at the intersection. With the beaconing APS and guide strips, participants were outside the crosswalk by 6 feet or more at 16.5% and 27.7% of the time respectively.

A study evaluated which push-button-integrated APS features and how much information was required to use those features correctly were useful to blind pedestrians (Bentzen, Scott, & Barlow, 2006). All APSs used in this research comprised of push-button locator tone, an audible actuation indicator, an audible walk indication, a tactile arrow that vibrates during the walk interval, and automatic volume adjustment. However, the acoustic characteristics of the locator tone, walk signal, and the actuation indicator varied across devices. Results suggested that none of the APS reliably provided useful information on wayfinding than any other devices.

Surveys investigating problems experienced by blind pedestrians while crossing streets with audible signals were conducted by the American Council of the Blind (ACB) and the Association for Education and Rehabilitation of the Blind and Visually Impaired (AER). In the AER survey, 66% of participants indicated that they had difficulty knowing where the destination corner was because of the offset of the intersection or that traffic was intermittent, while in the ACB survey, 79% of respondents indicated that they sometimes had difficulty determining the location of the destination corner. In the case that sounds are broadcasted from speakers mounted on the pedestrian signal head, ACB and AER survey respondents indicated that blind pedestrians did not have the ability to localize APS sounds for guidance in crossing streets (ACB, 6%; AER, 39%). Furthermore, 85% of ACB survey respondents indicated that they were sometimes confused by unexpected features as median islands. As for intersections equipped with APS that had “bird call”, bells, and buzzers sounds, 45% of the ACB survey respondents considered signals to be too loud, while 71% considered them as too quiet.

However, in the AER survey, 24% considered the signals too loud and 52% reported that they were too quiet. When intersections are closely spaced, APS from one intersection might have been heard from another, causing confusion for the blind pedestrians, incorrectly thinking that they have the walking interval. Additionally, 8% of the ACB respondents claimed that they had been struck by a car at an intersection and 28% had had their long canes run over (Carroll & Bentzen, 1999; Bentzen, Barlow, & Franck, 2000).

Radio Frequency Identification (RFID)

RFID is defined as the short-range radio technology used for digital information communication between two objects, a stationary and a moving one. RFID technology was discovered as early as 1948 by Harry Stockman. He indicated "Evidently, considerable research and development work must be done before the remaining basic problems in reflected-power communication are solved, and before the field of useful applications is explored" (Landt, 2005, p. 9).

Radio Frequency Identification (RFID) is one of the several technologies that have been integrated and implemented to aid blind pedestrians in their wayfinding and navigation skills. Commercial activities of RFID began in the 1960s, and the 1970s witnessed the revolution of the RFID technology. In the 1970s, as developers and academic institutions worked actively on RFID, noticeable advances in this area were witnessed. The 1970s were characterized by principally developmental work. RFID was implemented fully in the 1980s. In the United States, the main implementation of the RFID technology was in the field of transportation, particularly for electronic toll collection and personnel access. The first electronic tolling system in the world was used on highways in Oklahoma in 1991, where vehicles could pass toll collection points at highway speeds (Landt, 2005).

RFID is generally comprised of simple devices (tags or transponders) on one end of the link and a complex device (readers, interrogators, beacons) on the other. RFID systems can be either read-only or read-write and most frequencies of this system often range from 100 KHz to 10 GHz (Landt, 2005). Radio Frequency Identification (RFID) is an essential part of our everyday life.

Tags are mostly cheap and small, and they can be deployed economically in considerable numbers. Tags can be powered by a battery while others are powered by rectification of the radio signal sent by the reader. Tags have the ability to send data to the reader by changing the loading of the tag antenna in a coded manner or by generating and modeling a radio signal. Readers, on the other hand, have greater capabilities and are usually connected to a host computer or network. Typical RFID system uses the principle of modulated backscatter in which data are transferred from the tag to the reader through a unmodulated signal that is sent from the reader to the tag. In its turn, the tag reads its internal memory and changes loading on the tag antenna in a coded manner, corresponding to the stored data on the tag. Thus, the signal reflected from the tag is modulated with this coded information, which is received and demodulated by the reader, using a receiver and is decoded, and the outputs are disseminated as digital information (Landt, 2005).

There are various applications of the RFID, ranging from anti-theft systems in vehicles and merchandise, passing by non-stopping toll collection and traffic management, to building access authorization and automating parking lots. One of the applications of RFID technology for blind pedestrians, who lack visual perception of their surroundings, was the provision of location and navigational information. Using RFID tag grid system, locational and navigational determination system was made available to the blind (Willis & Helal, 2005). Each RFID tag contains spatial coordinates and information describing the surrounding environment. To provide the navigational guidance both indoor and outdoor, the proposed system requires short-range communication (7~15 cm or 2.75~6 in) and high density of tags (30 cm or 12 in apart). The system is technically and economically feasible and might be used in small businesses, government buildings, and college campuses.

Another system proposed, Radio Virgilio/Sesamonet, uses a novel Information and Communication Technologies (ICT), which implements RFID technologies for the navigation of both indoor and outdoor for visually impaired pedestrians (Ceipidor, et al., 2007). It was developed to help users increase usability, safety, and discreetness in mobility while navigating an urban environment. Traditional assistive technologies were integrated with wireless and RFID to have an intelligent and easy to use the navigational system.

A contextualized geographical information using RFID technology, integrated on a cane to assist in navigation for blind pedestrians, was provided for both indoor and outdoor environment. The main objective of using RFID in this study is to correct the GPS error in case of outdoor positioning since each tag is appropriately georeferenced and is able to correct the Wi-Fi location error in case of indoor positioning. Furthermore, it provides the user with warnings and information relative to each specific point where the RFID tags are deployed (Faria, Lopes, Fernandes, Martins, & Barroso, 2010).

Chumkamon, Tuvaphanthaphiphat, & Keeratiwintakorn (2008) proposed a RFID navigational system for indoor environments, where this system relies on the tags' locational information, user destination, and a routing server, where the shortest path is calculated based on the user's current location. This system is comprised of three sub-systems, navigation runway, a communication module, and a user interface and data module. The main purpose of this system is to calculate the route between two places by obtaining the locational information of the tags through the reader, and a remote server which calculates the route between two points.

Ding, Yuan, Jiang, & Zang (2007) introduced a system consisting of a white cane with a RFID reader build in, connecting through Bluetooth to a mobile phone, and an installed software on the mobile phone to translate information stored in the tags to audible notifications. The system also has a software to store messages and other information. The navigation server calculates best the route between the current position and desired destination, using the tag information and a routing algorithm. This integrated system is designed to provide blind pedestrians with their location, road conditions, buildings in the vicinity, and acquire optimal routes to their destinations.

Another system is the Smart Robot (SR) which is comprised of RFID and GPS integrated navigation system for the visually impaired (Yelmarthi, Haas, Nielsen, & Mothersell, 2010). The SR uses the RFID technology for indoor navigation, while the GPS is used for outdoor navigation. The portable terminal unit, which is an embedded system equipped with RFID reader, GPS, and an analog compass, is used as input devices to obtain location and orientation. The Smart Robot system enables visually impaired pedestrians to become less dependent on other cues to commute, and it demonstrated promising results in improving their quality of life as it could make routine tasks easier, simpler, and feasible.

CHAPTER III

SMART CANE DEVELOPMENT

Attention is not given to non-motorized road users in terms of developing technologies that may assist in their everyday commuting; therefore, developing a system (Smart-Cane) that can enhance safety and mobility of BVI pedestrians through technology has become a must. Looking at the evolution of smart cities and Connected Vehicles (CV) developments, there is no doubt that disabled pedestrians should be considered through technology in transportation advancements occurring in the modern day.

Since the problem has been identified and the solution to this has been recognized, the matter of choosing a feasible, applicable, cheap, and convenient technology was the next problem that was tackled through extensive studies on alternative technologies. Radio Frequency Identification (RFID) has been identified as the most appropriate technology among different sets of alternatives since it is the most feasible and practical for the proposed system. RFID technology has many advantages: 1) it is convenient; 2) the RFID tags are small and rugged enough to be operated under different environmental conditions, and 3) the database is portable and communication occurs in real time.

Smart-Cane Components

The Smart-Cane is similar to that used by BVI pedestrians in shape, but it utilizes modern technologies embedded within to assist BVI pedestrians at intersection crossings. The cane was developed and tested in this study. The cane consists of several components that serve its primary goal of guiding BVI pedestrians to the correct destination corner. The components that were installed on the Smart-Cane include the RFID reader, 360° antenna, and a microcontroller.

A power bank (battery) was also used to provide power to the RFID reader and microcontroller, the power bank is included in the Smart-Cane but can be handheld or placed in the pedestrians' pocket. The microcontroller is connected to the RFID reader from one end and wirelessly to a mobile phone from the other to disseminate information to the BVI pedestrian accordingly. The final component is the RFID tags which are deployed on the crosswalk. It should be brought to attention that the Smart-Cane is only a prototype at this stage. Through the commercialization process, all the components installed on the cane including the power bank can be integrated into the cane in a way that none of the components can be seen by the naked eye. Figure (1) depicts the Smart-Cane.

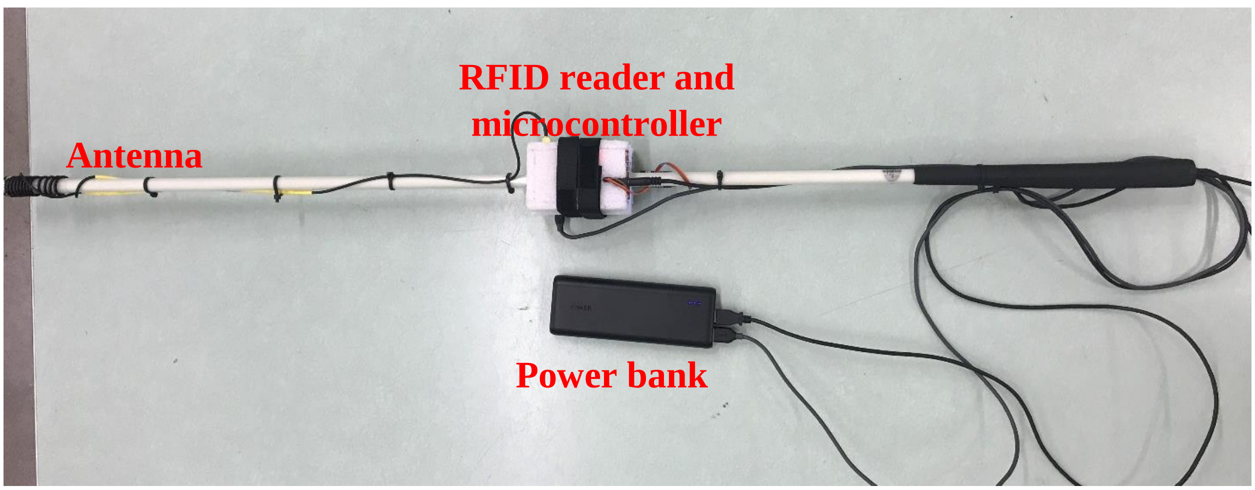

Figure (1): Smart-Cane Components

RFID uses short-range radio technology to establish communication between stationary and movable objects. In our case, the movable object is depicted as the RFID reader installed on Smart-Cane. The RFID reader generates electromagnetic fields to automatically identify and track the RFID tags. The passive RFID tags (sensors) represent the stationary objects which are small and inexpensive transponders as demonstrated in Figure (2) (Landt, 2005). Passive RFID tags do not require an energy source; they collect energy from the nearby reader through the radio waves emitted by the RFID reader. RFID tags are pre-classified using their ID's. A database was established to include all the tag IDs and their corresponding information. This information stored in the database is accessed through the unique tag ID that is scanned by the reader.

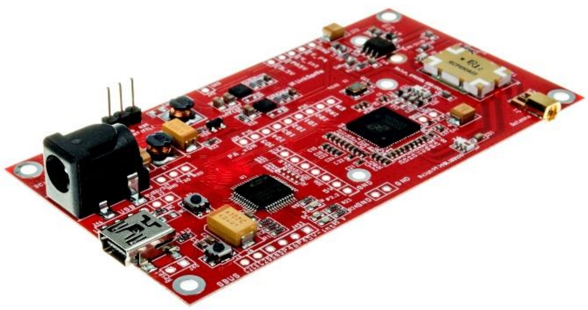

Figure (2): RFID Reader (left) and RFID Tag (right)

The 360° antenna, which has the ability to read in all directions, is used to increase the effective reading range of the RFID reader, giving it more flexibility. The antenna is shown in Figure (3) establishes communication between the RFID reader and the tags. The effective reading range of this antenna can reach up to 4 feet which are considered an acceptable range for our application. The antenna is based on coax cable and can be easily installed in myriads of shapes. It can also be connected to any type of RFID reader. The antenna generates a homogeneous electromagnetic field along the antenna cable.

Figure (3): The 360° Antenna

The RFID reader scans the tags through the antenna and sends the tag ID to the microcontroller, where the latter performs further processing through a programmed decision table stored in the database by calculating various real-time information, depending on the tag ID scanned. The microcontroller is the third generation of Raspberry Pi, as illustrated in Figure (4). The microcontroller sends the information wirelessly to the connected mobile phone, and the mobile phone broadcasts the information verbally to the user. This information includes general intersection information such as intersection name, type, geometry, number of lanes, and what direction is about to be crossed. Moreover, directional guidance information based on the BVI pedestrian position relative to the crosswalk is disseminated to the user. Guiding information includes “Keep going” if a pedestrian is at the center line of the crosswalk, “Veer Left” if s/he is at the right boundary of the crosswalk, and “Veer Right” if s/he is present at the left boundary of the crosswalk.

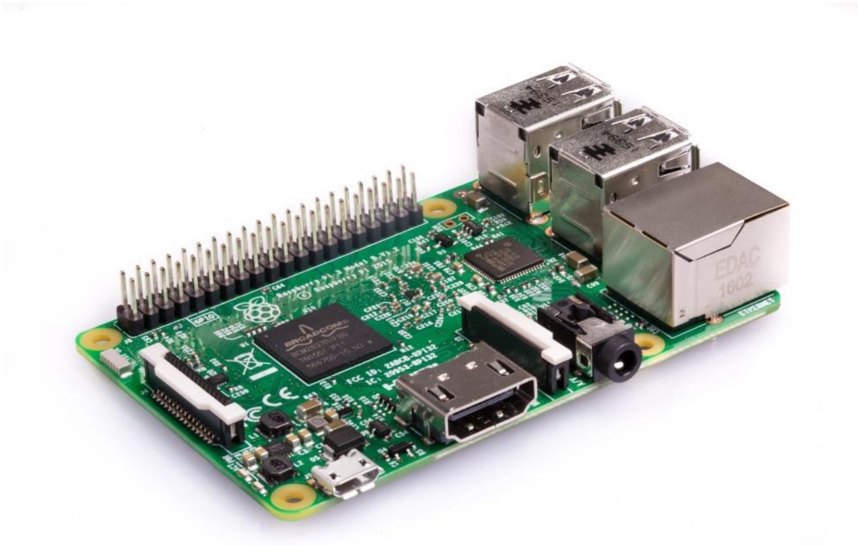

Figure (4): 3rd Generation Raspberry Pi Microcontroller

The power bank chosen for the Smart-Cane is the Anker PowerCore 20100 Figure (5). The Anker PowerCore 20100 was chosen for many reasons. One of the most important reasons was that it supports two outputs which are feasible for our cane since we need two power sources for both the reader and microcontroller. The second reason is its huge 7-day charge capacity. Additionally, it is portable, handheld, and pocket-friendly. Finally, it has a high-speed universal charging which provides high performance in the least amount of time.

Figure (5): Anker PowerCore 20100

The final component of the Smart-Cane is the mobile application that retrieves information from the microcontroller and forwards it to the user verbally or by vibrations. The application was developed using Swift programming language. The mobile phone along with the installed application communicates wirelessly using Bluetooth Low Energy with the microcontroller.

System Description

The Smart-Cane is an integrated system that is designed to meet the needs of BVI pedestrians at intersection crossings and is comprised of three subsystems that can work together to provide the required guidance and assistance that BVI pedestrians might need while traversing an intersection, yet these subsystems can be used separately and according to personal preference, giving the Smart-Cane more flexibility and convenience. The basic goal of the Smart-Cane is to improve safety, crossing performance, and mobility of BVI pedestrians at intersection crossing locations through disseminating information to the BVI pedestrian, either audibly or using vibrotactile features integrated within the mobile phone which is connected wirelessly to the Smart-Cane.

The first of these three subsystems is the veering adjustment system; the basic function of this system is to minimize veering behaviors of BVI pedestrians as much as possible. The second is the driver alert system that basically informs approaching and idling drivers at intersections of the presence of BVI pedestrians. This system increases alertness of drivers and safety of BVI pedestrians. The last is the green time system which basically communicates with the signal controller and asks permission for allocating pedestrians' green time; moreover, it provides extra green time for pedestrians to complete crossing safely and accordingly when needed and is allocated for future research due to lack of time to complete it. Figure (6) below shows the Smart-Cane system architecture.

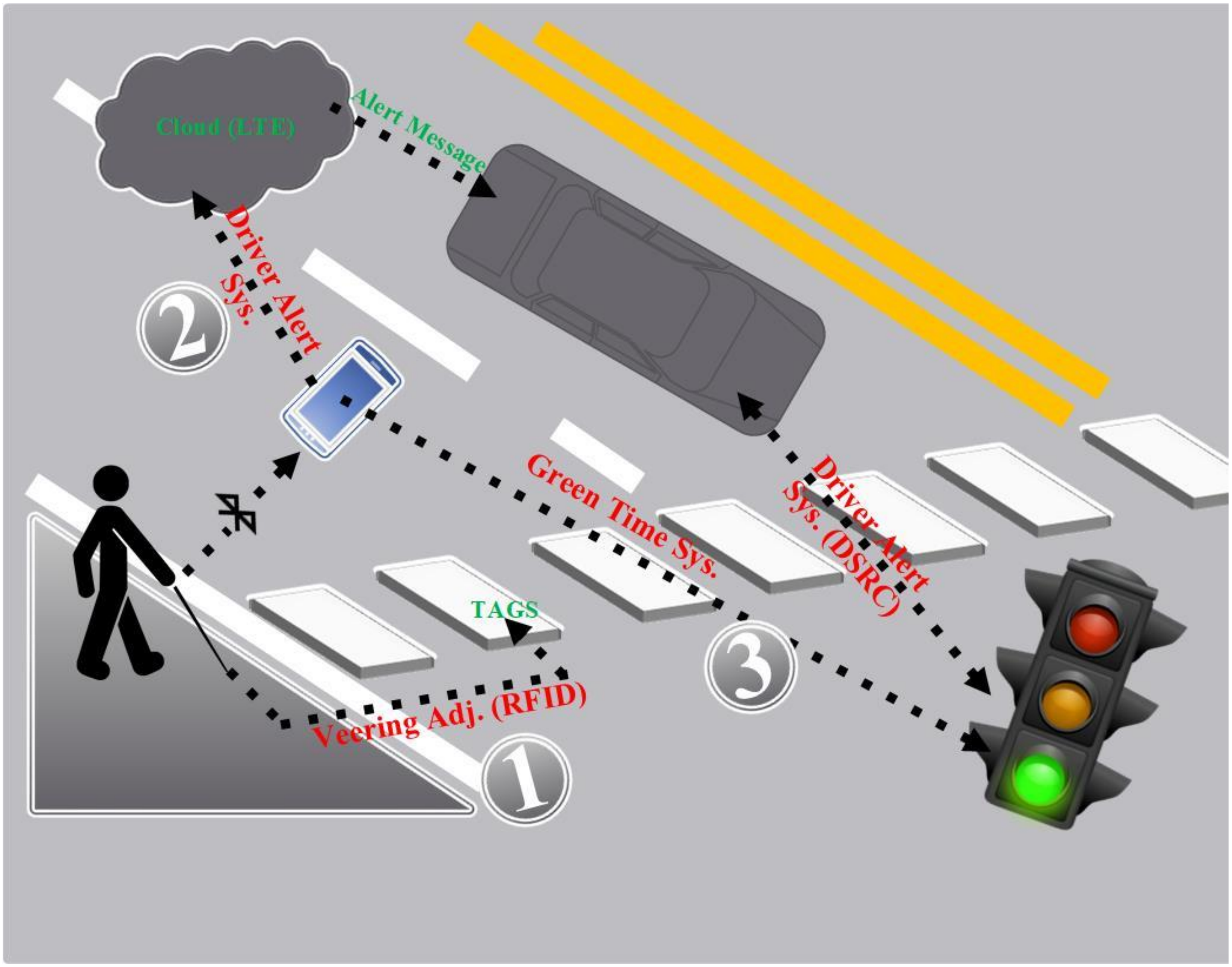

Figure (6): Smart-Cane Architecture

Veering Adjustment System

This system is subdivided into two parts, the Smart-Cane, and the RFID tags. The RFID tags are deployed on the crosswalk on four levels, starting line tags, right boundary tags, centerline tags, left boundary tags, and finish line tags. Upon experimentation, the most feasible and convenient vertical and horizontal spacing between tags was considered, based on the effective reading range of the antenna and blind spots between tags, where tags might not be detected. The vertical spacing (along with the length of the crosswalk) separating the tags is 1 feet, and the horizontal spacing (along with the width of the crosswalk) separating the tags is 2.5 feet, as shown in Figure (**7**). The total number of tags used in our study was 272 tags, 84 for each boundary line (left, center, right) and 10 tags for the starting and finishing lines.

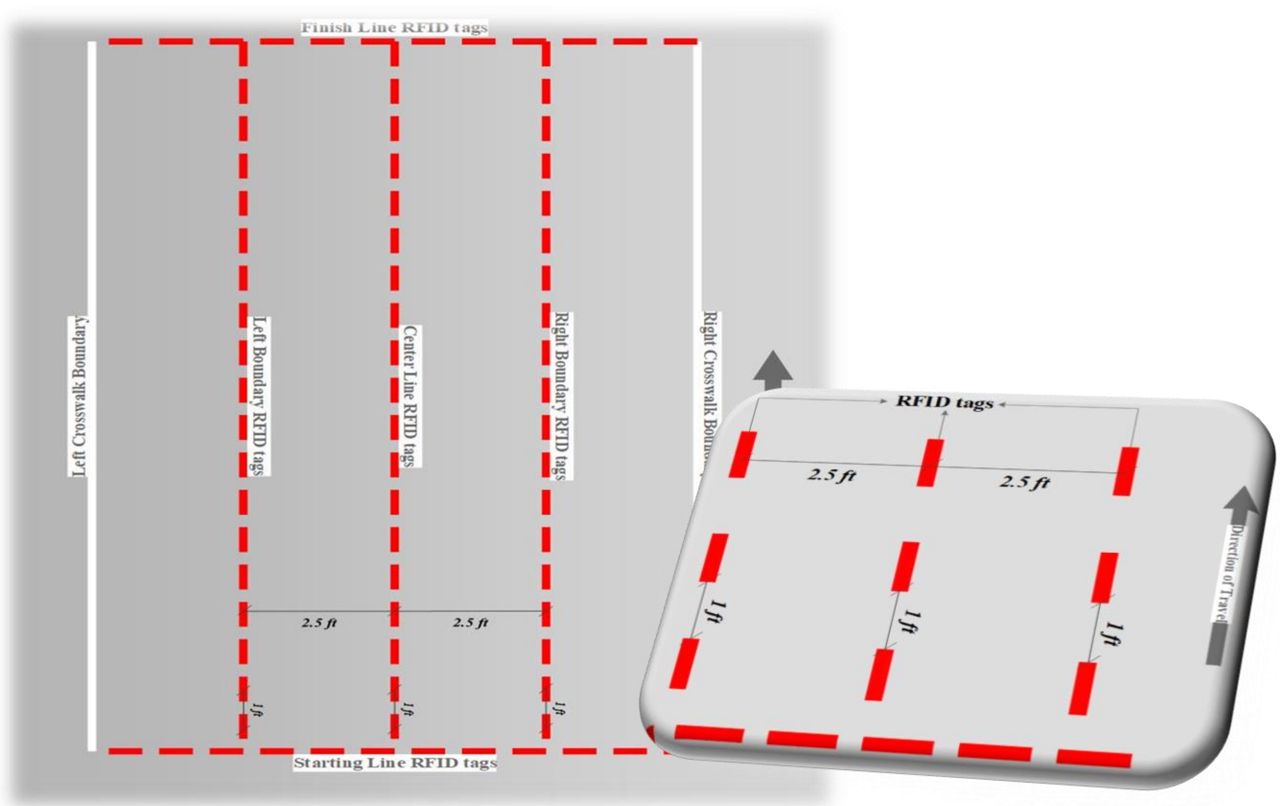

Figure (7): RFID Tags Spacing

As the BVI pedestrian initiates crossing with the Smart-Cane and as soon as it detects and scans the tags, information stored in the portable database begin to disseminate through the handheld mobile device. When the starting line tags are detected, information about the intersection such as intersection name, type, geometry, number of lanes, and direction of crossing is provided to the BVI pedestrian, and this information can be edited and changed according to the location crossed. There are three main navigational instructions delivered to the BVI through his/her mobile device, depending on his/her location relative to the crosswalk and on what tags are scanned by the Smart-Cane. As long as the Smart-Cane scans the center line tags, the mobile phone gives the instruction of "Keep going", indicating that the BVI pedestrian is within 1 feet of the center line, and this message is delivered at a 3 seconds frequency. The Smart-Cane stops instructing BVI pedestrians to "Keep going" when s/he detects the left or right boundary tags through the cane. When the BVI pedestrian begins veering either to the left or to the right and when the respective tags are scanned, the mobile phone tells the BVI pedestrian either to "Veer left" or "Veer right" every 2 seconds, depending on his/her position, and it keeps providing this information until his/her path is corrected and the center line tags are detected, implying that s/he is on the correct path again. A decision table was also constructed by the research team and stored in the database for the cases where two different types of tags are detected (left and center, or right and center), where this decision table gives the instruction of "Keep Going" in case the pedestrian is located between the center line and the left or right boundary, indicating that there is no need for him/her to veer either left or right, and this decision table is accessed if the specified requirements are met. This feature was included in the design of the Smart-Cane to minimize confusion and incorrect guidance instructions. Finally, when the finish line tags are detected, a message informing the BVI pedestrian of the end of the crosswalk is disseminated. In the case where the pedestrian initiates crossing from the opposite end of the crosswalk, a Boolean variable assigned the name “reverse” is used to dynamically update the crossing location of the BVI pedestrian to remove any restrictions on the direction of the Smart-Cane, but for research purposes, this feature was not included. Figure (8) shows a crosswalk with RFID tags deployed on it and a description of each type of tag.

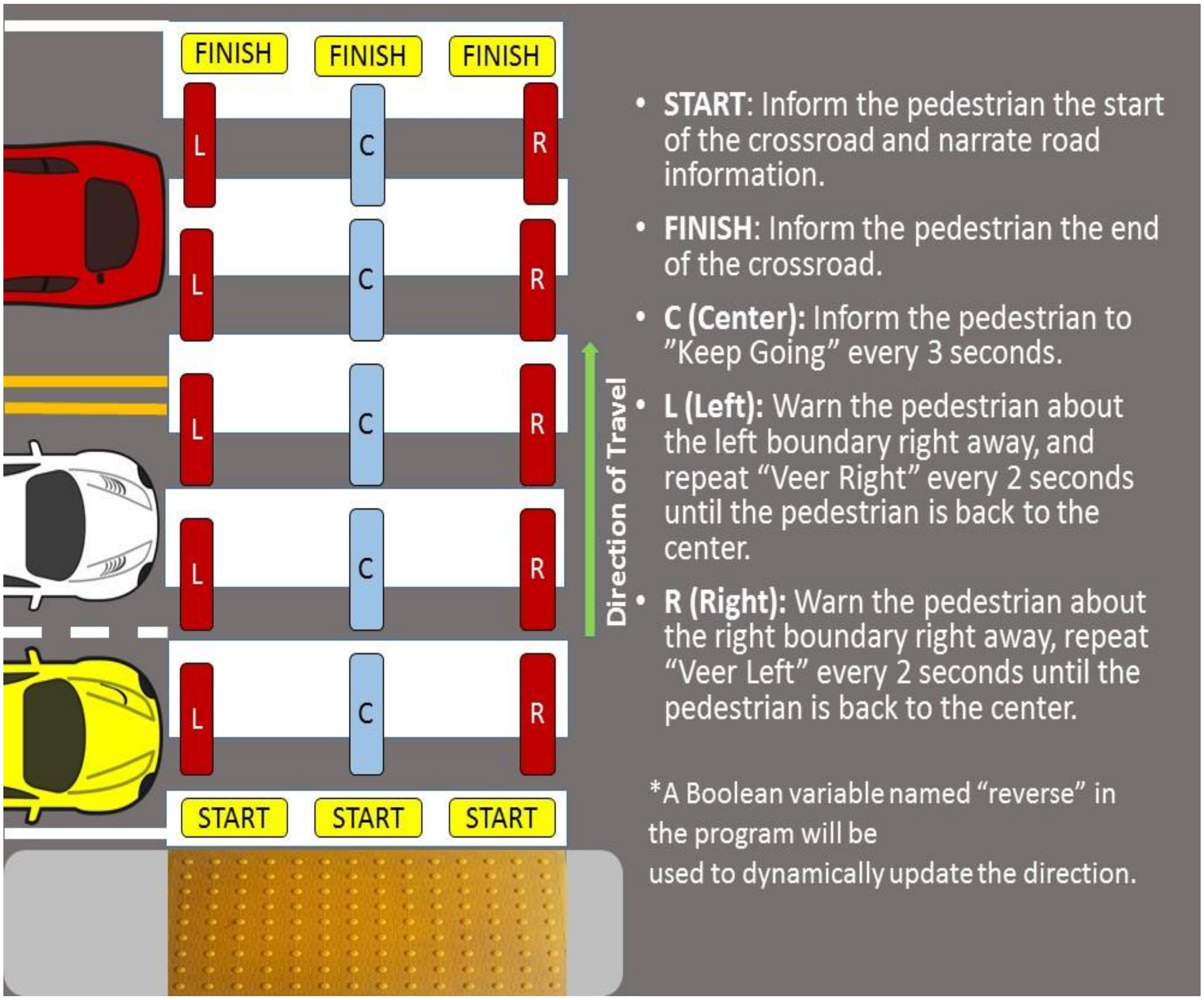

Figure (8): RFID Tag Description and Deployment

Through the connection between the Smart-Cane and tags deployed on the crosswalk, a Device-to-Infrastructure (D2I) communication is established through RFID technology in our case. The infrastructure here is depicted by the RFID tags deployed on the crosswalk, and the device depicts the Smart-Cane developed by our research team. The advantages of the D2I communication established are identifying intersection, preventing veering to the maximum extent possible, keeping the BVI pedestrian within the crosswalk boundaries. This results in increasing pedestrians' safety and minimizing crossing time needed to complete crossing which in its turn increases their self-confidence and fills the gaps in information that the BVI pedestrian may sometimes lack, especially at unfamiliar intersections. Furthermore, the veering adjustment system gives the BVI pedestrians the adequate perception they need to identify their location relative to the crosswalk and minimize their dependence on other conventional cues applicable at intersection areas, such as a parallel surge of traffic.

Driver Alert System

The second subsystem of the Smart-Cane is the driver alert system. As soon as the BVI pedestrian initiates crossing and the Smart-Cane scans the first tag, an alert message is sent to drivers approaching or idling at the intersection informing them of the presence of the BVI pedestrian within the crosswalk. This system increases the alertness of drivers and, therefore, increases the safety of BVI pedestrians and gives them more confidence that the surrounding drivers are aware of their presence.

At this stage of the project, the Smart-Cane utilizes the cloud (LTE) to broadcast the alert message on the Message Queue Telemetry Transport (MQTT) server, where drivers can access this information and receive the alert message. Figure (9) explains the MQTT roles and flow of information. The MQTT is a publish-subscribe-based lightweight messaging protocol, and it is designed for connections to remote locations, where a small code footprint is required or network bandwidth is limited (Stanford-Clark & Truong, 2013). Eventually, Dedicated Short Range Communication (DSRC) can be used for this purpose instead of the cloud (LTE), where the present Smart-Cane was designed to have such technology in the future. DSRC is a two-way medium range wireless communication with a range that can reach up to 300 meters that permits very high data transmission in active safety applications. The Federal Communications Commission (FCC) allocated 75 MHz of spectrum in the 5.9 GHz band for the DSRC communications and in the vehicle safety and mobility applications (Research and Innovative Technology Administration, 2015).

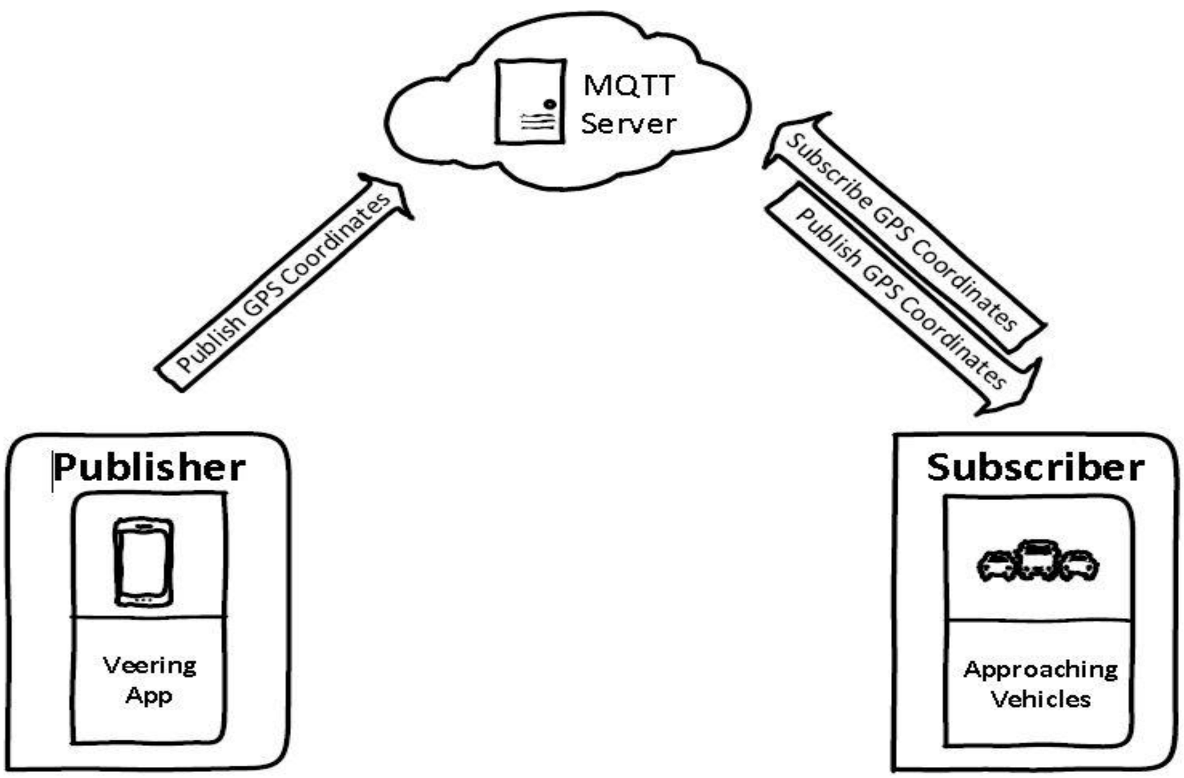

Figure (9): Driver Alert System

The driver alert system establishes Vehicle-to-Infrastructure (V2I) communication through DSRC or Device-to-Vehicle (D2V) communication through publishing the alert message or notification to the MQTT server. When DSRC is fully integrated within vehicles, then the DSRC technology can be easily integrated onto the Smart-Cane, providing more flexibility, convenience, increase in BVI safety at intersection location and more comfort to users while crossing the intersection.

Green Time System

The final Smart-Cane subsystem is the green time system. The main communication method of this system is wireless communication via WiFi with the signal controller Figure (10). It has two main functions. The first function permits the BVI pedestrian permission for green time allocation before initiating crossing through a button that can be pushed either through the mobile phone or the Smart-Cane.

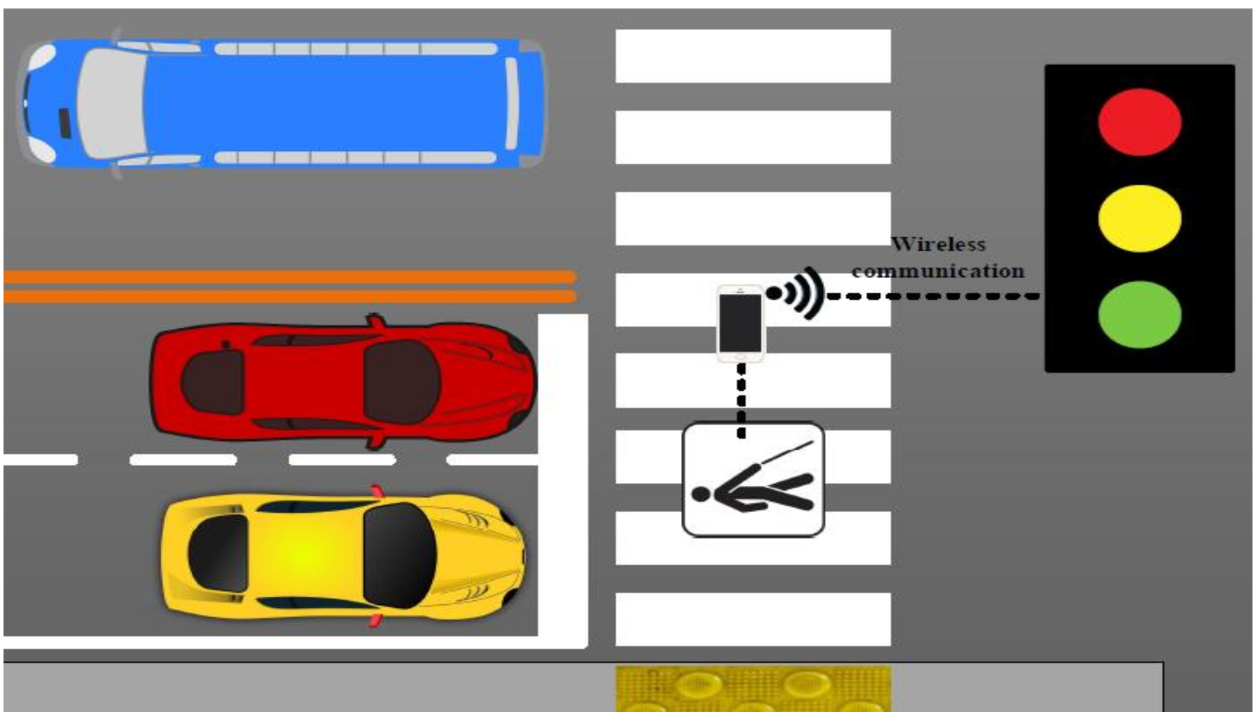

Figure (10): Green Time System

The second function is that it allows the BVI pedestrian to extend his/her green time to the maximum while crossing in the case where the green time allocated for crossing is insufficient. The green time extension feature can be adaptive in that it can have the ability to collect, measure, and store BVI pedestrians' walking speed and information. This information can be used automatically by the system to calculate the green time needed for BVI pedestrian to complete crossing at specific intersections based on their personal walking speeds; moreover, this information is then compared with the green time given by the signal controller. In the case where this green time allocated by the controller is not enough, then the Smart-Cane asks the signal controller for more green time to make sure that the pedestrian can complete crossing and reach the opposite curb of the intersection safely. Unfortunately, at this stage of the research, we did not have the opportunity to develop this feature due to time constraints, but we hope that this feature can be examined and developed in the next stage along with the other Smart-Cane subsystems.

Through the green time system, Device-to-Infrastructure (D2I) communication is established between the Smart-Cane and the signal controller through WiFi if through experimentation it proves to be an applicable, feasible, reliable source of communication.

By utilizing the D2I communication whether through the veering adjustment system or the green time system and by utilizing the V2I or D2V communication through the driver alert system, a complete system is built within the Connected Vehicles (CV) technology that assures safety and convenience for the BVI pedestrians. Furthermore, the technologies that are used by the Smart-Cane guarantee that this system can be connected to the CV technology and used in conjunction with the underlying CV technology.

CHAPTER IV

METHODOLOGY

Two tools were used to collect data and address the proposed research question. The first tool was field experimentation of the prototype Smart-Cane, and the second was pre and post surveys responded to by the BVI participants before and after experimentation of the Smart-Cane. Three different scenarios were selected to investigate the improvements that the Smart-Cane had over the Accessible Pedestrian Signals (APS) installed at intersections. The performance measures that were quantified through experimentation included veering tendency and maintaining heading and crossing time. Independence and self-confidence were performance measures examined through field observations and surveys responded to by BVI participants.

Participants

The experimentation phase of this research was divided into two stages; the first stage included experimentation with sighted participants, and the second stage was conducted with BVI participants. Thirty-two pedestrians, who voluntarily participated in the study, were colleagues, staff, and faculty members at the College of Engineering and Applied Science at Western Michigan University (WMU). All the participants were blindfolded throughout the experimentation to assure consistency across the participants. Twenty-two participants were males and ten were females. Twenty-three participants aged 18 to 34 and 9 aged 35-64.

The second stage of experimentation was conducted on BVI participants. The participants for this stage were recruited through MidWest Enterprises for the Blind (MWEB) which is a manufacturing company that provides employment opportunities to the Blind and

Visually Impaired to maximize their potential for independent living and assists in achieving economic self-support. Several meetings were held with BVI employees and the administrative manager at MWEB to brief them on the purpose of the study and to introduce the Smart-Cane concept. Those who attended the meetings showed interest in the technology, and a total of 10 BVI pedestrians voluntarily participated in the study, and those who had minimal visual perception were blindfolded as a precaution and to ensure consistency within the participants. The sample size included 3 females and 7 males, five of which age ranged between 35 and 44 and the other 5 aged between 45 and 64.

Five of the BVI participants reported using a long cane as their main mobility instrument, and the other 5 reported using other means but also had experience using the cane. Additionally, participants stated having normal hearing and no disabilities.

All participants whether sighted or BVI provided their informed consent before initiating experimentation. The described experimentation procedure, methods, and surveys were approved by Western Michigan University's Human Subjects Institutional Review Board (HSIRB). Copies of the approval letter and consent form are attached in Appendices A and B.

A pre-survey was conducted prior to the experimentation initiation to study the participants' navigational and mobility skills and important information needed for crossing. Also, to study the usefulness and applicability of Accessible Pedestrian Signals (APS) in terms of providing guidance while crossing. A post-survey was conducted to study the BVI participants' opinion and feedback on the Smart-Cane. A copy of the pre-survey and post-survey are attached in Appendices C and D.

Experimental Design

The experimental site that was selected for our study was an isolated parking lot (P4) near the College of Engineering and Applied Sciences at Western Michigan University (WMU) as shown in Figure (11). This parking lot was chosen to minimize the risk associated with experimenting at a real intersection, and since this phase of experimenting with the Smart-Cane was conducted to prove the efficiency of the technology and serve as a proof of concept. The parking lot is not frequently used, and most of the time is empty with a small number of vehicles entering and exiting during weekdays, and on the experimentation days, the entrance was temporarily closed to avoid unanticipated vehicle noises. The first stage of experimentation with sighted participants took place on 3 consecutive weekdays during July 2017, and the second stage of experimentation with the BVI participants took place on two consecutive weekends (Saturdays and Sundays) in August 2017 where vehicles were limited to those used by the research team present at the experimental site.

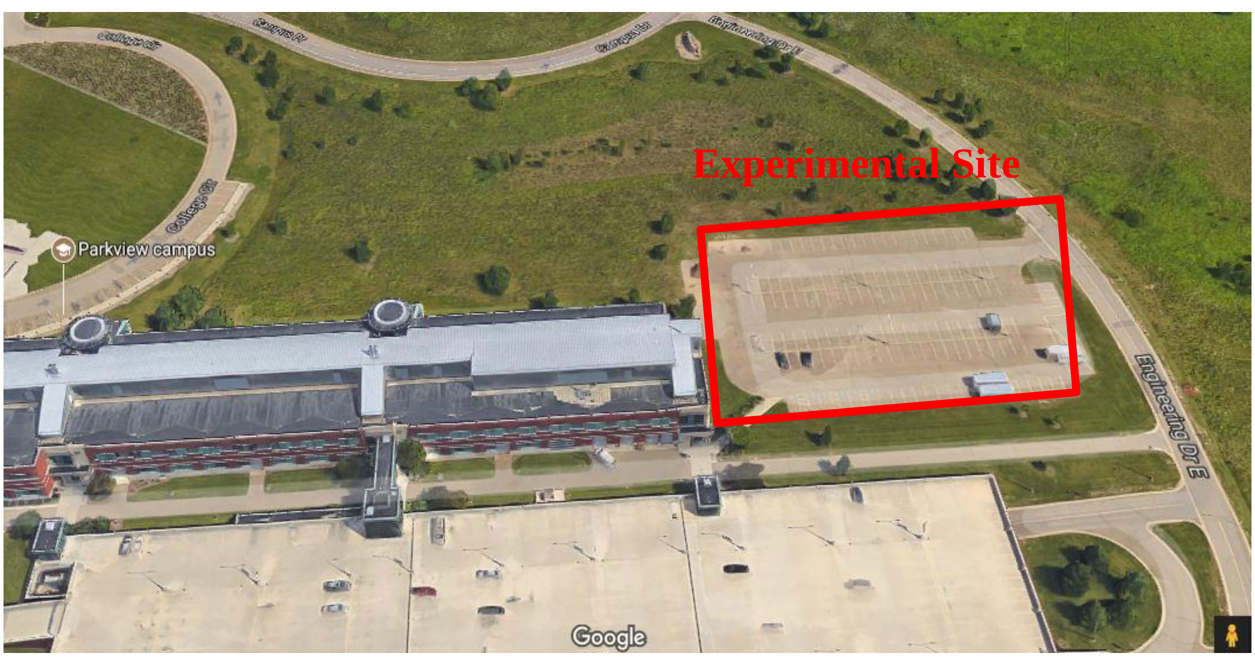

Figure (11): Experimental Site at the College of Engineering and Applied Science at WMU (Source: Google Maps)

A simulated crosswalk was constructed on the parking lot pavement surface. The simulated crosswalk represents a typical 7 lanes (12 feet wide lanes) roadway with a total length of 84 feet and a typical width of 10 feet (MUTCD, 2003) to simulate a wide crosswalk. As discussed before, the crosswalk boundaries, locations of speakers used to simulate traffic noise, APS beaconing speaker, and locations of the tag deployment (1 feet vertical distance and 2.5 feet horizontal distance) were indicated using durable white colored duct tape. Orange colored duct tape was also used to mark data measurement points which were 6 feet vertically apart up to 84 feet (crosswalk length) and 1 feet horizontally apart up to 5 feet both to the right and to the left of the centerline (crosswalk width). Figure (12) demonstrates a diagram of the simulated crosswalk with distances and Figure (13) demonstrates the actually simulated crosswalk constructed.

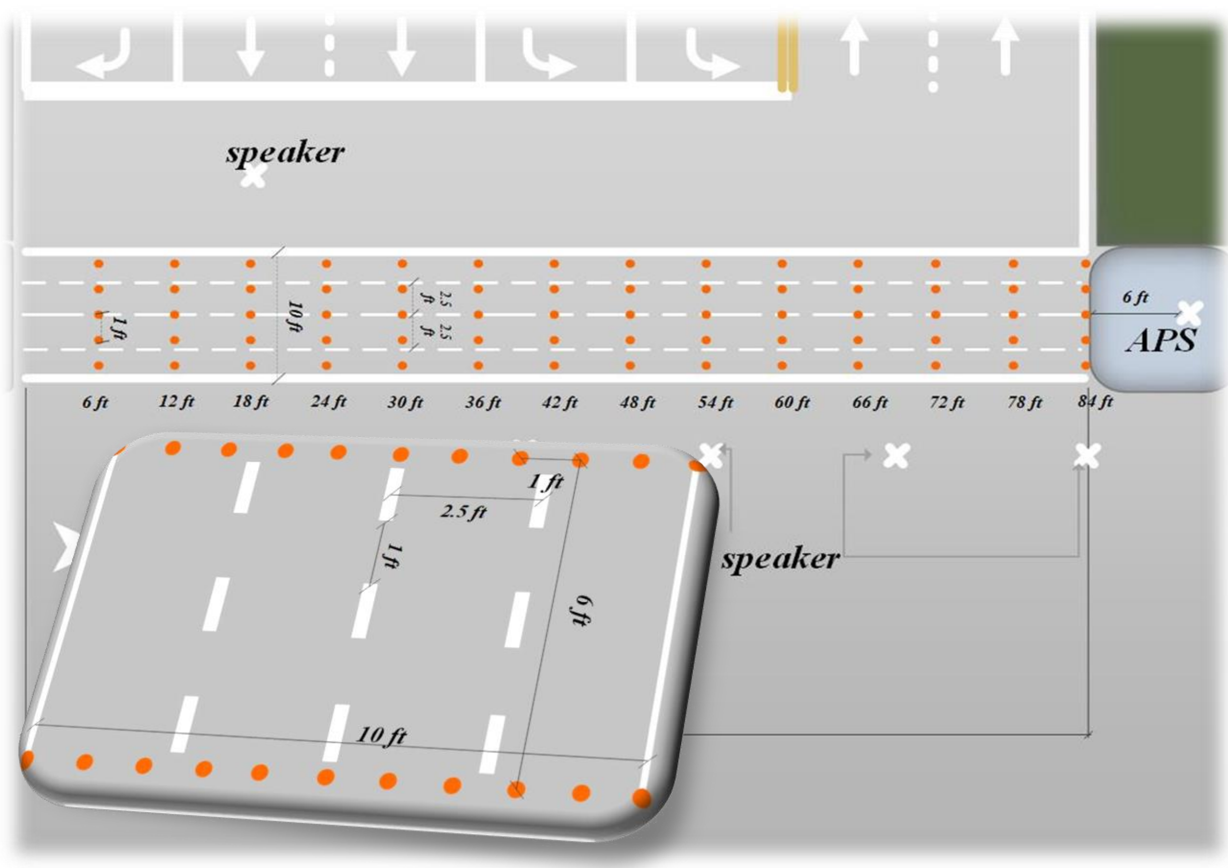

Figure (12): Simulated Crosswalk Diagram

Figure (13): Actual Simulated Crosswalk

To make the experimental apparatus look as realistic as possible, traffic noise was simulated using speakers. The traffic noise was emitted through 5 loudspeakers deployed on the crosswalk in a way that they provide similar traffic noise to an actual intersection and were directed towards the starting center point as seen in Figure (14). The speakers were also placed on chairs of about 2 feet height which would mimic vehicles engine height from the ground. The traffic noise audio recording was downloaded from YouTube and was chosen amongst several other recordings to represent the most realistic traffic noise. The traffic noise level was measured using RadioShack digital sound level meter in Figure (15) and after calibration, it was between 65 dBA and 70 dBA throughout the entire recording. For calibration purposes, a higher quality sound level meter (Larson-Davis) calibration curve was used to provide more accurate values. The noise level was measured from the centerline of the crosswalk at various points on the crosswalk to ensure consistency. The noise level was chosen based on a study conducted on different sites in Kalamazoo, Michigan (Kim, Emerson, Naghshineh, & Myers, 2014). The range considered was for 2 busy signalized intersections in the study (Kilgore & Westnedge, and Michigan & Rose). The speakers used for the experimentation purpose were Anker SoundCore Bluetooth speakers as shown in Figure (15)

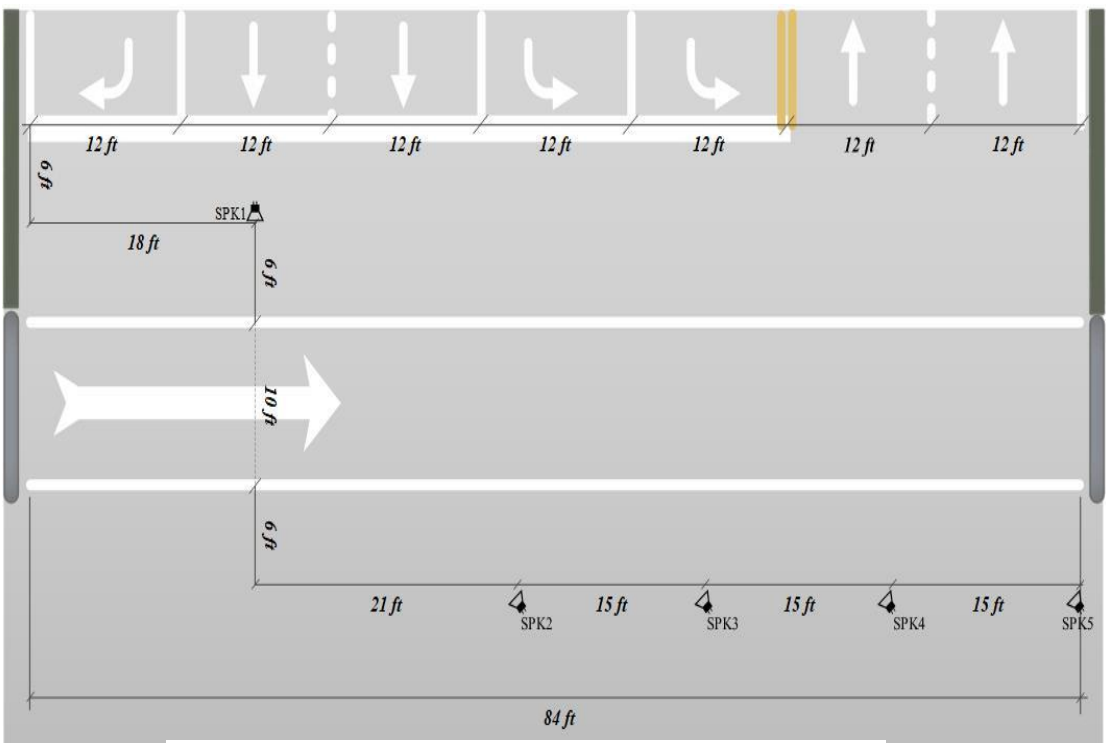

Figure (14): Speakers Deployment

Figure (15): RadioShack Sound Level Meter (left) and Anker SoundCore Bluetooth Speaker (right)

The Accessible Pedestrian Signal (APS) beacon speaker used was of a beeping type and was mounted on a tripod as seen in Figure (16). The beacon was actuated by an on-off button attached to the tripod. The research team connected the system to an electric converter to provide the speaker with the appropriate voltage and electric current, the APS speaker was mounted at a typical height of 8 feet above ground level and was positioned about 2.5 feet from the center and 6 feet from the end of the crosswalk as in Figure (16). The audible beaconing was compliant with the MUTCD requirements for APS and sounded at 1 Hz and a frequency of 880 Hz. The sound level of the beacon was at a theoretical value of 82 dBA at 1 m distance.

Figure (16): APS Beacon Speaker (left) and Position (right)

The general experimental design for both the first stage (sighted pedestrians) and second stage (BVI pedestrians) consisted of 3 practice crossings and 3 scenarios: A, B and C. Data that was collected throughout the scenarios include distance from the center line, where those distances (readings) were taken every 6 feet from the starting line, and there was a total of 15 readings such that measurements taken to the right of the centerline were given a positive (+ve) sign and measurements to the left were assigned a negative (-ve) sign. The second set of data examined whether the pedestrian veers outside the crosswalk boundaries. The third set examined whether pedestrian completes crossing inside or outside the crosswalk and time taken to complete each trial.

People with visual perception tend to store a map of the surrounding area in their brains and might use that as guidance when crossing blindfolded; furthermore, this might be helpful for sighted pedestrians as it could be a baseline for their alignment and keen on it when crossing. Consequently, before initiating the actual trials of the first stage, sighted participants were diverted away from the starting point and guided to the starting line with the help of a researcher while being blindfolded. At the starting line, the researcher aligned the participants and located them at the centerline with their faces directed towards the end of the crosswalk.

Prior to the experimentation, the sighted participants were given a training session on the techniques taught by Orientation & Mobility (O&M) instructors to the BVI pedestrians on the methods of using the cane (i.e. double tap technique). Participants were blindfolded and underwent 3 practice crossings after the training session to get familiar and be comfortable with applying the double tap technique.

There were 3 scenarios that included one trial per scenario where data were collected for the first stage of experimentation. Scenario A was the base scenario where the participants attempted to cross the crosswalk blindfolded with nothing provided as a cue except for the cane. The researcher was following the participants to collect data. For scenario B, the participants were asked to attempt crossing with the presence of simulated traffic noise emitted from speakers as well as a beeping sound emitted from the APS beaconing speaker. In scenario C, the participants attempted to cross with the aid of the Smart-Cane and the presence of the same simulated traffic noise that was present in scenario B. The purpose of this design is to study the effect that the Smart-Cane has and improvements over currently installed treatments as the APS installed at intersections.

For the second stage of experimentation with the BVI pedestrians, the experimental design was slightly altered. The participants also underwent 3 scenarios: A, B, and C. Each scenario of this stage consisted of 3 practice crossings prior to experimentation and 3 trial crossings where data were collected, indicating that each participant went through a total of 9 crossing attempts. It was decided to conduct a total of 3 trials per scenario to minimize the occurrence of chance performance that results from human behavior and to minimize the error associated with only undergoing one trial per scenario. Whereas scenario A was altered to have the same simulated traffic noise presented in scenario B and C, scenario B and C were kept the same without making any changes to their designs. Scenario A was changed at this stage of experimentation to provide consistency in traffic noise throughout the entire experimental procedure.

A table was positioned 3 feet before the simulated crosswalks' starting line, and the long edge of the table was aligned parallel to the starting line and the center of the table was marked by a grove in the table which was positioned with the crosswalk centerline. The method that BVI utilized to align their bodies perpendicular to using a physical cue was known to be the most effective method of establishing a nonvisual walking trajectory (Scott A. , et al., 2011). BVI participants' first task was to use the long edge to align correctly and use the grove to center themselves on the crosswalk. When the participants felt comfortable and were ready to start crossing, they were given permission to start crossing, and they attempted to maintain a straight heading throughout the 84 feet (typical 7 lane roadway).

Throughout the experiments, the sighted and BVI participants were stopped if they veer more than 5 feet from the centerline to avoid collision with speakers and were also stopped if they completed crossing successfully. The scenarios were counterbalanced to minimize bias as well. The crossing direction was the same for all trials. Participants were asked to walk normally without providing any timing constraints.

Data Analysis

The participants' distance and direction from the intended path (centerline) that were taken into consideration for the analysis section of this research were at 24 feet, 48 feet, 72 feet and 84 feet (crosswalk end). These distances represent typical widths of two, four, five, six and seven traffic lanes.

An issue that was faced when conducting the data analysis is that not all participants finished crossing the crosswalk completely since participants were stopped when they veered outside of the crosswalk boundaries to prevent collision with the deployed speakers. This was most common for scenario A and at the second level for scenario B, whereas in scenario C, all the participants completed the crosswalk successfully. To tackle this limitation, readings that were missing were filled based on the last value presented for each participant, in particular; those missing values were either filled with +5 or -5, depending on the participants' last position relative to the centerline. This method was used throughout the results except for absolute deviation calculations, and this is because this method will largely increase the value of the results making it unrealistic at all and does not reflect true pedestrian performances. This approach was chosen among several other approaches because it was the most logical and feasible approach that fits our data.

There are several approaches used to treat missing data, and the 3 main methods used are removing the missing data method, mean imputation method, and last value carried forward method. The most appropriate method used for our missing data was the last value carried forward method which was considered a conservative approach (underestimates the true treatment effect). In our case, however, it was considered to be an anti-conservative approach, since all the missing values took either the value of +5 or -5, which was the last reading of the participant. Moreover, this value would increase due to the veering tendency of participants if they were given the chance to proceed with walking; therefore, missing values took the minimum value of veering after that point. The standard deviation is minimized for this approach, which is considered a limitation, but since all participants completed crossing for scenario C, the effect was noticed for data collected for scenario A and scenario B, and it was found that participants performed best in scenario C (Gelman & Hill, 2006).

Due to lack of trials conducted in the first stage of experimentation (sighted pedestrians), the maximum deviation to the left and to the right, absolute deviation of participants and percent completion of the crosswalk throughout the three scenarios were the main descriptive statistics used.

Upon handling the issue of missing data, descriptive statistics were considered for the second stage of experimentation. There are three main descriptive statistics that are widely used to best measure and quantify the veering tendency of the BVI pedestrians. Absolute, constant and variable error are the main descriptive statistics used by most researchers (Guth, 1990).

Absolute error, the average absolute deviation of responses from a target (Schmidt, 1988), cannot alone describe what improvements should be considered in the performance due to the fact that it does not take into consideration the direction of each response from the target (centerline), indicating that it is an unsigned error. Furthermore, absolute error is the basic measure of the overall accuracy of performance, and it is used to estimates the probability in which an individual can respond within a fixed distance around a target. To overcome the limitation of absolute error and to best describe the true, correct and accurate error as it really appears, it should be combined with the constant and variable error (Guth, 1990).

A constant error is calculated as the means of a set of signed error scores which results from the directional bias of responses. The constant error calculations should yield an estimate of the spatial center of distribution under the assumption of normal distribution of errors. A variable error results from within-subject variability, and it estimates the variability around the center. Basically, the variable error is the standard deviation.

For the calculation of variable and constant errors, collected data should be signed to indicate the direction of error, where the positive (+) sign indicates veering to the right, and the negative (-) sign indicates veering to the left (Guth & LaDuke, 1994).

Upon completion of the descriptive statistics, a single-factor ANOVA (one-way ANOVA) statistical analysis of variance test was conducted to test the statistical significance of the improvements caused by the Smart-Cane and answer the research question of the second stage of experimentation. The significant level used was 0.1 with a confidence level of 90%. Corresponding to each factor level, there is a probability distribution of responses. To check the presence of overall directional bias (constant error) in each scenario, a one-sample t-test was conducted for each. All statistical analysis was conducted using SAS version 9.4.

The one-way ANOVA was chosen to make a comparison of 3 different scenarios, where the conclusions pertain to just those factor levels included in a study. The assumptions of the ANOVA model are:

1. Each probability distribution is normal.
2. Each probability distribution has the same variance.
3. The response of each factor level are random selections from the corresponding probability distribution and are independent of the responses for any other factor level.

The null hypothesis of the one-way ANOVA states that there is no difference between the means of the scenarios (all means are equal), that is $H_o: \mu_1 = \cdots = \mu_k$. The alternative hypothesis (H_a) states that there is at least one mean of a scenario that is different from the others. If the significance value (P-value) is less than 0.1 then we reject the null hypothesis and accept the alternative hypothesis.

For analysis of variance (one-way ANOVA) model that we used, the last subscript was used to represent the scenario (A, B and C) used for the given factor level (24, 48, 72 and 84 ft). Y_{ij} denotes the value of the response variable in the *i*th scenario for the *j*th factor level. The ANOVA model can be stated as follows:

$$Y_{ij} = \mu_i + \varepsilon_{ij}$$

Where:

$\boldsymbol{Y_{ij}}$: $the\ value\ of\ response\ variable\ in\ the\ ith\ scenario\ of\ jth\ factor\ level$

$\boldsymbol{\mu_i}$: $is\ a\ parameter$

$\boldsymbol{\varepsilon_{ij}}$: $Random\ error\ term$

$\boldsymbol{i}$: $A\ or\ B\ or\ C$; $\boldsymbol{j}$: $24, 48, 72, 84\ ft$

After completion of the ANOVA test, where the model was significant, Tukey multiple comparison (Tukey test) procedures were used. Tukey test was used to find means that are significantly different from each other and it compares all possible pairs of means. Tukey's test compares the means of every treatment to the means of every other treatment; that is, it applies simultaneously to the set of all pairwise comparisons. Tukey's test can be applied when all the sample size throughout the treatments are the same (i.e. our case).

Tukey's test, which leads to a narrower confidence interval, was chosen to compare all pairwise comparisons. The hypothesis of this test takes the form of:

$$H_o: \mu_i - \mu_{i'} = 0$$

$$H_a: \mu_i - \mu_{i'} \neq 0$$

Where:

$\boldsymbol{\mu_i}$: $the\ mean\ of\ a\ scenario$

$\boldsymbol{\mu_{i'}}$: $the\ mean\ of\ the\ other\ scenario$

CHAPTER V

RESULTS AND DISCUSSION

The first part of this chapter reports the results and discussion for the first stage of experimentation, whereas the second part reports the results and discussion of the second stage of experimentation.

1st Stage Results

Figure (17) demonstrates a sample of pedestrian walking trajectory over the 3 scenarios. The straight solid gray lines are the tag deployment boundaries, and the straight solid red lines are the crosswalk boundaries, the 'X' at the end of the trajectory means that the participant veered outside of the crosswalk boundaries.

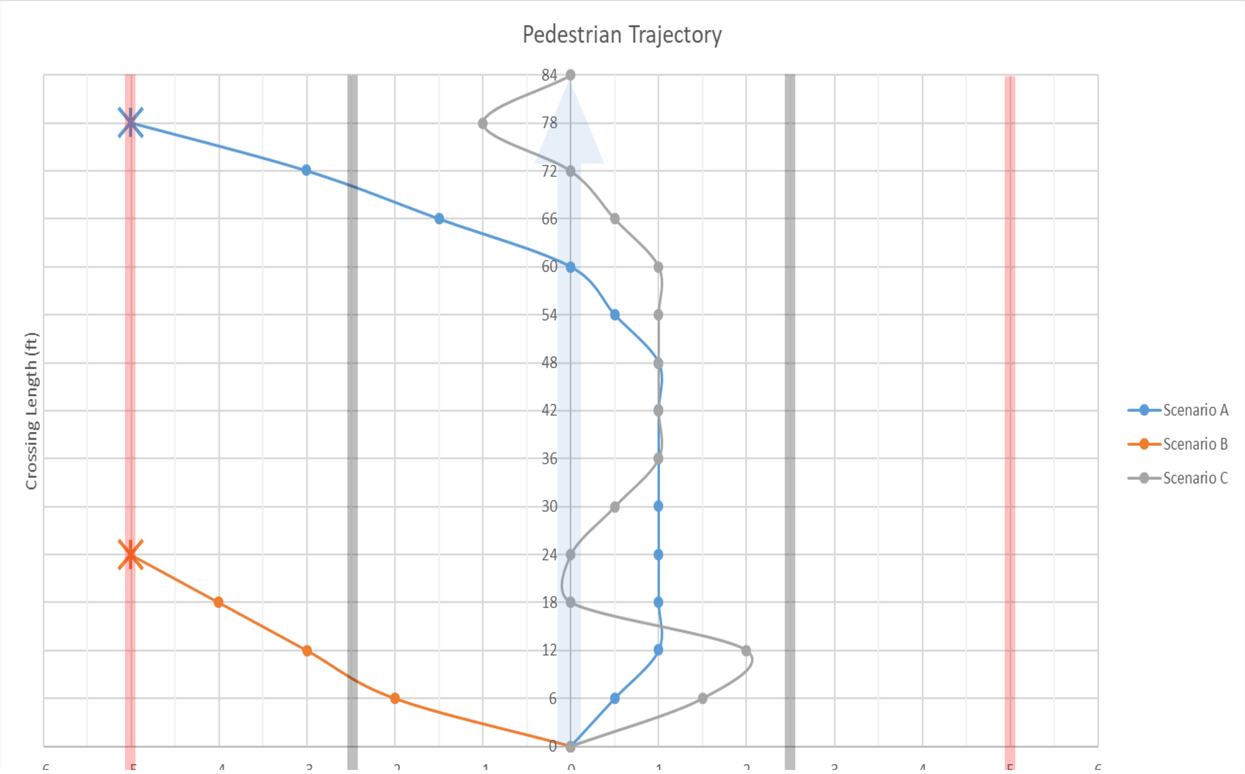

Figure (17): Sample Pedestrian Walking Trajectory

We can see from the sample trajectory above that the difference between pedestrians' performance over the 3 scenarios is very clear, where the performance was best using the Smart-Cane (trajectory closest to the centerline). Scenario B was the worst, and this was due to the fact that participants stated that the APS beaconing caused confusion where they were not able to perceive their location anymore.

The descriptive statistics that best fit the data was the maximum deviation to the right of centerline, maximum deviation to the left of the centerline, absolute deviation over the total length of the crosswalk and the average percent completion of the crosswalk.

The results of the absolute deviation over the total crosswalk length and maximum deviation to right and left can be seen in Table 1. An analysis for the percent completion of the crosswalk throughout the scenarios is illustrated in Table 2.

Table 1: 1st Stage absolute deviation, maximum to the right and left

SC	N Obs	Variable	N	Mean	Std Dev	Minimum	Maximum
A	**32**	**ABS_DEV**	32	171.009	120.801	23.154	479.500
		MAX_R	32	2.625	2.419	00.000	5.000
		MAX_L	32	2.781	2.433	5.000	00.00
B	**32**	**ABS_DEV**	32	99.422	75.314	12.000	308.000
		MAX_R	32	2.516	2.340	00.000	5.000
		MAX_L	32	2.500	2.279	5.000	00.000
C	**32**	**ABS_DEV**	32	13.313	5.796	3.000	26.000
		MAX_R	32	1.766	0.718	00.000	2.500
		MAX_L	32	1.797	0.761	2.500	00.000

The mean absolute deviation over the entire length of the crosswalk was 13.313 feet for scenario C with a standard deviation of 5.796 feet. Scenario A proved to have the worst performance in terms of absolute deviation, the value was 171 feet and the standard deviation was very large (120 feet). The absolute deviation value improved for scenario B (99 feet) with a standard deviation of 75 feet. It is evident that scenario C is the best in terms of minimizing the absolute deviation; furthermore, there is a large decrease in absolute deviations between scenario B and C. There is a big difference between the maximum value of the absolute deviation between scenarios A, B and scenario C.

In terms of the maximum deviation to the left and to the right, the maximum deviation for scenario C was 2.5 feet, whereas the maximum deviation was 5 feet for both scenarios A and B. Taking into consideration the mean and standard deviations of the maximum deviation (right or left), we can also see that it has improved over the 3 scenarios from A to C respectively.

Table 2: Percent completion

Analysis Variable: % COMP						
SC	**N Obs**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
A	**32**	32	45.536	24.992	14.286	92.858
B	**32**	32	67.411	28.336	21.429	100.000
C	**32**	32	100.000	00.000	100.000	100.000

The participants completed about 45.5% of the crosswalk on average in scenario A, whereas, in scenario B, participants finished 67.4% of the crosswalk on average. In scenario C, they completed crossing the entire crosswalk successfully (100%).

2nd Stage Results

Figure (18) demonstrates a sample of the BVI pedestrian walking trajectory averaged over the 3 scenarios. The straight solid gray lines are the tag deployment boundaries, and the straight solid red lines are the crosswalk boundaries, the 'X' at the end of the trajectory means that the participant veered outside of the crosswalk boundaries.

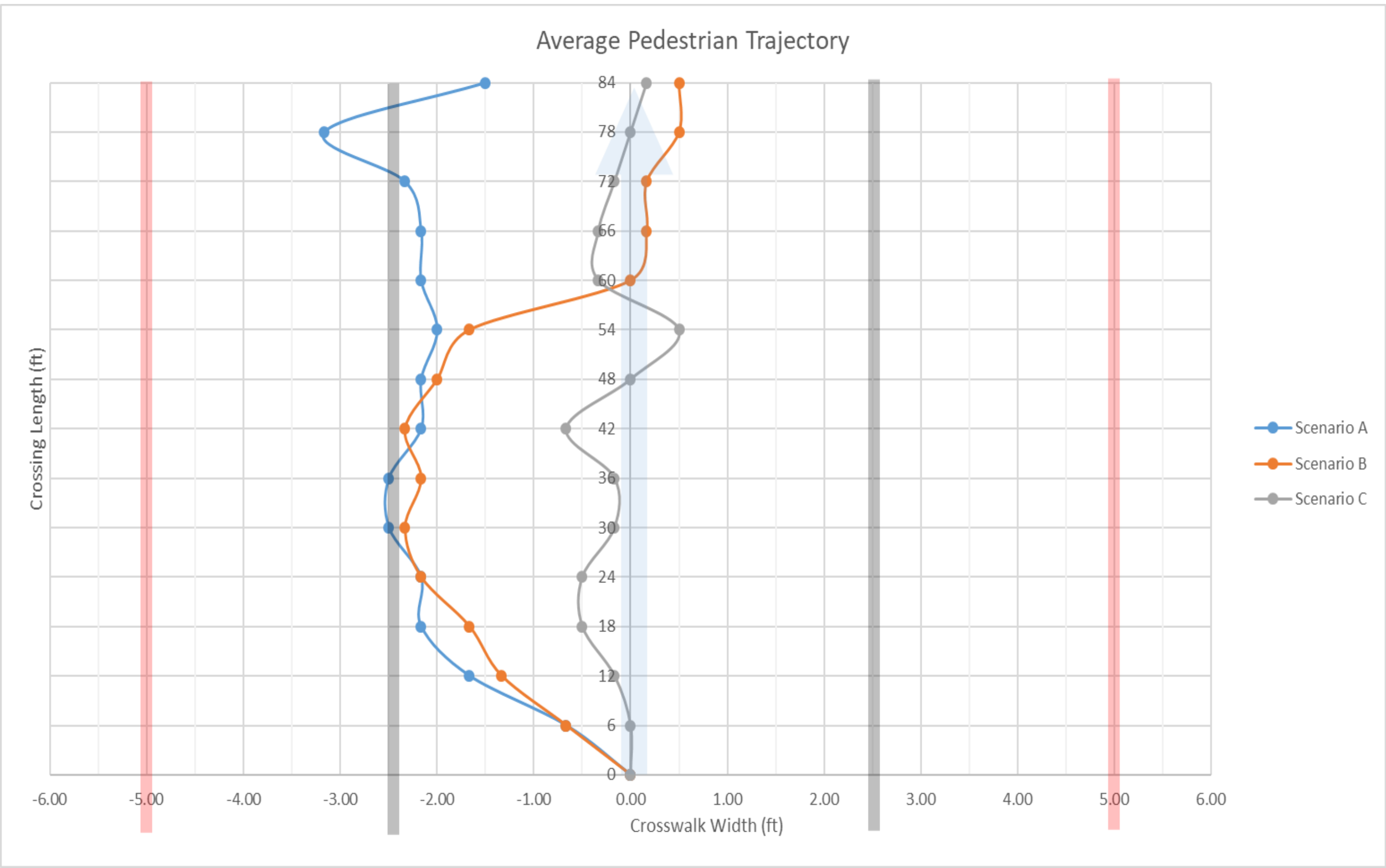

Figure (18): Average Pedestrian Trajectory

Each trajectory in the previous figure is averaged out for the 3 trials performed by the participant. It is clear again that the best performance was that of those in scenario C. Scenario B ranked the second.

As a comparison between scenario A, B and C in terms of the walking trajectories for all 10 participants, Figure (19) through Figure (20) illustrate the difference in performance of all participants throughout the three scenarios.

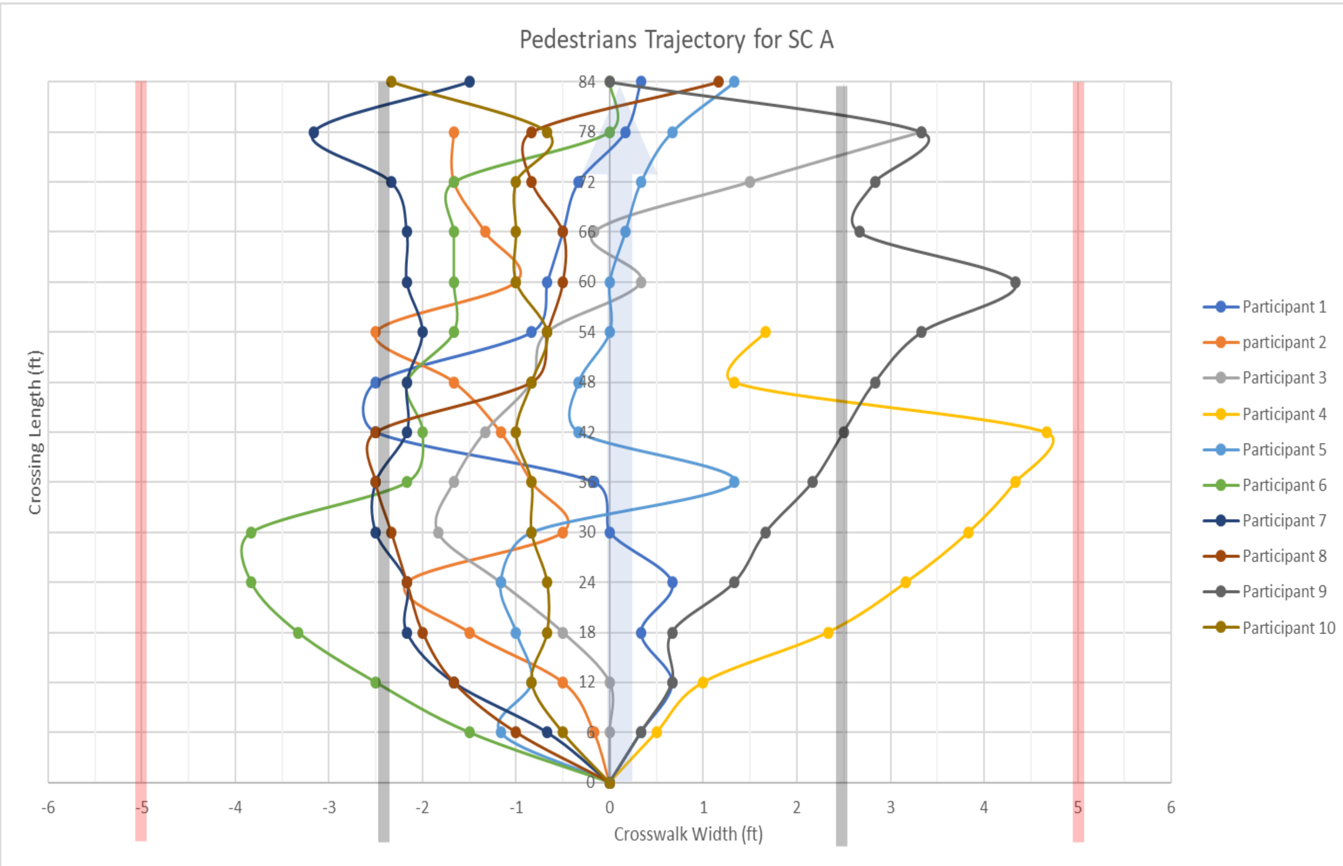

Figure (19): Pedestrian Trajectories for Scenario A

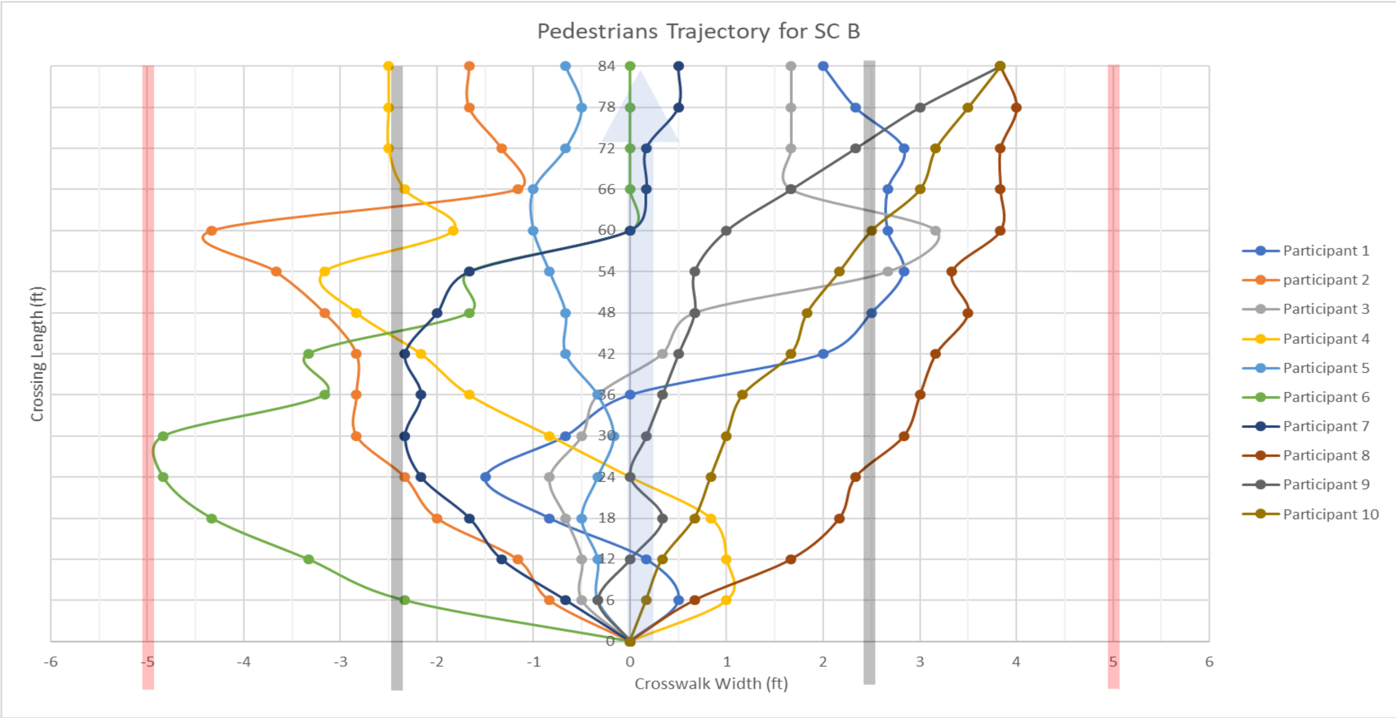

Figure (21): Pedestrian Trajectories for Scenario B

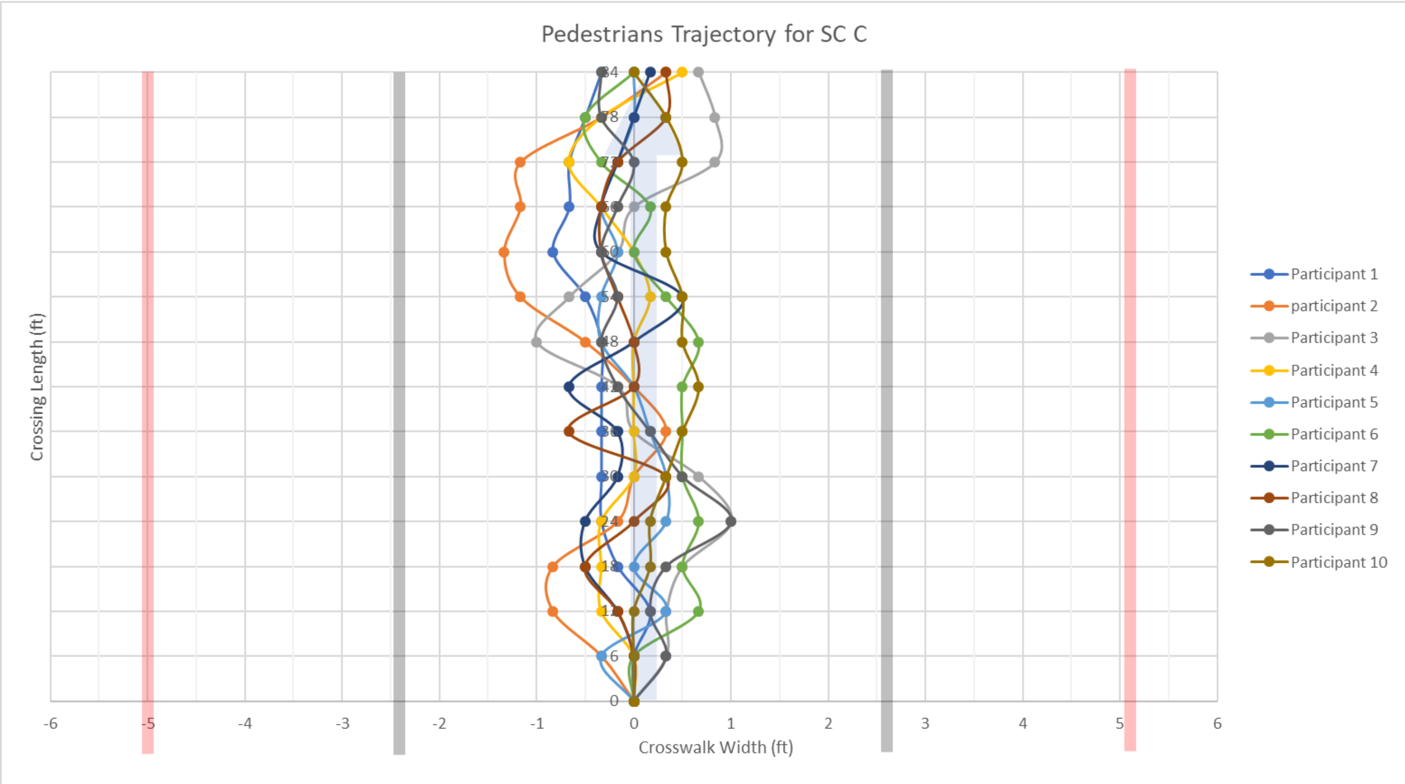

Figure (20): Pedestrian Trajectories for Scenario C

The 2nd stage results are divided into 8 parts: the pre-survey, the absolute deviation, the absolute error, variable error, constant error, average percent crosswalk completion, average pedestrian speed and post-survey. In the errors part of this section, descriptive statistics of each type of error was used. For the surveys part, tables showing percentages of responses to questions asked in the surveys were provided.

Pre-survey

The pre-survey was conducted to get the BVI participants' feedback on the difficulties they faced at intersections with and without APS, whether they experienced APS before and rely on it, and whether they think it provides guidance to them. The first part of the pre-survey points out difficulties that BVI pedestrians faced with and without the presence of APS. This part was given scoring values that ranged from 1 to 5, where 1 was given to those who never faced difficulties, 2 to those who rarely faced difficulties, 3 to those who sometimes faced difficulties, 4 to those who very often faced difficulties and 5 to those who always faced difficulties. The second section of the pre-survey studied the importance of intersection information for the BVI and importance of alerting drivers at intersections. The third part of this survey asked participants for their feedback on how helpful crossing the intersections was with the presence of APS. Table 3 summarizes the results obtained from BVI participants for the first part of the survey. Participants who answered either “very often” or “always” were combined under one column (>very often), and who replied with a “sometimes” were in the same column and finally those who answered with a “never” or “rarely” were combined under one column (<rarely).

Table 3: Part one of the pre-survey

	>Very often (%)	Sometimes (%)	<Rarely (%)	Score (out of 5)
Difficulties at intersections (without APS)				
Not knowing direction of crossing	10	40	50	2.6
Maintaining heading	10	50	40	2.5
Veering outside crosswalk	20	30	50	2.5
Ending outside crosswalk	30	10	60	2.4
Insufficient information	10	50	40	2.4
Insufficient time	50	30	20	3.4
APS				
Have you encountered APS	40	60	0	3.4
Do you rely on APS	10	20	70	2.3
Does beeping provide guidance	10	50	40	2.7
Difficulties at intersections (with APS)				
Not knowing direction of crossing	0	50	50	2.1
Maintaining heading	20	40	40	2.4
Veering outside crosswalk	10	30	60	2.1
Ending outside crosswalk	20	30	50	2.3
Insufficient information	20	30	50	2.4
Insufficient time	50	20	30	3.2

When crossing an intersection, not equipped with APS, on average 21.6%, 35%, and 43.4% of BVI participants indicated that they always or very often had difficulties, they sometimes had difficulties, and they rarely or never had a difficulty respectively. The average total score for pedestrians who face difficulties at intersections not equipped with APS was 2.64. All participants stated experiencing crossing with the presence of an APS throughout their lifetime with a score value of 3.4. 10% of participants stated that they very often or always relied on APS when crossing intersections, another 20% reported that they sometimes relied on APS while crossing, and 70% stated that they either rarely or never relied on APS while crossing, which had a score of 2.3. 10% of participants think that the beeping sound from the APS very often or always provided guidance, while 50% stated that it sometimes provided guidance, whereas, 40% stated that it rarely or never provided guidance, the score for this question was 2.7. When crossing an intersection equipped with an APS, 20% of participants indicated facing difficulties very often or always, 33.4% indicated facing difficulties sometimes, and 46.6% indicated rarely or never facing difficulties. The average total score for pedestrians who face difficulties at intersections equipped with APS was 2.42. When comparing difficulties faced (without APS) with difficulties faced (with APS), we found that the percentages, as well as the scores, are very close to each other, indicating that the difficulties existed even when APS was installed at intersections (2.64 without APS compared to 2.42 with APS).

For the second part of the survey, participants who replied with important or very important were combined under one column (>important), and those who stated that it was moderately important were under the same column and finally those who replied with slightly important or not important were combined under the same column (<slightly important). 90% of participants indicated that the various intersection information required for the crossing was either important or very important, 5% indicated it was moderately important, and 5% indicated that the intersection information was either slightly or not important. 90% of the participants felt that it is important or very important for drivers approaching or idling at the intersection to be informed of their presence, while the remaining 10% stated that it is moderately important.

Table **4** shows the results obtained from the second part of the survey. Intersection information is not always available at intersections, and most participants confirmed the importance of this information. The Smart-Cane provides the BVI pedestrians with the information they need to complete crossing safely.

Table 4: Part two of the pre-survey

	>Important (%)	**Moderately Important (%)**	**<Slightly important (%)**
Intersection information required to cross			
Name	100	0	0
Type	90	10	0
Geometry	70	10	20
# of lanes	90	0	10
Direction of crossing	90	10	0
Median island presence	100	0	0
Drivers alerted of BVI presence	90	10	0

Although 60% of the participants declared that it was either helpful or very helpful to cross intersections equipped with the APS, 40% of them declared that it was slightly or not helpful at all.

Absolute Deviation

For this part of the results, we calculated the absolute deviation from the centerline and was averaged over the entire crosswalk length (84 feet), we should note here that the last value carried forward method was not used for this part of the results because by replacing the missing values with the last recorded value, the absolute deviation would increase dramatically and will make the results unrealistic. Furthermore, the maximum deviation to the left and right were also calculated. The results of the absolute deviation are shown in Table 5.

Table 5: 2nd stage absolute deviation, maximum to the right and left

SC	N Obs	Variable	N	Mean	Std Dev	Minimum	Maximum
A	**30**	**MAX_L**	30	2.650	2.182	5.000	00.000
		MAX_R	30	2.300	2.427	00.000	5.000
		ABS_DEV	30	36.022	12.489	15.500	62.000
B	**30**	**MAX_L**	30	2.367	2.224	5.000	00.000
		MAX_R	30	2.117	2.066	00.000	5.000
		ABS_DEV	30	36.057	14.819	12.500	69.125
C	**30**	**MAX_L**	30	1.150	0.671	2.500	00.000
		MAX_R	30	1.050	0.674	00.000	2.000
		ABS_DEV	30	7.500	3.622	1.500	16.500

The absolute deviation for scenario A had a mean of 36 feet for the entire length of the crosswalk (84 feet). Scenario B had the same value which means that in terms of the absolute deviation, there were not any improvements witnessed between scenario A and B. The maximum deviation to the left and right was 5 feet, depicting that participants veered outside the boundaries at various points. Scenario C had the best performance in terms of absolute deviation where the value of the mean absolute deviation was 7.5 feet and it decreased intensely as compared to both scenario A and B. The maximum deviation to the left was 2.5 feet (tag deployment boundary) and the maximum deviation to the right was 2 feet which means that no one veered outside the tag deployment boundaries (2.5 feet). In general, scenario C was the best scenario in terms of absolute deviation meaning that the Smart-Cane greatly helped participants cross completely and safely with the minimum absolute deviation (veering).

Absolute Error

The absolute error is defined as the average absolute deviation of responses from a target. The last value carried forward method was implemented for the missing values to obtain better results. Table 6 summarizes the absolute error results across all scenarios:

Table 6: Absolute error statistics

SC	N Obs	Variable	N	Mean	Std Dev	Minimum	Maximum
A	**10**	**ABS_24**	10	2.417	0.802	1.333	3.833
		ABS_48	10	3.283	0.813	2.167	4.667
		ABS_72	10	3.783	0.835	2.333	5.000
		ABS_84	10	4.333	0.733	3.167	5.000
B	**10**	**ABS_24**	10	2.017	1.156	0.833	4.833
		ABS_48	10	3.117	1.066	1.667	5.000
		ABS_72	10	3.650	1.263	1.333	5.000
		ABS_84	10	3.783	1.301	0.667	5.000
C	**10**	**ABS_24**	10	0.583	0.354	0.167	1.000
		ABS_48	10	0.667	0.451	00.000	1.667
		ABS_72	10	0.700	0.375	00.000	1.333
		ABS_84	10	0.367	0.322	00.000	1.000

It can be seen from the table that the mean absolute error for scenario A increased as the pedestrians crossed the crosswalk, and the value of the standard deviation was around 0.80 feet, which was low because of the missing value of the last value carried forward method that was used to fill in the missing data. The standard deviation of the absolute error is considered somewhat unrealistic.

For scenario B, the means of the absolute errors decreased over all the distance, proposing that the APS provided little guidance for the participants. As the pedestrians reached the crosswalk end, the absolute error increased which might have to do with pedestrians confusing traffic noise with the APS beeping sound. There is no trend in the standard deviation for scenario B although standard deviations were around 1 foot. Again, the standard deviations here were not realistic due to the limitation of the last value carried forward procedure. The number of missing data entries for this scenario decreased compared to scenario A because the performance was much better in that more participants finished crossing completely. The minimum absolute error was 0.666 feet at 84 feet and the maximum was 5 feet starting at the 48 feet mark.

There is no doubt that scenario C was the best in terms of mean absolute error at all distances. Furthermore, the low values of absolute deviations show that participants did not face much variability using the Smart-Cane as in the other scenarios. The minimum absolute error was 0.167 feet at 24 feet and the maximum was 1.67 feet at the 48 feet mark. The difference between the minimum and maximum values of the absolute error in this scenario substantially decreased as compared to the other scenarios.

When comparing all 3 scenarios with regard to the mean absolute deviation, it is evident that scenario C was the best of all 3. It is the same case when comparing with the standard deviations of the absolute errors and the maximum and minimum deviations.

In short, we found out that scenario C was the best scenario in terms of participants absolute error. Statistical analysis was used to prove the statistical significance of the improvement (absolute error). Each distance mark (24, 48, 72 and 84 ft) was tested separately to study the statistical significance.

24 feet mark

Table 7 demonstrates the results of the one-way ANOVA analysis for the absolute error at 24 feet.

Table 7: One-way ANOVA for absolute error at 24 feet

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	2	18.585	9.293	13.25	<.0001
Error	27	18.942	0.702		
Corrected Total	29	37.527			

R-Square	**Coeff Var**	**Root MSE**	**ABS_24 Mean**
0.495250	50.088	0.838	1.672

Source	**DF**	**Anova SS**	**Mean Square**	**F Value**	**Pr > F**
SC	2	18.585	9.293	13.25	<.0001

Since the P-value was less than 0.0001 which is also less than the cutoff point (0.1), then we reject the null hypothesis (H_o) and accept the alternative hypothesis (H_a). This means that there was at least one mean that was different. Figure (22) demonstrates the distribution of the absolute error over the 3 scenarios.

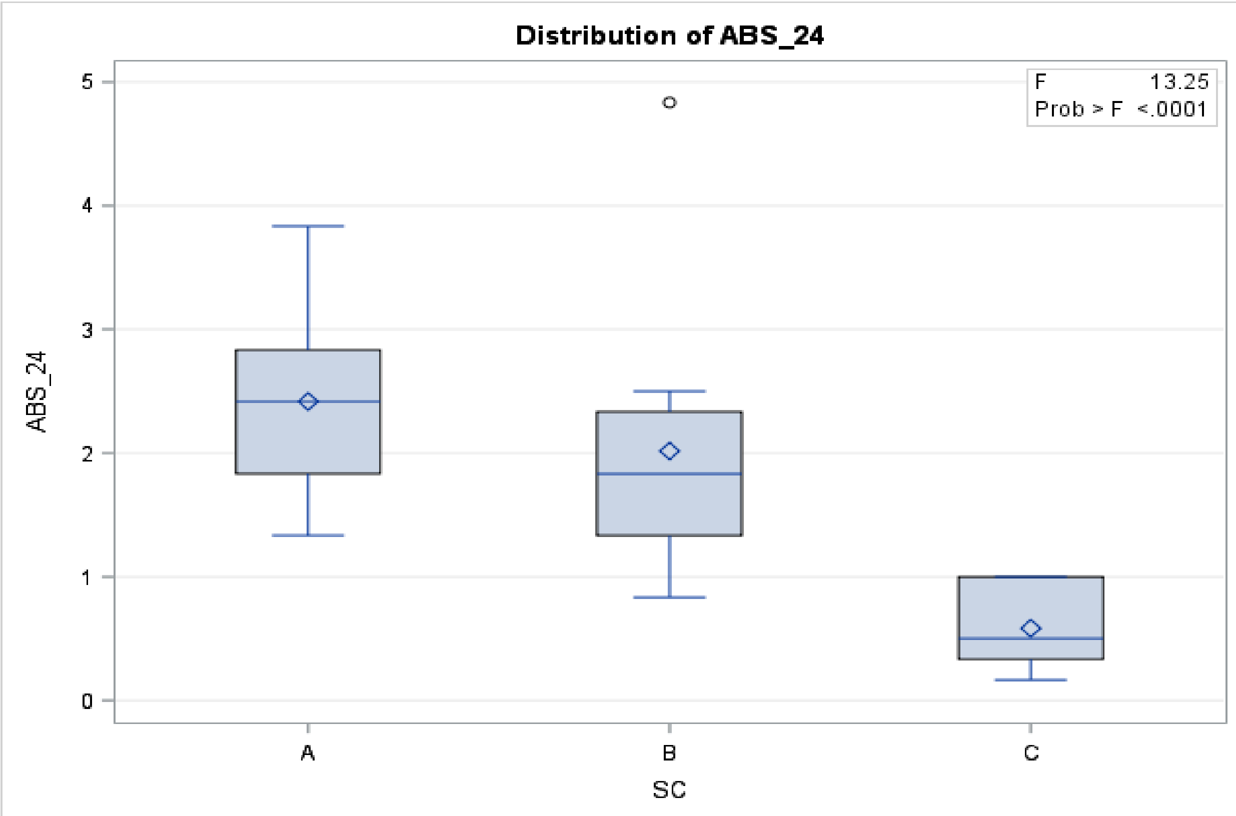

Figure (22): Absolute Error Distribution at 24 feet

Since the absolute error at 24 feet model (ANOVA model) was significant, then we can compare all scenarios in terms of absolute error using Tukey test to make all the pairwise comparisons and find which scenario was the best. Table 8 shows the results obtained from Tukey's test.

Table 8: Tukey's test for absolute error at 24 feet

Alpha	0.1
Error Degrees of Freedom	27
Error Mean Square	0.702
Critical Value of Studentized Range	3.506
Minimum Significant Difference	0.929

Table 8 -Continued

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**SC**
A	2.417	10	A
A			
A	2.017	10	B
B	0.583	10	C

Due to multiple comparisons, we used Tukey adjustment to compensate for inflation of type 1 error rate. The minimum significant difference of this adjusted procedure was 0.929. The differences A-C and B-C were greater than this value, so C was significantly smaller than either A or B. Scenario C was the best scenario with regards to the absolute error at 24 feet because the mean of absolute error for this scenario was the smallest compared to scenario A and B.

<u>*48 feet mark*</u>

Table 9 demonstrates the results of the one-way ANOVA analysis for the absolute error at 48 feet.

Table 9: One-way ANOVA for absolute error at 48 feet

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	2	42.924	21.462	32.18	<.0001
Error	27	18.006	0.667		
Corrected Total	29	60.929			

R-Square	**Coeff Var**	**Root MSE**	**ABS_48 Mean**
0.704	34.668	0.8166	2.356

Source	**DF**	**Anova SS**	**Mean Square**	**F Value**	**Pr > F**
SC	2	42.924	21.462	32.18	<.0001

Since the P-value was less than 0.0001 which was also less than the cutoff point (0.1), then we reject the null hypothesis (H_o) and accept the alternative hypothesis (H_a). This means that there is at least one mean that was different. Figure (23) demonstrates the distribution of the absolute error over the 3 scenarios.

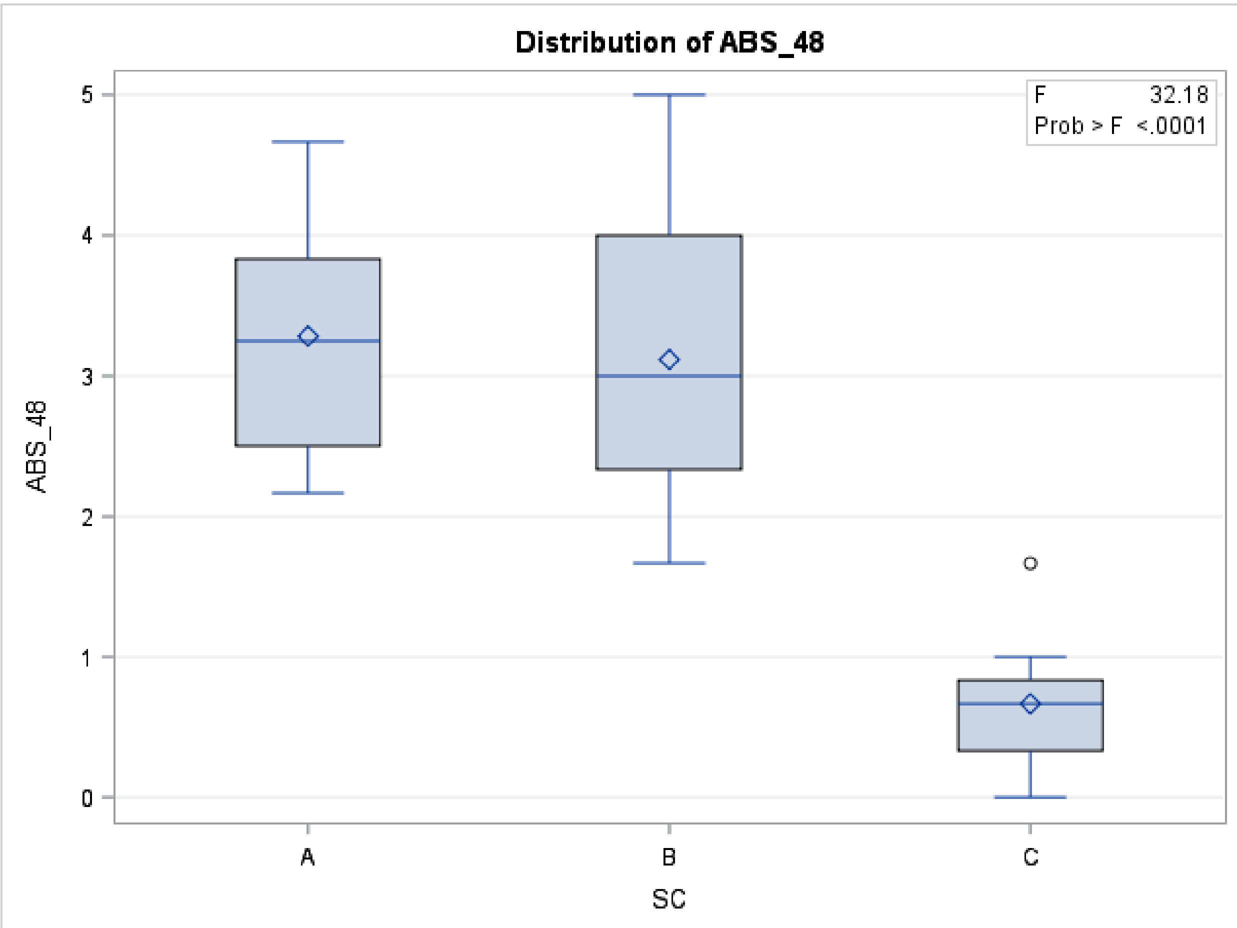

Figure (23): Absolute Error Distribution at 48 feet

Since the absolute error at 48 feet model (ANOVA model) was significant, then we can compare all the scenarios in terms of absolute error using the Tukey test to make all the pairwise comparisons and find which scenario was the best. Table 10 shows the results obtained from Tukey's test.

Table 10: Tukey's test for absolute error at 48 feet

Alpha	0.1
Error Degrees of Freedom	27
Error Mean Square	0.667
Critical Value of Studentized Range	3.506
Minimum Significant Difference	0.906

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**SC**
A	3.283	10	A
A			
A	3.117	10	B
B	0.667	10	C

Due to multiple comparisons, we used Tukey adjustment to compensate for the inflation of type 1 error rate. The minimum significant difference of this adjusted procedure was 0.906. The differences A-C and B-C were greater than this value, so C was significantly smaller than either A or B. Then, scenario C was the best regarding the absolute error at 48 feet because the mean of absolute error for this scenario was the smallest compared to scenario A and B.

72 feet mark

Table 11 demonstrates the results of the one-way ANOVA analysis for the absolute error at 72 feet.

Table 11: One-way ANOVA for absolute error at 72 feet

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	60.757	30.379	37.44	<.0001
Error	27	21.906	0.811		
Corrected Total	29	82.663			

R-Square	Coeff Var	Root MSE	ABS_72 Mean
0.735	33.224	0.901	2.7111

Source	DF	Anova SS	Mean Square	F Value	Pr > F
SC	2	60.757	30.379	37.44	<.0001

Since the P-value was less than 0.0001 which was also less than the cutoff point (0.1), then we reject the null hypothesis (H_o) and accept the alternative hypothesis (H_a). This means that there was at least one mean that was different. Figure (24) demonstrates the distribution of the absolute error over the 3 scenarios.

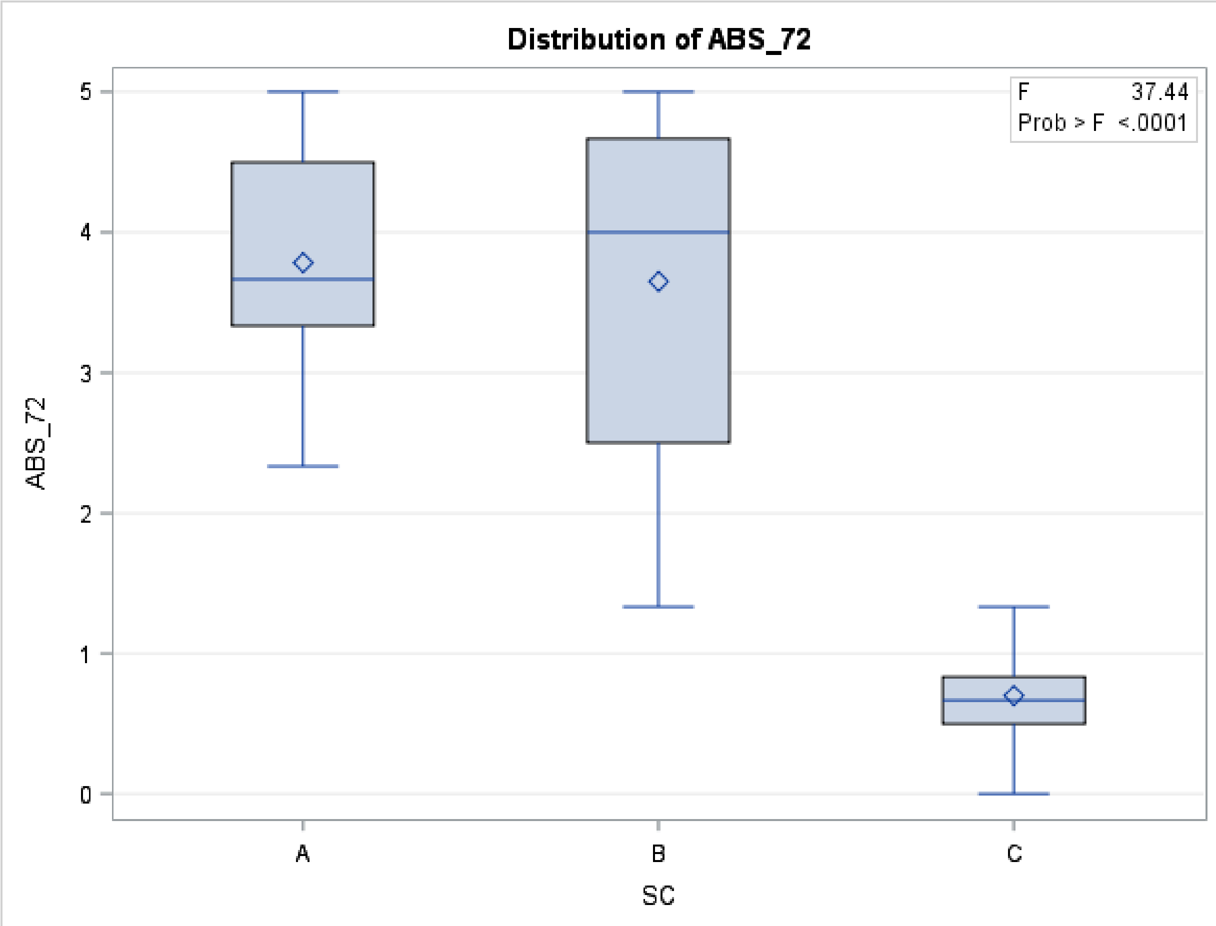

Figure (24): Absolute Error Distribution at 72 feet

Since the absolute error at 72 feet model (ANOVA model) was significant, then we can compare all scenarios in terms of absolute error using the Tukey test to make all the pairwise comparisons and find which scenario was the best. Table 12 shows the results obtained from Tukey's test.

Table 12: Tukey's test for absolute error at 72 feet

Alpha	0.1
Error Degrees of Freedom	27
Error Mean Square	0.811
Critical Value of Studentized Range	3.506
Minimum Significant Difference	0.999

Table 12 -Continued

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**SC**
A	3.783	10	A
A			
A	3.650	10	B
B	0.700	10	C

Due to multiple comparisons, we employed Tukey adjustment to compensate for the inflation of type 1 error rate. The minimum significant difference of this adjusted procedure was 0.9987. The differences A-C and B-C were greater than this value, so C was significantly smaller than either A or B. So, scenario C was the best in terms of the absolute error at 72 feet because the mean of absolute error for this scenario was the smallest compared to scenario A and B.

84 feet mark

Table 13 demonstrates the results of the one-way ANOVA analysis for the absolute error at 84 feet.

Table 13: One-way ANOVA for absolute error at 84 feet

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	2	92.369	46.184	59.40	<.0001
Error	27	20.992	0.777		
Corrected Total	29	113.360			

R-Square	**Coeff Var**	**Root MSE**	**ABS_84 Mean**
0.815	31.181	0.882	2.828

Source	**DF**	**Anova SS**	**Mean Square**	**F Value**	**Pr > F**
SC	2	92.369	46.184	59.40	<.0001

Since the P-value was less than 0.0001 which was also less than the cutoff point (0.1), then we reject the null hypothesis (H_o) and accept the alternative hypothesis (H_a). This means that there was at least one mean that was different. Figure (25) demonstrates the distribution of the absolute error over the 3 scenarios.

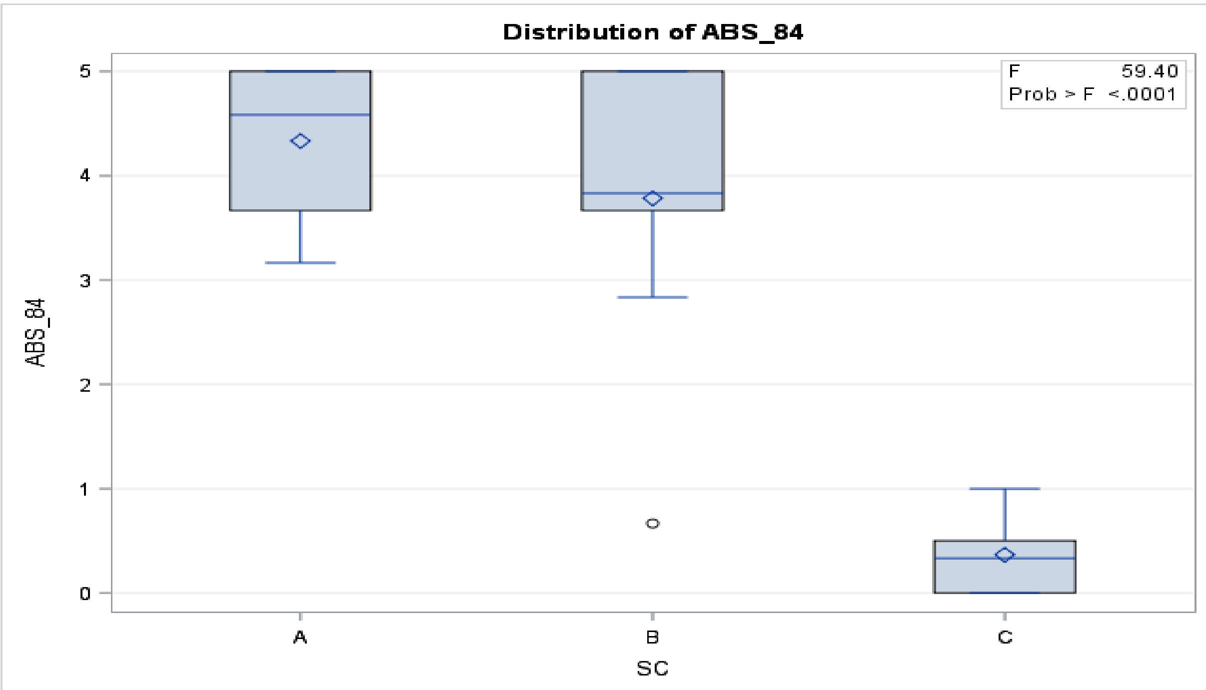

Figure (25): Absolute Error Distribution at 84 feet

Since the absolute error at 84 feet model (ANOVA model) was significant, then we can compare all scenarios in terms of absolute error using the Tukey test to make all the pairwise comparisons and find which scenario was the best.

Table 14 shows the results obtained from Tukey's test.

Table 14: Tukey's test for absolute error at 84 feet

Alpha	0.1
Error Degrees of Freedom	27
Error Mean Square	0.777
Critical Value of Studentized Range	3.506
Minimum Significant Difference	0.977

Table 14 -Continued

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**SC**
A	4.333	10	A
A			
A	3.783	10	B
B	0.367	10	C

Due to multiple comparisons, we implemented Tukey adjustment to compensate for inflation of type 1 error rate. The minimum significant difference of this adjusted procedure was 0.977. The differences A-C and B-C were greater than this value, so C was significantly smaller than either A or B. So, scenario C was the best concerning the absolute error at 84 feet because the mean of absolute error for this scenario was the smallest compared to scenario A and B.

It is evident from the results that the best scenario was C as far as the absolute error is concerned, meaning that the Smart-Cane had substantially improved the crossing performance of the BVI pedestrians.

Variable error

The variable error results from with-in subject variability and estimates the variability around the center. Basically, it is the standard deviation. Table 15 summarizes the variable error results across all scenarios:

Table 15: Variable error statistics

SC	N Obs	Variable	N	Mean	Std Dev	Minimum	Maximum
A	**10**	**VAR_24**	10	1.819	1.247	0.289	3.786
		VAR_48	10	2.488	1.856	0.289	5.204
		VAR_72	10	2.422	2.007	00.000	5.033
		VAR_84	10	2.488	2.429	00.000	5.508
B	**10**	**VAR_24**	10	1.189	1.064	0.289	3.617
		VAR_48	10	2.228	1.794	00.000	5.107
		VAR_72	10	2.159	2.002	00.000	5.774
		VAR_84	10	1.988	2.011	00.000	5.774
C	**10**	**VAR_24**	10	0.679	0.356	0.289	1.323
		VAR_48	10	0.949	0.481	00.000	1.732
		VAR_72	10	0.784	0.375	00.000	1.443
		VAR_84	10	0.568	0.503	00.000	1.528

The mean variable error of scenario A was almost the same across the crosswalk distance with a standard deviation around 2 feet. The minimum variable error was zero feet at 72 and 84 feet respectively, and that is because of the last value carried forward method used to solve the missing data issue. The maximum was 5 feet at the 48, 72, and 84 feet mark.

For scenario B, the means of the variable errors decreased as compared to those of scenario A, proposing that the APS provided little guidance for the participants. Although there was no trend in the standard deviation for scenario B, the standard deviations were around 1.5

feet. Again, the standard deviations here were not realistic due to the limitation of the last value carried forward procedure employed to fill in the missing data. The number of missing data entries for this scenario decreased compared to scenario A because the performance was much better in that more participants finished crossing completely. The minimum variable error was zero feet at 48, 72, and 84 feet and the maximum was 5 feet starting at the 48 feet mark.

There is no doubt that scenario C was the best scenario in terms of mean variable error at all distances. Furthermore, the low values of variable deviations showed that the participants' performance was not as much variety as that in scenario A and B. The minimum variable error was zero feet at 48 feet and the maximum was 1.73 feet at the 48 feet mark. The difference between the minimum and maximum values of the variable error in this scenario substantially decreased as compared to the other scenarios.

When comparing all 3 scenarios in terms of the mean variable deviation, it is evident that scenario C was the best of all 3. It is the same case when comparing the standard deviations of the variable errors.

In conclusion, analyzing the variable error showed that scenario C was the best. The next is a statistical analysis of the improvement (variable error) that the participants had. Each distance mark (24, 48, 72 and 84 ft) is tested separately to study the statistical significance.

24 feet mark

Table 16 demonstrates the results of the one-way ANOVA analysis for the variable error at 24 feet.

Table 16: One-way ANOVA for variable error at 24 feet

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	2	6.526	3.263	3.48	0.0452
Error	27	25.322	0.938		
Corrected Total	29	31.848			

R-Square	**Coeff Var**	**Root MSE**	**VAR_24 Mean**
0.205	78.793	0.968	1.229

Source	**DF**	**Anova SS**	**Mean Square**	**F Value**	**Pr > F**
SC	2	6.526	3.263	3.48	0.0452

Since the P-value was 0.0452 which was less than the cutoff point (0.1), then we reject the null hypothesis (H_o) and accept the alternative hypothesis (H_a). This means that there was at least one mean that was different. Figure (26) demonstrates the distribution of the variable error over the 3 scenarios.

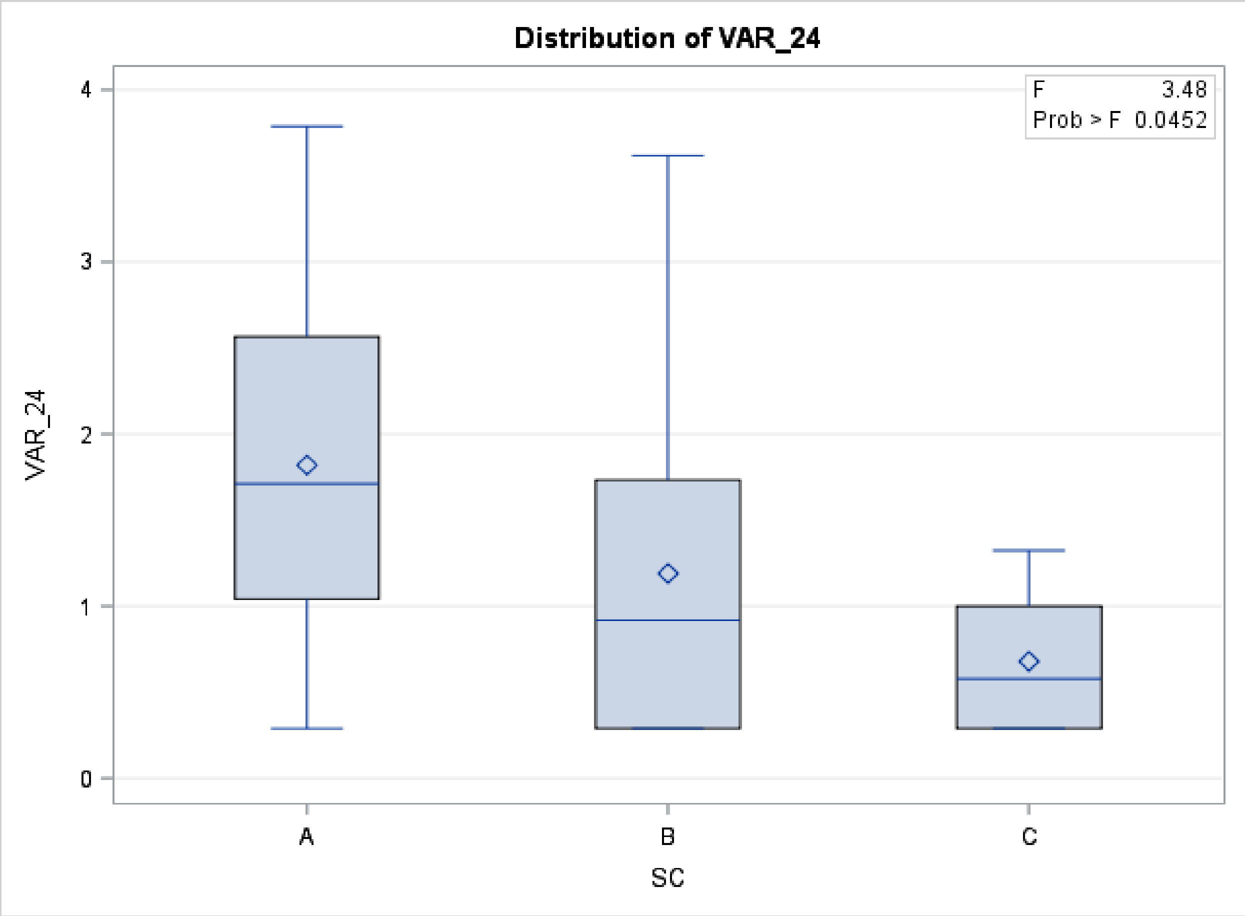

Figure (26): Variable Error Distribution at 24 feet

48 feet mark

Table 17 demonstrates the results of the one-way ANOVA analysis for the variable error at 48 feet.

Table 17: One-way ANOVA for variable error at 48 feet

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	2	13.574	6.787	2.95	0.069
Error	27	62.051	2.298		
Corrected Total	29	75.625			

R-Square	**Coeff Var**	**Root MSE**	**VAR_48 Mean**
0.179490	80.288	1.516	1.888

Table 17 -Continued

Source	**DF**	**Anova SS**	**Mean Square**	**F Value**	**Pr > F**
SC	2	13.574	6.787	2.95	0.0692

Since the P-value was 0.0692 which was less than the cutoff point (0.1), then we reject the null hypothesis (H_o) and accept the alternative hypothesis (H_a). This means that there was at least one mean that was different. Figure (27) demonstrates the distribution of the variable error over the 3 scenarios.

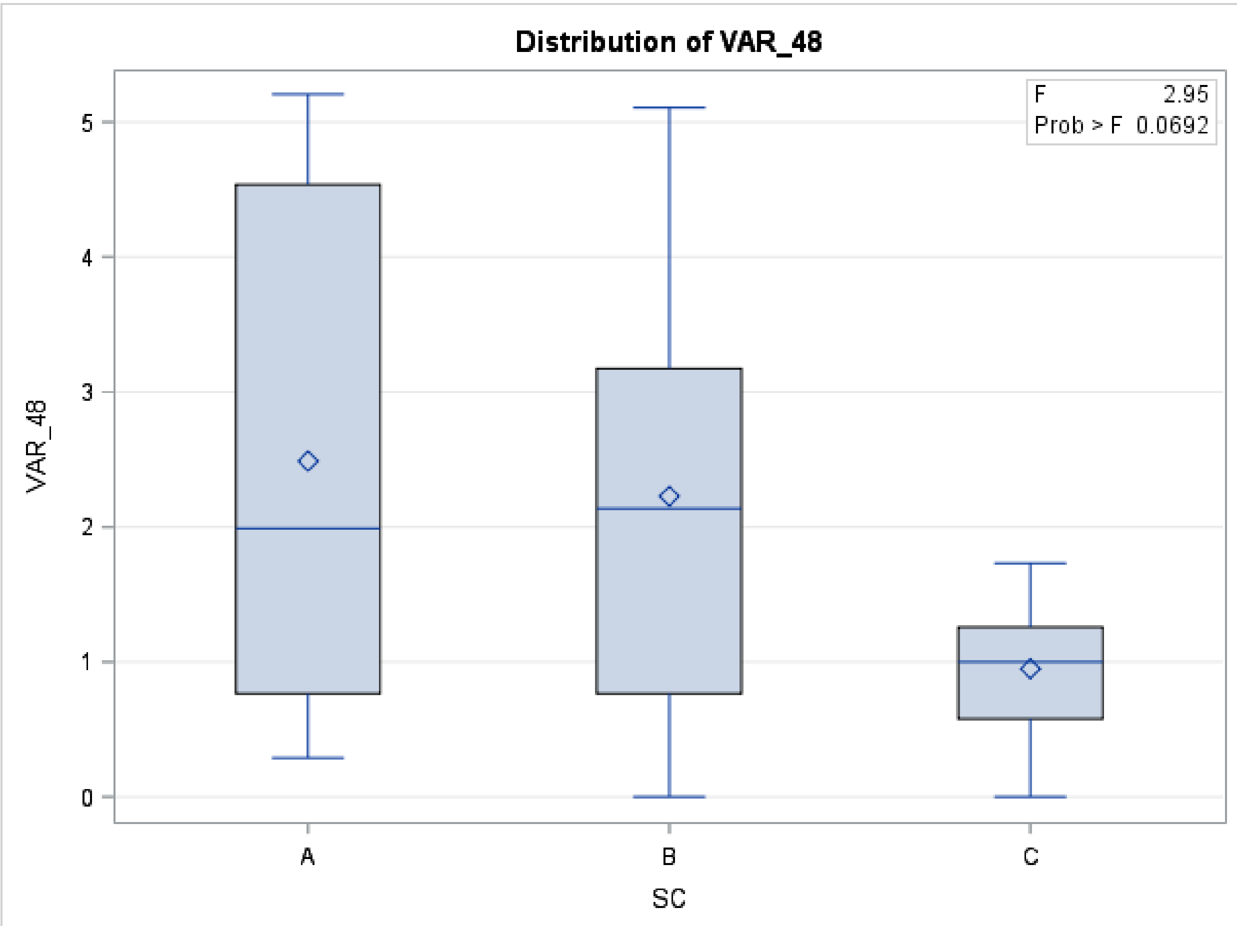

Figure (27): Variable Error Distribution at 48 feet

72 feet mark

Table 18 demonstrates the results of the one-way ANOVA analysis for the absolute error at 72 feet.

Table 18: One-way ANOVA for variable error at 72 feet

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	2	15.469	7.735	2.84	0.0761
Error	27	73.573	2.725		
Corrected Total	29	89.043			

R-Square	**Coeff Var**	**Root MSE**	**VAR_72 Mean**
0.174	92.299	1.651	1.788

Source	**DF**	**Anova SS**	**Mean Square**	**F Value**	**Pr > F**
SC	2	15.469	7.735	2.84	0.0761

Since the P-value was 0.0761 which was also less than the cutoff point (0.1), then we reject the null hypothesis (H_o) and accept the alternative hypothesis (H_a). This means that there was at least one mean that was different. Figure (28) demonstrates the distribution of the absolute error over the 3 scenarios.

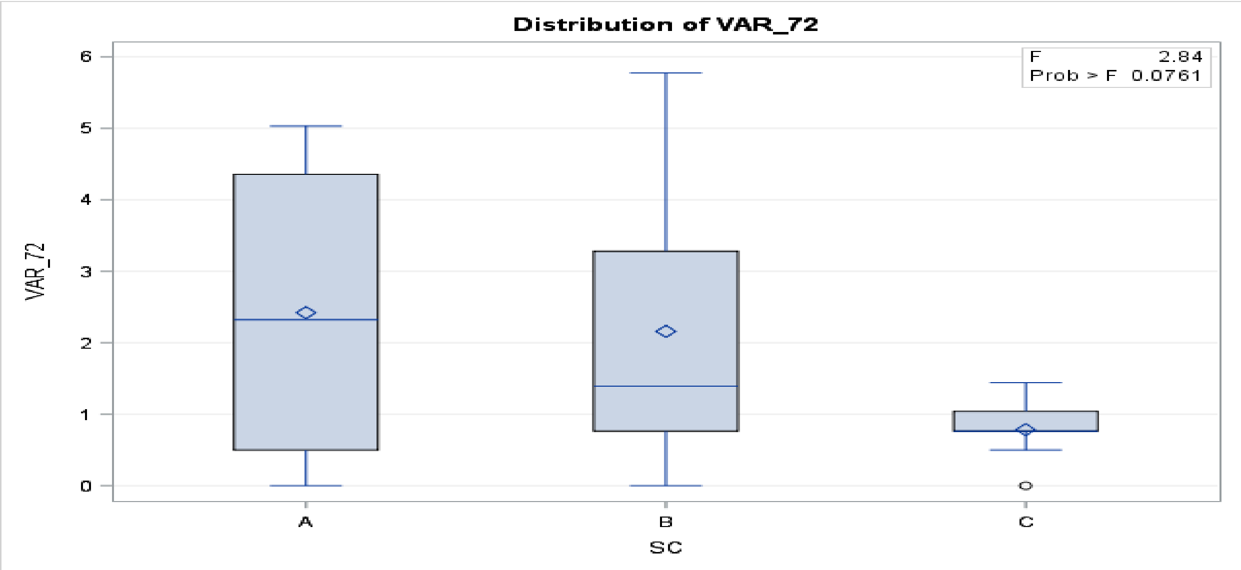

Figure (28): Variable Error Distribution at 72 feet

84 feet mark

Table 19 demonstrates the results of the one-way ANOVA analysis for the variable error at 84 feet.

Table 19: One-way ANOVA for variable error at 84 feet

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	19.838	9.919	2.92	0.0713
Error	27	91.802	3.400		
Corrected Total	29	111.639			

R-Square	Coeff Var	Root MSE	VAR_84 Mean
0.178	109.689	1.844	1.681

Source	DF	Anova SS	Mean Square	F Value	Pr > F
SC	2	19.838	9.919	2.92	0.0713

Since the P-value was 0.0713 which was less than the cutoff point (0.1), then we reject the null hypothesis (H_o) and accept the alternative hypothesis (H_a). This means that there was at least one mean that was different. Figure (25) demonstrates the distribution of the absolute error over the 3 scenarios.

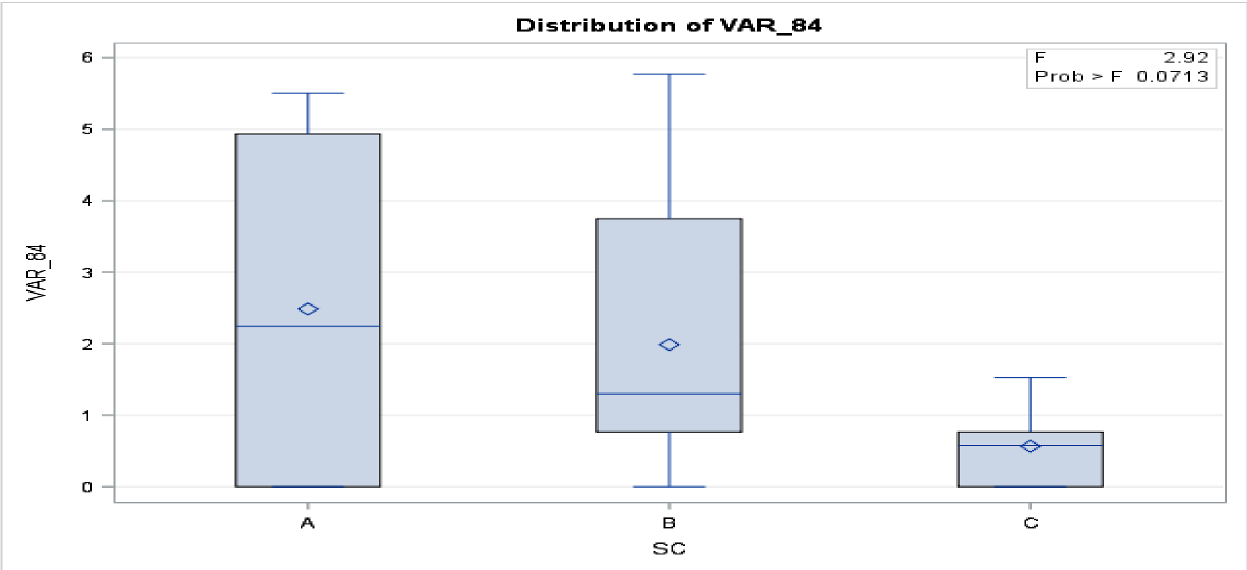

Figure (29): Variable Error Distribution at 84 feet

Constant Error

The constant error is calculated as the mean of a set of signed error scores and results from the directional bias of responses. Table 20 summarizes the variable error results across all scenarios.

Table 20: Constant error statistics

SC	N Obs	Variable	N	Mean	Std Dev	Minimum	Maximum
A	**10**	**CNST_24**	10	-0.883	2.101	-3.833	3.167
		CNST_48	10	-0.683	2.624	-3.833	4.667
		CNST_72	10	-0.150	3.401	-5.000	5.000
		CNST_84	10	0.233	3.766	-5.000	5.000
B	**10**	**CNST_24**	10	-0.883	1.969	-4.833	2.333
		CNST_48	10	-0.617	2.601	-5.000	3.500
		CNST_72	10	-0.383	3.328	-5.000	3.833
		CNST_84	10	-0.250	3.583	-5.000	3.833
C	**10**	**CNST_24**	10	0.183	0.552	-0.500	1.000
		CNST_48	10	-0.133	0.483	-1.000	0.667
		CNST_72	10	-0.200	0.576	-1.167	0.833
		CNST_84	10	0.133	0.331	-0.333	0.667

The above table shows that the mean constant error for scenario A increased as the pedestrians crossed the crosswalk, where the value of the standard deviation was around 3 feet. The minimum constant error was 3.8 feet to the left at 24 feet and the maximum was 5 feet to right at the 72 feet mark, which means that as pedestrians crossed more distances, the veering tendency increased.

For scenario B, the means of the constant errors decreased over all the distance. The standard deviation for scenario B increases with distance. The minimum constant error was 5 feet to the left at 48 feet, and the maximum was 3.6 feet to the right starting at the 72 feet mark.

Undoubtedly, scenario C was the best scenario in terms of mean constant error at all distances. Furthermore, the low values of constant errors show that participants had the smallest directional bias of all scenarios. The minimum constant error was 1.17 feet to the left at 72 feet, and the maximum was 1 feet to the right at the 24 feet mark. The difference between the minimum and maximum values of the constant error in this scenario substantially decreased as compared to the other scenarios.

When comparing all 3 scenarios with regard to the mean constant error, it is evident that scenario C was the best of all 3. It is the same case when comparing the standard deviations of the constant errors.

To check the presence of overall directional bias (constant error) in each scenario, a one-sample t-test was conducted for each scenario at each distance mark.

The analysis showed that no significant constant error was found over all scenarios and distance marks. For scenario A, at 24 feet ($t = -1.33$, $p = 0.216$), at 48 feet ($t = -0.82$, $p = 0.432$), at 72 feet ($t = -0.14$, $p = 0.892$) and at 84 feet ($t = 0.2$, $p = 0.849$). For scenario B, at 24 feet ($t = -1.42$, $p = 0.189$), at 48 feet ($t = -0.75$, $p = 0.473$), at 72 feet ($t = -0.36$, $p = 0.724$) and at 84 feet ($t = -0.22$, $p = 0.830$). For scenario C, at 24 feet ($t = 1.05$, $p = 0.321$), at 48 feet ($t = -0.87$, $p = 0.405$), at 72 feet ($t = -1.1$, $p = 0.301$) and at 84 feet ($t = 1.27$, $p = 0.235$). If there was significant constant error, this means that there was an error associated with the treatment, but since no significance was found, this means that the constant error was caused by pure human behavior.

Average Percent Completion

The participants completed on average about 75% of the crosswalk in scenario A. In scenario B, they on average finished 85% of the crosswalk. In scenario C, they completed crossing the entire crosswalk successfully (100%), as shown in Table 21. Figure (30) shows the average percent completion distribution over the 3 scenarios

Table 21: Average percent completion

Analysis Variable: AVG % COMP						
SC	**N Obs**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
A	**10**	10	75.000	13.895	54.762	97.619
B	**10**	10	85.000	16.912	50.000	100.000
C	**10**	10	100.000	00.000	100.000	100.000

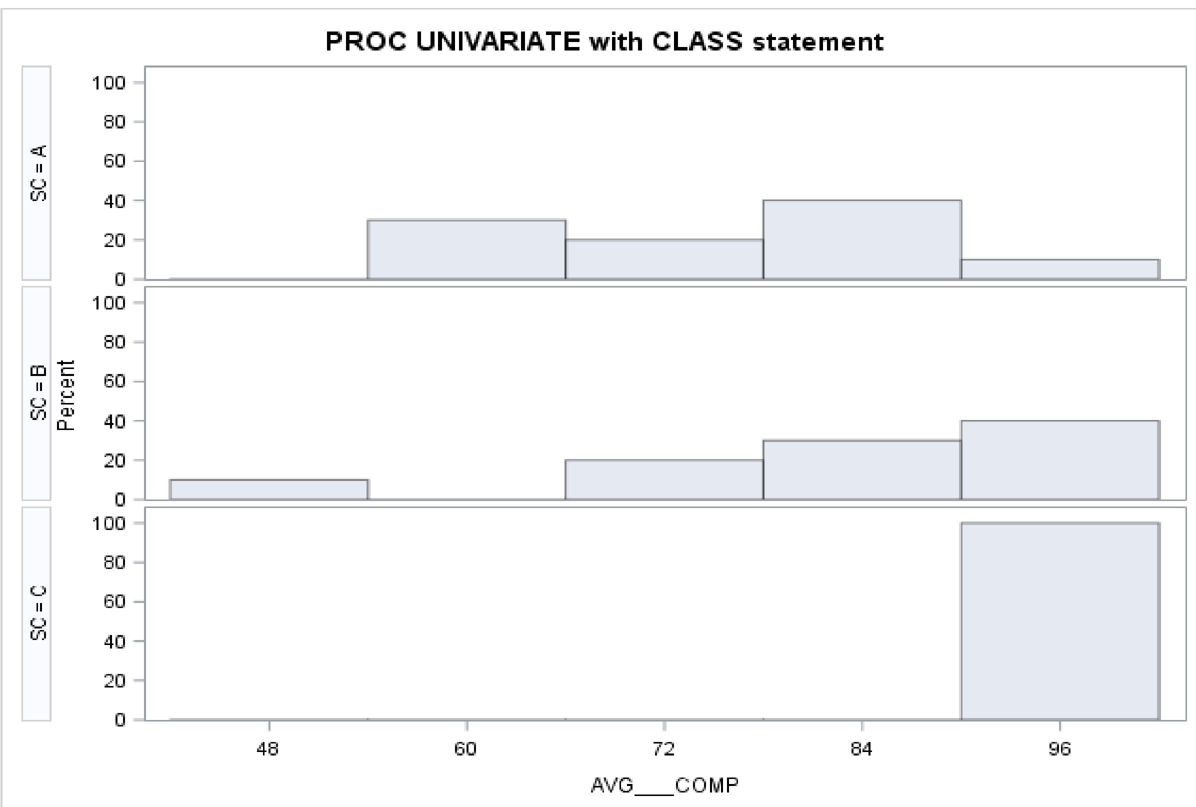

Figure (30): Average % Completion Distribution Over all 3 Scenarios

Average Pedestrian Speed

The participants' average speed for scenario A was about 1.8 ft/sec. In scenario B, the average participants' speed was 2.1 ft/sec. In scenario C, their average speed was 2.4 ft/sec representing an increase in self-confidence and improvements in their walking speed as seen in Table 22.

Table 22: average pedestrian speed

Analysis Variable: AVG_SPD						
SC	**N Obs**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
A	**10**	10	1.891	0.457	1.419	2.867
B	**10**	10	2.144	0.299	1.531	2.623
C	**10**	10	2.395	0.391	1.989	3.364

Post-Survey

The post-survey basically examined participants' satisfaction of the Smart-Cane and their opinions regarding any improvements. Additionally, it investigated whether the participants would prefer to use the Smart-Cane over APS. Table 23**: Post-survey results**

demonstrates the results obtained.

	>satisfied (%)	Neutral (%)	<Dissatisfied (%)	>very prob (%)	Prob (%)	<prob not (%)	>Agree (%)	Neutral (%)	<Disagree (%)
Overall satisfaction of the Smart-Cane	100	0	0						
Would consider using Smart-Cane				90	10	0			
Does Smart-Cane need more development				20	10	70			
Consider using over APS				70	20	10			
Does Smart-Cane increase independence on other cues							90	10	0

Table 23: Post-survey results

As can be seen from the survey, all the participants showed their satisfaction of the Smart-Cane. 90% of participants would consider using the Smart-Cane if it was commercialized and 90% stated that they would prefer to use it over APS. Finally, 90% reported that the Smart-Cane increased their independence and self-confidence.

The Smart-Cane showed more preference over APS by the BVI pedestrians, where it improved their crossing abilities. The error calculations proved that the veering tendency of participants decreased significantly while using the Smart-Cane. The participants also maintained their heading and did not veer outside of the crosswalk all the time when using the Smart-Cane. The results of the pre-survey showed that the intersection information, which is sometimes unavailable, is very important to BVI pedestrians while crossing. The Smart-Cane provided missing information that BVI pedestrians might need to complete crossing safely, giving them more perception of the intersection they are about to cross. Finally, by taking a look at the post-survey, we can see that BVI overall satisfaction of the Smart-Cane was high and they were willing to use such technology to assist them in crossing. The Smart-Cane also proved that it decreased BVI pedestrian dependence on other cues and increased their self-confidence while crossing. These results are very promising, yet more experimentation and research must be conducted to generalize the idea over a large population.

CHAPTER VI

CONCLUSION

The objective of this study is to assist blind pedestrians to make their crossing easier and safer through aiding them in: maintaining heading while crossing wide, unfamiliar, and complex intersections, ending their crossing within the crosswalk, decreasing crossing time, increasing their independence on other cues while crossing, increasing self-confidence, and making crossing behaviors of BVI pedestrians safer. Hopefully, the Smart-Cane technology could create more livable and safer communities where pedestrians with disabilities can exercise their right by making use of this technology to move from one place to another conveniently and easily.

The components of the Smart-Cane include the RFID reader, 360° antenna and a microcontroller and a power bank (battery). Another component is the RFID tags which are deployed on the crosswalk.

The Smart-Cane is comprised of three systems, the first of these is the veering adjustment system; the basic function of this system is to minimize veering behaviors of BVI pedestrians as much as possible. The second is the driver alert system that basically informs approaching and idling drivers at intersections of the presence of BVI pedestrians. This system increases alertness of drivers and safety of BVI pedestrians. The last is the green time system which basically communicates with the signal controller and asks permission for allocating pedestrians' green time; moreover, it provides extra green time for pedestrians to complete crossing safely and accordingly when needed.

The experimentation phase of this research was divided into two stages; the first stage included experimentation with (32) sighted participants, and the second stage was conducted on (10) BVI participants.

The experimental site that was selected for our study was an isolated parking lot at WMU. A simulated crosswalk was constructed on the parking lot pavement surface. The simulated crosswalk represents a typical 7 lanes (12 feet wide lanes) roadway with a total length of 84 feet and a typical width of 10 feet (MUTCD, 2003). Traffic noise was simulated using 5 loudspeakers. The Accessible Pedestrian Signal (APS) beacon speaker used was of a beeping type and was mounted on a tripod.

The general experimental design consisted of 3 practice crossings and 3 scenarios: A, B, and C. Various data were collected throughout the scenarios. 1 trial was given for each participant per scenario in the 1st stage of experimentation and 3 trials were given for each participant per scenario in the 2nd stage of experimentation.

The participant's distance and direction from the intended path (centerline) were taken into consideration for the analysis of the data, at 24 feet, 48 feet, 72 feet and 84 feet (crosswalk end). These distances represent typical widths of two, four, six and seven traffic lanes.

The maximum deviation to the left and to the right, absolute deviation of participants, and percent completion of the crosswalk of participants throughout the three scenarios were the main descriptive statistics used for the first stage of experimentation.

Descriptive statistics (absolute, variable and constant error) were made in the second stage of experimentation.

A single-factor ANOVA (one-way ANOVA) statistical analysis of variance test was conducted to test the statistical significance of the improvements caused by the Smart-Cane and to answer the research question for the second stage of experimentation. To check the presence of overall directional bias (constant error) in each scenario, a one-sample t-test was conducted for each.

The null hypothesis of the one-way ANOVA states that there is no difference between the means of the scenarios (all means are equal). The alternative hypothesis states that there is at least one mean of a scenario that is different from the others.

Where the ANOVA was significant, Tukey multiple comparison procedures were used to find means that are significantly different from each other and to compare all possible pairs of means.

The absolute error was minimal for scenario C, proving that the Smart-Cane did a very good job in minimizing veering for the BVI pedestrians, and in improving their crossing abilities and performances as compared to scenario A and B. The case was the same for the variable error and the constant error. Scenario C had the least amount of variable and constant errors. When the one-way ANOVA model was constructed for the absolute error, it was statistically significant ($P<0.1$) throughout all distance marks (24, 48, 72 and 84 feet). Moreover, when Tukey's test was performed, we found that scenario C was the best among all 3 scenarios, proving again the Smart-Cane is applicable and feasible. With the Smart-Cane, all participants completed the entire crosswalk successfully.

The Smart-Cane in line with Connected Vehicles technology and Smart-Cities. The Smart-Cane with RFID, D2I, I2V and D2V communications improve BVI pedestrians' safety by providing them with intersection information (location, type, name, geometry, etc.), by alerting drivers of the BVI pedestrians presence and providing and increasing the green time allocated to the crossing. More attention should be assigned to people with disabilities to ease their everyday life.

As transportation engineering progresses over time and what once was just a thought has become a reality. As nations compete in the implementation of smart cities, technologies are suggested, researched, tested, and implemented to meet smart cities requirements. And as we are one step closer to implementing Connected Vehicles (CV) technology which one day might be an essential part of our everyday life, it is our duty as transportation engineers to provide safer and more livable communities where all layers of the community can perform their basic rights in life such as safe and convenient mobility from one place to the other.

Limitation

One of the major limitations of this research is that experimentation was not at an actual intersection. Experimentation was held at a simulated parking lot which in general isn't as realistic as an actual intersection. For the next research stage, this might be conducted at an actual intersection and data between the actual and simulated site can be compared.

Another limitation is that pedestrians were not given the freedom to veer outside the crosswalk boundaries due to safety issues. If pedestrians were given complete freedom to proceed with crossing, then the veering would exceed the values collected from the site.

One of the limitations we encountered is the missing data. Missing data occurred because the number of trials for each scenario was only 3, and if the missing data issue was to be solved, then we should increase the number of trials to a minimum of 8 trials per scenario.

Future Research

Further experimentation with the Smart-Cane should be conducted with increasing the number of trials per scenario. Another thought would be to conduct experimentation at actual intersections to prove the efficiency of the Smart-Cane.

DSRC should be integrated with the Smart-Cane and test the interactions with nearby vehicles at intersections, and study the rate at which drivers will collaborate with this technology and the alert which they are receiving through DSRC built in their vehicles. Smart-Cane should be further developed to include roundabouts and un-signalized intersections

The green time concept that was mentioned in this research should be studied and developed to improve the process of crossing intersections for the BVI pedestrians to provide a complete system for the Blind and Visually Impaired pedestrians at intersections.

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Appendix A

HSIRB Approval Letter

WESTERN MICHIGAN UNIVERSITY

Human Subjects Institutional Review Board

Date: May 2, 2017

To: Ala Al-Fuqaha, Principal Investigator
Jun Oh, Co-Principal Investigator
Valerian Kwigizile, Co-Principal Investigator
Mohammad Al-Akash, Student Investigator for thesis

From: Amy Naugle, Ph.D., Chair

Re: HSIRB Project Number 17-04-24

This letter will serve as confirmation that your research project titled "Toward More Livable Communities through Enhancing Pedestrians' Road Crossing Safety Using D2I Communication" has been **approved** under the **expedited** category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note: This research may **only** be conducted exactly in the form it was approved. You must seek specific board approval for any changes in this project (e.g., ***you must request a post approval change to enroll subjects beyond the number stated in your application under "Number of subjects you want to complete the study***)." Failure to obtain approval for changes will result in a protocol deviation. In addition, if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

Reapproval of the project is required if it extends beyond the termination date stated below.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: **May 1, 2018**

1903 W. Michigan Ave., Kalamazoo, MI 49008-5456
PHONE: (269) 387-8293 FAX: (269) 387-8276
CAMPUS SITE: 251 W. Walwood Hall

Appendix B

Consent Form

Western Michigan University
H.S.I.R.B.
Approved for use for one year from this date:

MAY 02 2017

x [signature]
HSIRB Office

Western Michigan University
Department of Civil and Construction Engineering

Principal Investigator:	Ala Al-Fuqaha, Computer Science Department
Co-Principal Investigator:	Jun-Seok Oh, Civil and Construction Engineering
Co- Principal Investigator:	Valerian Kwigizile, Civil and Construction Engineering
Student Investigator:	Mohammad Al-Akash, Civil and Construction Engineering
Title of Study:	Towards More Livable Communities through Enhancing Pedestrians' Road Crossing Safety Using D2I Communication.

You have been invited to participate in a research project titled "*Towards More Livable Communities through Enhancing Pedestrians' Road Crossing Safety Using D2I Communication.*" This project will serve as Mohammad Al-Akash Thesis for the requirements of the Masters in Civil and Construction Engineering. This consent document will explain the purpose of this research project and will go over all of the time commitments, the procedures used in the study, and the risks and benefits of participating in this research project. Please read this consent form carefully and completely and please ask any questions if you need more clarification.

What are we trying to find out in this study?
The objective of this study is to investigate technologies that might assist you in crossing wide and busy intersections through maintaining heading and ending your crossing within the crosswalk. Thus, decreasing crossing time, increasing your self-confidence and independence on other cues, and making your crossing behaviors safer. Eventually, creating more livable and safer communities where you can take advantage of your right to move from one place to another conveniently through such technologies.

Who can participate in this study?
Anyone of both genders and age ranges from 18-80 years can participate in this study with the emphasis on the Blind and Visually Impaired (BVI).

Where will this study take place?
This study will take place at the Park View campus parking lot in Western Michigan University and will end at the same location.

What is the time commitment for participating in this study?
The whole process is expected to take approximately 1-2 hours, including introduction, a pre-survey, a field experiment, and a post survey.

What will you be asked to do if you choose to participate in this study?
You will be asked to participate in a pre-survey, conduct the experimentation of crossing a 97 feet simulated crosswalk for 3 scenarios, and using a cane equipped with a device provided by the research team for the 3rd scenario.

What information is being measured during the study?
In the experimentation phase, we will measure your distance from the center line at various stages from starting point, whether you veer outside the crosswalk, location of crossing completion (inside or outside crosswalk), time needed to complete crossing and if interference was needed in crossing.

What are the risks of participating in this study and how will these risks be minimized?
There are no known risks facing you while conducting the experimentation outside of normal risks of everyday activity. The study will be held in an isolated and safe environment. The only possible risk that may lead to injury includes falling down while crossing.

What are the benefits of participating in this study?
There are no direct benefits to you as a participant. Potential benefits of this research are to assist you in the process of crossing and maintaining your heading while crossing wide and busy intersections, ending crossing within crosswalk, decrease crossing time, increase independence and self-confidence and increasing livability and safety of communities and making transportation easier for you.

Are there any costs associated with participating in this study?
There is no cost to you in this experiment other than your time commitment. The research team will provide water for you.

Is there any compensation for participating in this study?
There is no compensation for your participation in this study. However, the research team will provide beverages for your rest.

Who will have access to the information collected during this study?
The data collected will be analyzed only by the research team members. No others will have access to the data collected. The results of the study are expected to be disseminated on an aggregate basis through a report to US Department of Transportation as well as possible journal/conference publications and a Master's degree thesis.

What if you want to stop participating in this study?

You can choose to stop participating in the study at any time for any reason. You will not suffer any prejudice or penalty by your decision to stop your participation.

Western Michigan University
H.S.I.R.B.
Approved for use for one year from this date:

MAY 02 2017

x [signature]
HSIRB Office

You will experience NO consequences either academically or personally if you choose to withdraw from this study. The investigator can also decide to stop your participation in the study without your consent.

Should you have any questions prior to or during the study, you can contact the primary investigator, Dr. Ala Al-Fuqaha at (269) 276-3868 or ala.al-fuqaha@wmich.edu. You may also contact the Chair, Human Subjects Institutional Review Board at 269-387-8293 or the Vice President for Research at 269-387-8298 if questions arise during the course of the study.

This consent document has been approved for use for one year by the Human Subjects Institutional Review Board (HSIRB) as indicated by the stamped date and signature of the board chair in the upper right corner. Do not participate in this study if the stamped date is older than one year.

I have read this informed consent document. The risks and benefits have been explained to me. I agree to take part in this study.

____

Please Print Your Name

______________________________ ______________________________

Participant's signature Date

Appendix C

Pre-Survey

Pre-survey:

We appreciate your consent to participate in this research project on technology that may assist in navigation and wayfinding of blind and low vision pedestrians. We will ask you several questions regarding the way you navigate through intersections. We would like to design a technology that may improve your experience of intersection crossing.

Answers will be confidential and if you do not feel comfortable answering any question, you may pass.

Demographic Information:

1. Age range: 18-24 25-34 35-44 45-54 55-64 65 and above
2. Sex:
   A. Male
   B. Female
   C. Other

Navigation and Mobility:

1) What is your preferred method of assistance while crossing intersections?
   a. Cane
   b. Guide dog
   c. None
   d. Other: ________________________________

2) How often do you require assistance from other pedestrians while crossing intersections?
   a. Always
   b. Very often
   c. Sometimes
   d. Rarely
   e. Never

3) How important is it to identify the following information when crossing an intersection?

	Very Important	**Important**	**Moderately Important**	**Slightly Important**	**Not Important**
Intersection name					
Intersection type					
Intersection geometry (skewness)					
Number of lanes					
Direction of Crossing					
Presence of median island					

4) What difficulties did/do you encounter while crossing wide and busy intersection? How often did it occur?

	Always	Very often	Sometimes	Rarely	Never
Not knowing direction of crossing					
Maintaining heading while crossing					
Veering outside crosswalk					
Ending outside the crosswalk					
Insufficient information for crossing					
Insufficient crossing time					
None					
Other:					

5) Have you ever encountered an Accessible Pedestrian Signal? These signals give you audio or tactile information about the state of the light at the intersection or the location of the crosswalks in addition to a light signal.
    a. Always
    b. Very often
    c. Sometimes
    d. Rarely
    e. Never

If NEVER, move to question 10

6) How helpful do you see crossing intersections equipped with Accessible Pedestrian Signals?
   a. Very helpful
   b. Helpful
   c. Moderately helpful
   d. Slightly helpful
   e. Not helpful

7) Do you rely on Accessible Pedestrian Signals when crossing wide and busy intersections?
   a. Always
   b. Very often
   c. Sometimes
   d. Rarely
   e. Never

8) Do you think that the beeping sound (audible beaconing) from Accessible Pedestrian Signals provides guidance to the correct destination?
   a. Always
   b. Very often
   c. Sometimes
   d. Rarely
   e. Never

9) Have you ever had any of the following difficulties while crossing intersections equipped with Accessible Pedestrian Signals? How often did it occur?

	Always	**Very often**	**Sometimes**	**Rarely**	**Never**
Not knowing direction of crossing					
Maintaining heading while crossing					
Veering outside crosswalk					
Ending outside the crosswalk					
Insufficient information for crossing					
Insufficient crossing time					
None					
Other:					

10) Have you ever used any technology to assist you in crossing intersections?
   a. Yes
   b. No

If YES, please mention: ___________________________________

If No, move to question 12

11) How would you rate the overall technology?
   a. Very good
   b. Good
   c. Acceptable
   d. Poor
   e. Very Poor

12) How do you feel about drivers being alerted and informed of your presence while crossing the intersection?
   a. Very important
   b. Important
   c. Moderately important
   d. Slightly important
   e. Not important

Comments: ____

____

Appendix D

Post-Survey

<u>Post-survey form</u>

System description:
The proposed system may assist pedestrians in minimizing veering and help in maintaining heading, and alerting drivers at intersection of the presence of blind pedestrian.

Pedestrian will be alerted and guided verbally, although it can be developed in the future to include vibrations.

1) What is your overall satisfaction of the developed device and/or technology?
    a. Very satisfied
    b. Satisfied
    c. Neither
    d. Dissatisfied
    e. Very dissatisfied

2) Would you consider using the device after development?
    a. Definitely
    b. Very probably
    c. Probably
    d. Probably not
    e. Definitely not

3) Do you think this device needs further development or to include further features?
    a. Definitely
    b. Very probably
    c. Probably
    d. Probably not
    e. Definitely not

    Please mention what features
    ----

4) Would you consider using this device over Accessible Pedestrian Signals?
   a. Definitely
   b. Very probably
   c. Probably
   d. Probably not
   e. Definitely not

5) Does/did this device increase your independence on other cues?
   a. Strongly Agree
   b. Agree
   c. Neutral
   d. Disagree
   e. Strongly Disagree