RESEARCH & DEVELOPMENT

IOT Solutions for Near Horizon Challenges in Smart City Pedestrian Travel

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16. Abstract

Traffic and highway safety is advancing at an incredible rate with automation and artificial intelligence (AI) at the lead. Pedestrians, especially those with disabilities will experience access challenges and benefits as these new technologies emerge. This project sought to address opportunities using existing and near horizon technologies to improve access and inclusion for pedestrians with disabilities. To advance this effort the project engaged in three efforts centered around intersection corners and individuals with visual impairments.

The first task focused on enhancing pedestrian travel and safety in smart cities by reviewing, developing and illustrating the use of advanced technologies. The functionality of novel technologies and methods for collecting video data and assessing pedestrian actions using computer vision was demonstrated. Their applicability for individuals with visual impairments and how these individuals learn a unique skill set that may differentiate their travel patterns and behavior at intersections when intending to cross was discussed.

The second task sought to address potential solutions involving walk request buttons. Historical focus has been placed on signal communication, but button location and orientation can be just as critical and yet quite varied. To address this challenge the project explored and tested opportunities for alternative and mobile device communication. The project prepared a listing of potential technologies with evaluations of application and effectiveness. A market solution matching the preferred technology was deployed in the testing area and field evaluation was completed with volunteers who had visual impairments and blindness. The reliability, comfort, and usability of the system was confirmed with the participants. The participants completed a simple three-item scale (not at all, somewhat, very much) of agreement with statements regarding the features. Results suggested the technology was meeting the primary needs, but could be improved. The ratings suggest deployments of Bluetooth enabled and automated pedestrian-heads should take into consideration the preferences of the local users to ensure the correct features are being implemented.

The third task explored the transmission of corner orientation and crossing information via Bluetooth communication with personal smart phones. The goal of the task was two-fold; the development of a protocol for identifying the critical information needed by pedestrians with visual impairments and testing a means of communicating that information to a pedestrian using a format that meets accessibility standards. The team used a two-stage approach, expert and consumer prioritization, to identifying the critical features of an intersection. A survey format was used to gather the professional opinions of Orientation and Mobility Specialists regarding a generated list of items. That refined list was then implemented, and a rating was gathered during trials to get a user impression of the usefulness of the information. The top ten items were condensed to eight items, as some items had shared information. The final eight items performed well, and participant ratings confirmed expert ratings/suggestions.

Collectively these tasks contribute critical components in the development of any I2P and P2I protocols. The ability of the infrastructure to effectively recognize, perceive, and predict pedestrians will only make models that mitigate vulnerability stronger. Allowing the pedestrian to communicate more easily with the infrastructure removes barriers and adds reliability to traffic control choices. Providing methods to communicate infrastructure information, besides control state, to the pedestrian improves pedestrian safety and the predictability of an intersection. This project hopes its findings will guide future adoption of technology and inform the review of critical features and access to individuals with disabilities.

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Executive Summary

Traffic and highway safety is advancing at an incredible rate with automation and artificial intelligence (AI) at the lead. Pedestrians, especially those with disabilities will experience access challenges and benefits as these new technologies emerge. This project sought to address opportunities using existing and near horizon technologies to improve access and inclusion for pedestrians with disabilities. To advance this effort the project engaged in three efforts centered around intersection corners and individuals with visual impairments.

The first task focused on enhancing pedestrian travel and safety in smart cities by illustrating the use of advanced technologies with emphasis on video analytics. Firstly, the functional requirements necessary for testing and implementing these technologies, considering the specific challenges faced in pedestrian travel and safety within smart city environments, were reviewed. Secondly, the functionality of novel technologies and methods for collecting video data and assessing pedestrian safety (actions/behaviors) was developed and demonstrated. Thirdly, the components required for real-time notification of pedestrians, with a particular emphasis on visually impaired individuals, concerning incoming vehicular traffic were explored.

The second task sought to address potential solutions involving walk request buttons. Historical focus has been placed on signal communication, but button location and orientation can be just as critical and yet quite varied. To address this challenge the project explored and tested opportunities for alternative and mobile device communication. The project prepared a listing of potential technologies with evaluations of application and effectiveness. A market solution matching the preferred technology was deployed in the testing area and field evaluation was completed with volunteers who had visual impairments and blindness. The reliability, comfort, and usability of the system was confirmed with the participants. The participants completed a simple three-item scale (not at all, somewhat, very much) of agreement with statements regarding the features. Results suggested the technology was meeting the primary needs, but could be improved. The ratings suggest deployments of Bluetooth enabled and automated pedestrian-heads should take into consideration the preferences of the local users to ensure the correct features are being implemented.

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Introduction

To the layman reviewing traffic controls and systems there may appear to be very little change or innovation over time. The vehicle operator or pedestrian interactions that they interact with have been orientated around well established and familiar communication for some time. Behind these familiar interfaces, updates of technology, controls, and underlying systems for management have been steady and continuous. Recent innovations around smart cities and the Internet of Things (IoT) have opened significant new opportunities to create a more responsive and tuned system that can meet the needs of frequently overlooked or underserved populations. One of these populations are pedestrians with visual impairments and blindness. This project set forth with the core principle that if solutions were explored for the population with visual impairments, that those solutions would have broader application to the general public and other groups with unique needs.

The current solutions for accessibility at the street corner or almost entirely designed around the Human Computer Interface (HCI) level of interaction. Street curbs are blended to meet the needs of individuals with mobility issues. Audible messaging is added to pedestrian crossing buttons and signals to communicate to individuals who cannot see the signage. These technologies are effective but are by no means as responsive as dynamic traffic controls or inductive loops that detect the presence of vehicles. The amount of information communicated to and from the infrastructure from a pedestrian is limited to the presence of the pedestrian and the state of the sign. Meanwhile the individual with no visual impairment can evaluate the patterns of traffic, the design of the intersection, and predict the route to be traveled ahead. Even the name of the cross streets at a given corner are more available to these travelers compared to individuals with visual impairments who already bear a significantly higher cognitive load when traveling. Smartphones have provided a solution to orientation problems in a global sense with the name of cross streets, estimated address on the street grid, and current facing direction. They have also brought the navigation solutions of GPS systems like Garmin and TomTom to the pedestrian, including access to bus route information. Two major gaps in these innovations is the direct inclusion of traffic infrastructure communication to better make the systems aware of the pedestrian, similar to a vehicle, and allow the pedestrian to have access to more information about a given situation. The three tasks of this project are designed to provide the background and exploration necessary to create protocols and refined methods to close these gaps.

Task 1

Task 1 of the project focuses on assessing needs and research on state-of-the-art technologies and analysis for pedestrian safety while preserving privacy. Various solutions can be implemented for smart city pedestrian travel by leveraging IoT technologies. They include intelligent crosswalks equipped with sensors that detect pedestrians and adjust traffic signals accordingly, smart lighting systems that enhance visibility and safety, or real-time monitoring systems that provide pedestrians with up-to-date information on traffic conditions and alternative routes. These IoT-enabled solutions can significantly improve the efficiency, convenience, and safety of pedestrian travel in smart cities. To address this objective, this section is organized around the following points.

- Formalizing functional requirements for testing and implementation based on discussions with the stakeholders (accounting for technological advancements).
- Exploring, developing, and illustrating the working of novel technologies and methods to collect data and assess pedestrian safety.
- Building a mechanism for real-time notification/alarming of pedestrians, especially visually impaired individuals, to incoming vehicular traffic (directly to the user or through signs/signals).
- Assessing potential impacts and acceptability of advanced technologies by stakeholders and the general public.

Task 2

The original objective of task two was to examine potential communication systems that would allow a pedestrian smartphone-based call system. The last revision of the APS best practices occurred in 2010 and was only 3 years after the release of the iPhone. Consumer smart devices with wide ranging signal capacity were still a developing market. The conclusion at the time was that new possibilities would likely develop "…to provide information to pedestrians and for pedestrians to call a WALK interval in the future." (Harkey, Carter, Barlow, & Bentzen, 2010; NCHRP, 2010) Continuing changes in the communication protocols and developments in the device market made task two obsolete by the second year of the project. As a result, the project shifted from development to evaluation. At that time two systems had emerged in the market with different solutions to the communication challenge. The two systems were reviewed and the one with stronger deployment presence in North Carolina was included in the task three trials. Those results will be discussed later in this section.

Task 3

Pedestrians who are blind or have low vision and approach and want to cross a street at an unfamiliar intersection do not know what to expect. They must use their hearing to determine as much as possible about the intersection. To make a safe crossing, they must try to identify the number of lanes that they will have to cross, determine if there is a pole with a pedestrian call button, determine if there is a median strip, understand the geometric configuration of the intersection, determine if there is a dedicated left turn lane, and understand the type of phasing of the traffic light. Most of these details will be dependent on careful listening and analysis that could be mistaken based on the traffic patterns present. The above details represent just a portion of the information that would support their ability to make a safe and accurate crossing.

One attempt that has been made to provide this information has been the use of a tactile map using raised lines and bumps to depict the physical layout of the street to be crossed (see Figure 9). These maps are located on the pole where a pedestrian call button is situated. However, the tactile layout is limited in the information provided and requires the individual to understand the symbols that represent the specific elements of the intersection. The first-time user would require training or access to a key, as some symbols may not be transparent in meaning. One benefit of the symbolic representation would be the fact that the information does not rely on any individual language.

Organization of report

The distinct tasks under this project each draw on distinct technologies, approaches, and background domains. This drawing together of diverse domains has allowed the products of this task to address the problems of intersections for individuals with visual impairments from multiple perspectives providing a more systemic set of solutions rather than a directed singular solution. As such, the background literature and state of the art, science, and practice is best digested within the context of each task. The discussion in the opening section of each task will build the context and knowledge base necessary for each task, while drawing on the research base from disciplines present on the team.

Report Body – Chapter - Project 2: Task 1

IOT Solutions for Near Horizon Challenges in Smart City Pedestrian Travel

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2.1. Formalizing functional requirements for testing and implementation based on discussions with the stakeholders (accounting for advancements in the technology)

This subtask involves defining functional requirements for testing and implementing IoT solutions to address near-term challenges in pedestrian travel within smart cities. The process is based on discussions with stakeholders and considering the latest technological advancements. In short, it entails determining the specific features and capabilities the IoT solutions need to effectively address the identified challenges and ensure that these requirements align with the stakeholders' needs and expectations.

Pedestrians face different challenges when navigating within cities, especially regarding their safety. These challenges include the lack of pedestrian safety education for both drivers and pedestrians, which contributes to a lack of awareness about proper safety practices, increasing risk of crashes, the lack of infrastructure, insufficient traffic control, distracted driving and walking, poor visibility, and lighting, encroachment on pedestrian spaces, speeding and aggressive driving, inadequate education and awareness, unequal access to safe pedestrian routes, inconsistent enforcement, and those with disabilities or other mobility disadvantaged population.

2.1.1. Common challenges related to pedestrian travel and safety

Some city locations lack proper sidewalks, crosswalks, and pedestrian-friendly infrastructure, making it unsafe for pedestrians to navigate busy streets. The increasing use of mobile devices by both drivers and pedestrians leads to distractions, reducing their awareness of each other and increasing the risk of crashes. Inadequate street lighting and visibility impairments due to obstructions, such as overgrown vegetation or poorly maintained infrastructure, make it difficult for drivers to see pedestrians, especially during nighttime or adverse weather conditions. On-street parking or encroachment of shoulders/sidewalks and pedestrian areas force pedestrians to walk on the road, exposing them to potential crashes and conflicts with motorized traffic.

Traffic violations, such as speeding, failure to yield to pedestrians, and disregarding traffic signals, contribute to unsafe pedestrian conditions. Excessive speeding and aggressive driving behaviors pose a significant threat to pedestrian safety, reducing the time available for drivers to react and increasing the severity of crashes. Inconsistent enforcement of traffic laws, including failure to enforce speed limits or yield the right-of-way to pedestrians, undermines pedestrian safety efforts and encourages risky behavior by drivers. Certain groups, such as children, older adults, and people with disabilities like visually impaired people, are particularly vulnerable as pedestrians and face additional challenges and risks in urban environments. Disadvantaged communities often lack safe and well-maintained pedestrian routes, forcing pedestrians to take longer and riskier routes or walk alongside high-speed traffic.

These challenges highlight the need for comprehensive measures to improve pedestrian safety in cities and create pedestrian-friendly environments. The concept of smart cities seems promising to efficiently tackle these common challenges that impede pedestrian travel and safety in urban areas by leveraging advanced technologies, data analytics, and IoT solutions to enhance the quality of life for residents, improve sustainability, and optimize urban infrastructure and services.

2.1.2. Technologies/devices enhancing pedestrian travel and safety in smart cities

There are currently several technologies and devices that can improve the travel and safety of pedestrians in a smart city environment. These technologies and devices include smart crosswalks, intelligent traffic lights, wearable safety devices, and smart street lighting. Smart crosswalks are equipped with sensors or LED lights to enhance visibility and provide visual cues to drivers, improving pedestrian safety at crossings. Intelligent traffic lights use advanced algorithms and sensors to optimize traffic flow, prioritize pedestrian safety, and adjust signal timings based on pedestrian volume. Wearable safety devices, such as reflective vests or LED armbands, increase pedestrian visibility in low-light conditions and improve road safety. Smart street lighting systems adjust lighting levels based on the pedestrian presence and ambient conditions, enhancing visibility, and ensuring safer walking environments.

A few researchers developed innovative and smart ideas for improving pedestrian safety at intersections in the past. For example, Nambisan et al. (2009) assessed automatic pedestrian detection and smart lighting for safety. They compared pedestrian behavior and driver yielding rates before and after installation at a Las Vegas location. By examining the percentages of pedestrians who attentively surveyed their surroundings before and during the crossing, as well as the percentages of drivers who yielded to pedestrians, a comprehensive evaluation was conducted to compare the pre- and post-installation conditions of automatic pedestrian detection and smart lighting at a mid-block location in Las Vegas, Nevada. The results revealed notable safety enhancements, affirming the positive impact of these devices on overall safety.

Table 1 describes some technologies and devices that can enhance the travel and safety of visually impaired pedestrians at intersections. Also, it presents the functional requirements associated with each of these technologies or devices.

Table 1 Functional requirements of different devices/technologies for assisting travel of visually impaired pedestrians at intersections

Device/technology	Description	Functional requirement
Audible Pedestrian Signal	These devices emit audible signals, such as beeps or spoken messages, to indicate when the walk phase of the pedestrian cycle is initiated.	• Emit clear and distinguishable audible signals to indicate when it is time to cross the intersection. • Provide different sound patterns or tones to convey crossing directions. • Offer adjustable volume levels to accommodate individual preferences and environmental conditions. • Include push-button activation for pedestrians to request a pedestrian signal.
Tactile Warning-Surface Indicator (TWSI)	These textured surfaces, commonly known as tactile paving, provide tactile feedback underfoot to help visually impaired individuals navigate the intersection safely.	• Provide detectable and slip-resistant tactile cues on the ground surface at the intersection. • Offer consistent patterns and textures to indicate the presence of a crosswalk or crossing points. • Maintain durability and resistance to weather and wear.
Accessible Pedestrian Signal	These signals incorporate audible and tactile elements, providing sound and vibration cues to assist visually impaired pedestrians in crossing the intersection.	• Combine audible signals and tactile cues to guide visually impaired pedestrians. • Align with established accessibility guidelines and standards. • Provide intuitive and easy-to-understand interfaces for pedestrians to interact with the signals. • Allow for customization of volume, tone, and timing parameters.
Bluetooth Low Energy (BLE) Beacon Systems	These systems use Bluetooth technology to communicate with smartphones or wearable devices, providing auditory or haptic cues to guide visually impaired individuals through intersections.	• Ensure compatibility with a wide range of smartphones and wearable devices. • Support reliable and accurate proximity detection and communication with user devices. • Enable seamless integration with navigation applications. • Provide clear and understandable auditory or haptic cues to guide visually impaired individuals.
Mobile applications	Various smartphone applications leverage GPS, real-time traffic data, and intersection information to provide audible or haptic instructions to visually	• Utilize GPS and real-time traffic data to provide accurate intersection information. • Deliver clear and concise audio instructions for crossing intersections. • Support accessibility features such as text-to-speech functionality.

Device/technology	Description	Functional requirement
	impaired individuals navigating intersections.	• Incorporate user-friendly interfaces with intuitive controls and navigation options.
Pedestrian detection system	These systems use advanced sensors, such as cameras or infrared sensors, to detect the presence of pedestrians at intersections. When a visually impaired person is detected, the system can trigger audible or tactile alerts to improve safety.	• Utilize advanced sensors, such as cameras or infrared sensors, for reliable detection of pedestrians. • Ensure real-time and accurate detection to trigger alerts or notifications. • Integrate with existing traffic management systems or infrastructure. • Provide adjustable detection range and sensitivity to accommodate various intersection layouts and conditions.
Wayfinding system	These systems provide audio directions and guidance, helping visually impaired individuals navigate from their current location to their desired destination, including assistance at intersections.	• Utilize reliable navigation algorithms and data to provide accurate and up-to-date directions. • Deliver clear and understandable audio instructions for navigating intersections. • Integrate with other accessibility features and applications. • Consider individual preferences and needs, such as customizable voice settings and route preferences.

It is worth noting that the specific technologies and devices implemented may vary depending on the smart city infrastructure and available resources. These functional requirements aim to ensure that each device and technology performs effectively in assisting visually impaired pedestrians at intersections, prioritizing their safety and ease of use.

Improving pedestrian travel and safety in smart city environments through technology and devices brings challenges that require collaboration among multiple stakeholders. These include the government, the general public, tech companies, experts in disability domains and Departments of Transportation (DOTs), who need to work together to ensure the effective deployment and resolution of these challenges.

2.1.3. Challenges related to pedestrian travel and safety in the context of smart cities

Table 2 provides an overview of the challenges associated with pedestrian travel and safety in smart cities. In addition to privacy concerns, integrating new technologies, managing cybersecurity risks, handling data overload and analysis, ensuring accessibility and inclusivity, addressing user acceptance and behavior, deploying infrastructure, and managing limited scalability pose significant hurdles for developing smart cities. Further details on each of these challenges are briefly discussed in Table 2.

Addressing these challenges requires collaboration between city planners, technology providers, policymakers, assistive technology professionals and community stakeholders to ensure smart city initiatives prioritize pedestrian safety and create inclusive, efficient, and secure urban environments.

Previous studies have examined different safety measures at intersections (Pulugurtha and Self, 2015; Pulugurtha et al., 2011; Vasudevan et al., 2011; Dangeti et al., 2010; Pulugurtha et al., 2010a; Pulugurtha et al., 2010b; Nambisan et al., 2009; Karkee et al., 2006). However, the unpredictability of pedestrian behaviors is still making pedestrian-vehicle interactions challenging. Therefore, enhancing road safety requires more accurate detection and tracking methods to effectively assess pedestrian-vehicle interactions.

Table 2 Challenges related to pedestrian travel and safety in the context of smart cities

Challenge	Description
Privacy concern	Smart city technologies collect and process vast amounts of data, including information about pedestrians. Balancing the use of this data for enhancing safety while protecting individual privacy poses a challenge that needs to be carefully addressed.
Integration of new technology	Implementing and integrating new technology, such as sensors, connected devices, and smart infrastructure, into pedestrian safety systems can present challenges. Ensuring seamless communication and interoperability between different components is essential for effective pedestrian safety management.
Cybersecurity risk	Smart city systems are vulnerable to cyber threats, and any compromise in the security of these systems can have severe implications for pedestrian safety. Implementing robust cybersecurity measures and ensuring the protection of sensitive data are critical challenges.
Data overload and analysis	Smart cities generate large volumes of data from various sources, including sensors, cameras, and mobile devices. Effectively managing and analyzing this data to extract meaningful insights for pedestrian safety planning and interventions can be challenging.
Accessibility and inclusivity	Smart city technologies should be accessible and usable by all individuals, including those with disabilities or special needs. Ensuring that pedestrian safety measures and smart infrastructure cater to diverse user groups is crucial for inclusive urban environments.
User acceptance and behavior	Encouraging pedestrians to adopt and adhere to new safety technologies and practices can be challenging. Changing user behavior, such as promoting distraction-free walking or educating pedestrians about interacting with smart infrastructure, requires effective communication and public awareness campaigns.
Infrastructure deployment	Installing and maintaining the necessary infrastructure for smart pedestrian safety systems can be complex and costly. Smart city initiatives require significant investments for deploying sensors, cameras, connectivity, and other supporting infrastructure to ensure seamless monitoring and response capabilities.

Challenge	Description
Limited scalability	Scaling up smart pedestrian safety systems across an entire city can be challenging due to budget constraints, technological limitations, and coordination among multiple stakeholders involved in the implementation.

The next section focuses on exploring, developing, and demonstrating novel technologies and methods for collecting data and evaluating pedestrian safety, building upon the preceding discussion on devices/technologies and challenges in pedestrian travel and safety.

2.2. Exploring, developing, and illustrating the working of novel technologies and methods to collect data and assess pedestrian safety

This subtask involves investigating, creating, and demonstrating the functionality of innovative technologies and methods for collecting data and evaluating pedestrian safety within smart city environments. This includes exploring new approaches and tools that can be utilized to gather relevant data on pedestrian movement and potential hazards. Additionally, it entails developing methods to analyze the collected data to assess pedestrian travel and safety within the context of smart cities. The objective is to showcase practical solutions that leverage IoT capabilities to enhance pedestrian safety and inform urban planning and infrastructure improvements.

In this regard, object detection and tracking technologies using video data are explored. Compared with other data sources such as radio detection and ranging (RADAR), light detection and ranging (LiDAR), loop detectors, and Bluetooth sensors, video data offer a microscopic view of natural traffic scenes of these interactions (Zhang et al., 2020; Ka et al., 2019; Wu et al., 2019; Wang et al., 2012). Also, pedestrians and vehicles are not necessarily aware that their behaviors are recorded through a camera, making this data collection option more convenient for understanding communication between pedestrians and vehicles and assessing the risks they pose to each other when they sometimes make evasive actions.

These detection and tracking algorithms are extensively used for video pattern recognition. They help detect and track pedestrians and vehicles and extract their patterns for assessing pedestrian safety. In this study, YOLOv4 (Redmon et al., 2016) and DeepSORT (Wojke et al., 2017) were used to detect, track, and extract patterns of pedestrians and vehicles in the road environment and assess pedestrian safety. YOLOv4 was chosen since it offers a better ratio of speed to accuracy (Chahal and Dey, 2018). DeepSORT can find a previously tracked object (person or vehicle) even if it has been occluded (Wojke et al., 2017). Figure 1 shows how YOLOv4 and DeepSORT algorithms work.

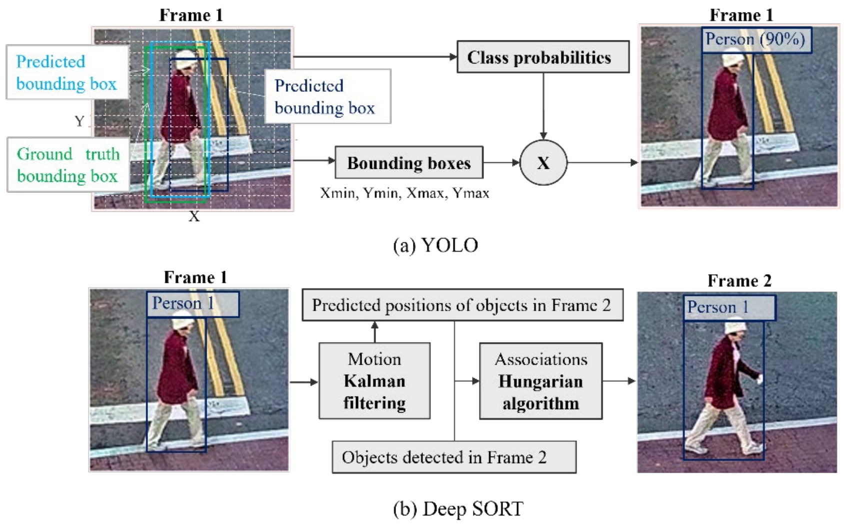


Figure 1 Steps involved in object detection and tracking

In object detection and tracking, as shown in Figure 1, the process begins by dividing Frame 1 into an S×S grid, typically 19×19. This grid is responsible for predicting probabilities of n object classes (e.g., pedestrian or vehicle) and b bounding boxes (usually 5), each accompanied by a confidence score. Motion information is estimated through the utilization of a Kalman filter. To maintain the identities of pedestrians and vehicles, their feature embeddings are tracked and associated across frames using the Hungarian algorithm (Wojke et al., 2017). A detection is considered a true positive if it has a minimum overlap of 50% with the corresponding ground truth bounding box.

2.2.1. Data collection and extraction

The data was collected at the intersection of Cabarrus Ave and Union St in Charlotte, North Carolina, specifically at a signalized crosswalk depicted in Figure 2. The geographical coordinates for this location are approximately 35.4105695° latitude and -80.5813986° longitude. Both intersecting roads have a speed limit of 25 mph. The traffic cycle at this intersection lasts 60 seconds, consisting of a 35-second green phase for vehicles and a 20-second red phase. This site was based on observed pedestrian violations, including disregarding traffic lights and jaywalking (defined as crossing outside designated crosswalks). The crosswalk's unique design, incorporating parking lanes, further increases the likelihood of jaywalking and makes it a suitable location for evaluating pedestrian safety.

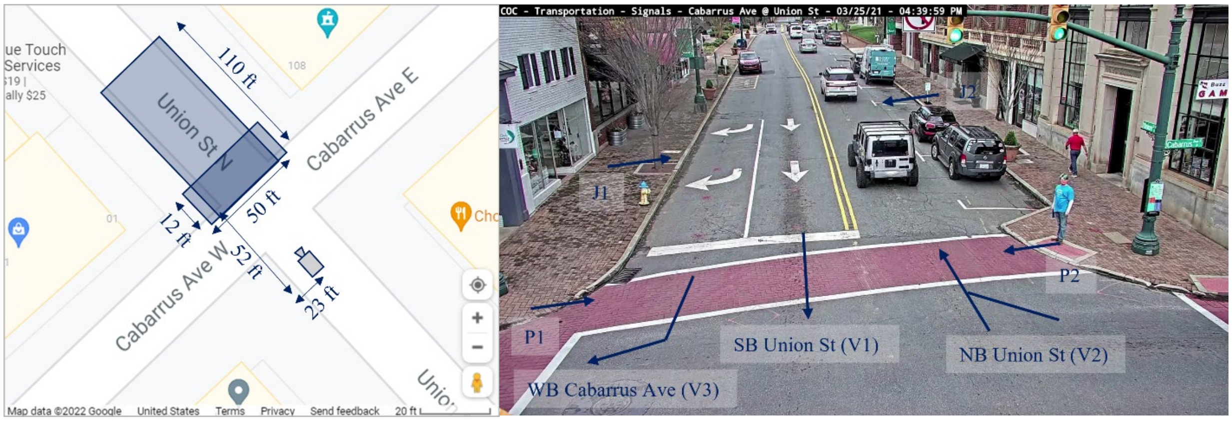


Figure 2. Study location© 2023 Google Maps, (a) Field of data collection, (b) Vehicle and pedestrian crossing directions

Note: V, P, and J denote the direction of travel or crossing of vehicles, regular pedestrians, and jaywalkers, respectively.

The video data was collected on March 25 and 26, 2021, using a camera mounted on the opposite traffic signal pole at an approximate height of 9 feet. The video has a resolution of 1920×1080 pixels and a frame rate of 30 frames per second (fps). A total of 12 hours of recorded videos (from 7:00 AM to 7:00 PM) for each day was used in this study. Figure 2 provides details on the field of data collection. A trap length of 110 feet was sufficient for effective observation of the road environment and vehicle and pedestrian patterns/trajectories near the crosswalk. This length also aligns with the driver stopping sight distance. Hence, the data collection focused on detecting and tracking pedestrians and vehicles within the highlighted zones in Figure 2a, utilizing YOLOv4 and DeepSORT algorithms.

The analysis comprises two primary phases. A safety analysis was conducted in the first phase based on the outputs obtained from detection and tracking patterns. Vehicle speed and post-encroachment time (PET) were considered as surrogate safety measures. By analyzing these factors, insights can be gained regarding the overall safety performance of the system in real-world scenarios. It is worth noting that only pedestrians and vehicles with consistent identities were used for analysis in this study. This evaluation allows for assessing how well the system performs in different environmental settings.

Vehicle speeds are computed using Equation 1 and Equation 2, based on Figure 3. These equations have been proposed by Fu et al. (2016) and can be used to compute pedestrian speeds as well. PET is computed using Equation 3. It is defined as the time difference between the first road user (pedestrian in this study) leaving the virtual conflict zone (t_1) and the second road user reaching the same conflict zone (t_2) (Varhelyi, 1998).

$$\mathrm{v_{i,j}} = \frac{1}{\mathrm{l - f + 1}} \sum_{\mathrm{k=f}}^{\mathrm{l}} (\mathrm{v_{i,j,k}}) \qquad (1)$$

$$\overline{v_i} = \frac{1}{\mathrm{q}} \sum_{\mathrm{j=1}}^{\mathrm{q}} (\mathrm{v_{ij}}) \qquad (2)$$

where $v_{i,j,k} = \frac{x_{j,k} - x_{j,k-1}}{t_{j,k} - t_{j,k-1}}$ is the instantaneous crossing speed of a certain pedestrian or vehicle $j, j = (1, \dots, q)$, x are its x-coordinates at frames k and $k-1$ that falls within the defined crosswalk area as shown in Figure 2, t refers to the related instants of its detections, $\overline{v_i}$ is the average crossing speed of pedestrians or vehicles depending on the side i of the crosswalk, or the direction they are traveling, and f and l stands for the first and last frames that falls within the conflict zone.

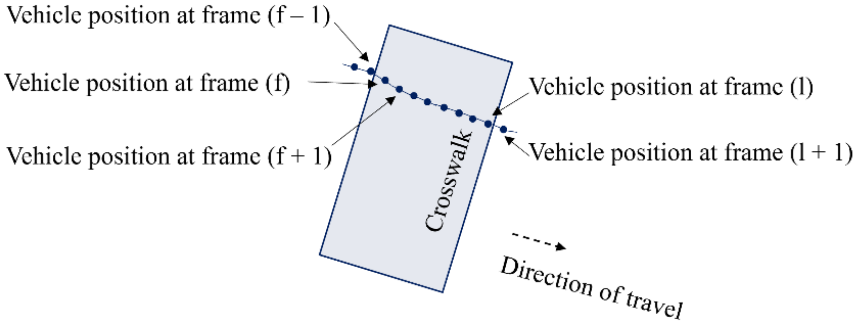


Figure 3. Illustration of vehicle speed estimation

$$\mathrm{PET} = \mathrm{t}_2 - \mathrm{t}_1 \qquad (3)$$

2.2.2. Results

Table 3 summarizes traffic volumes captured during the study period. None of the proportions exceeded 50%. However, there is a distinct pattern of increasing pedestrian and vehicular traffic in the afternoon compared to the morning.

Table 3. Results - variability of vehicular traffic and crossing pedestrian flows

Time of the day (TD)	Vehicular flow direction			Pedestrian flow direction			
	V1	**V2**	**V3**	**P1**	**P2**	**J1**	**J2**
07:00 AM - 09:00 AM (TD1)	216 (6.1%)	422 (13.1%)	102 (10.4%)	24 (7.9%)	22 (7.2.%)	14 (14.6%)	6 (15.0%)
09:00 AM - 11:00 AM (TD2)	330 (9.3%)	414 (12.8%)	94 (9.6%)	26 (8.6%)	40 (13.1%)	11 (11.5%)	4 (10.0%)
11:00 AM - 01:00 PM (TD3)	508 (14.4%)	564 (17.5%)	196 (20.0%)	72 (**23.8%**)	56 (18.3.%)	16 (16.7%)	4 (10.0%)
01:00 PM - 03:00 PM (TD4)	870 (**24.6%**)	618 (19.1%)	182 (18.5%)	66 (21.9%)	58 (19.0%)	18 (18.7%)	12 (**30.0%**)
03:00 PM - 05:00 PM (TD5)	772 (21.8%)	694 (**21.5%**)	190 (19.3%)	64 (21.2%)	62 (20.3%)	25 (**26.0%**)	8 (20.0%)
05:00 PM - 07:00 PM (TD6)	844 (23.8%)	516 (16.0%)	218 (**22.2.%**)	50 (16.6%)	68 (**22.2%**)	12 (12.5%)	6 (15.0%)
Total (TD1-TD6)	3540 (100%)	3228 (100%)	982 (100%)	302 (100%)	306 (100%)	96 (100%)	40 (100%)

Note: V1, V2, V3 are vehicle travel directions, and P1/J1 and P2/J2 are pedestrian/jaywalker crossing directions as indicated in Figure 2b.

Data extraction involves locating pedestrians and vehicles using the middle bottom point of their respective bounding boxes. This approach enables the generation of pedestrian and vehicle patterns, as shown in Figure 4. By focusing on the middle bottom point, the analysis captures the central position of each detected object, providing valuable information about their movements and trajectories. These patterns can offer insights into pedestrian crossing behaviors, vehicle interactions, and overall traffic dynamics.

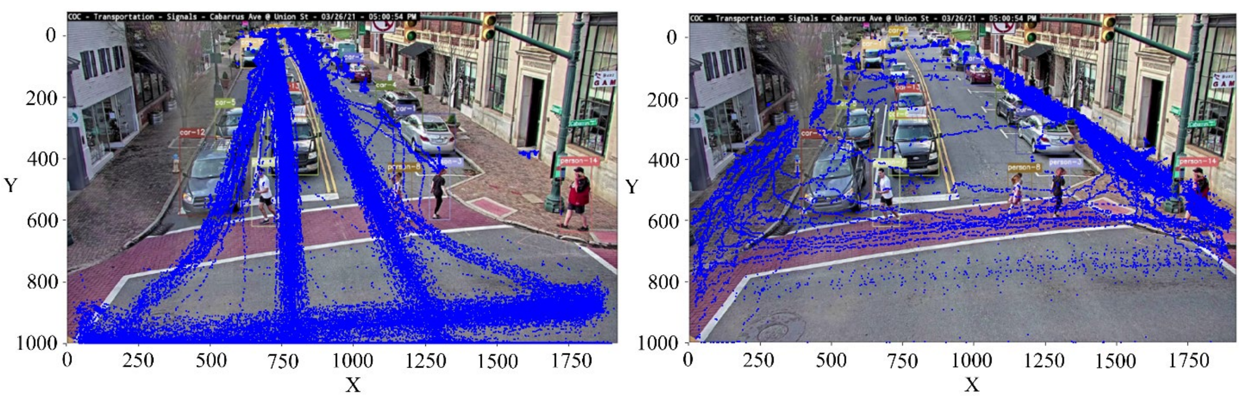
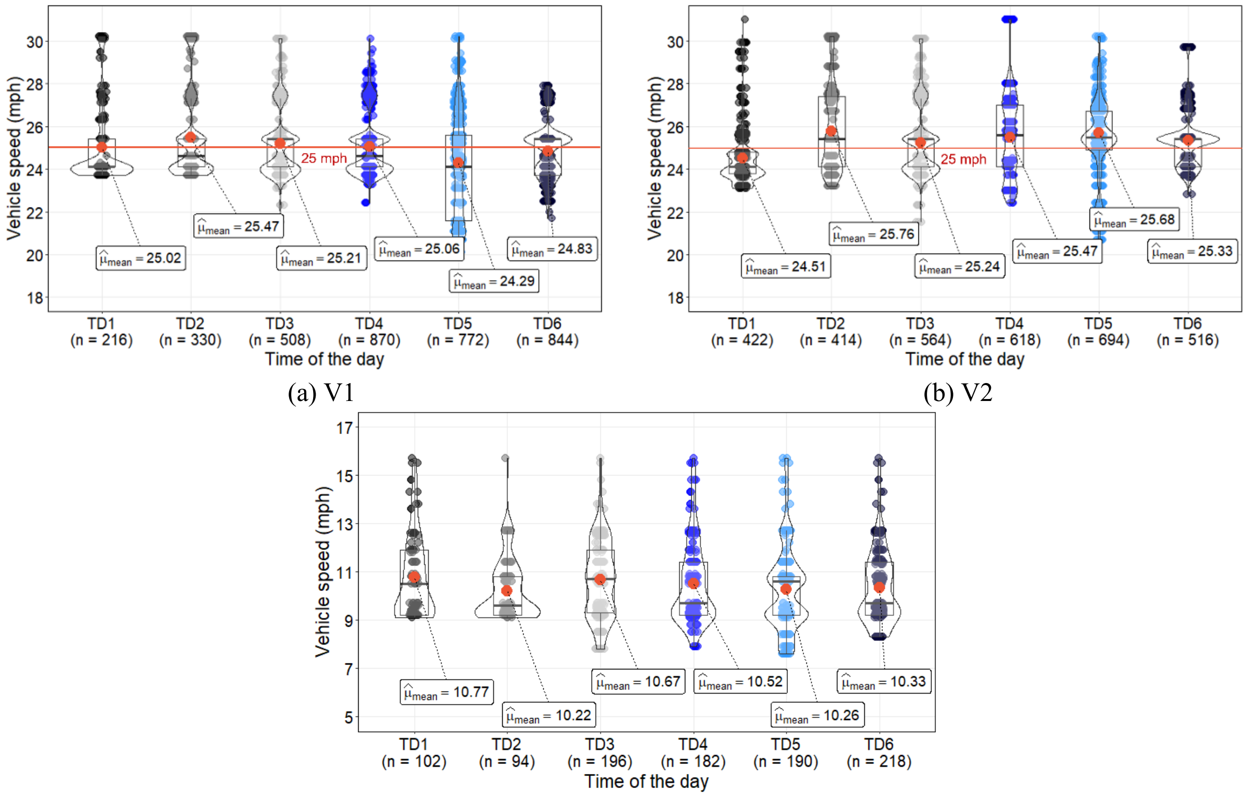


Figure 4. Snapshots of patterns/trajectories, (a) Vehicles, (b) Pedestrians

Figure 4b shows instances of jaywalking despite being a signalized intersection, indicating potential design, enforcement, and education issues. Pedestrian safety may be compromised due to the compact intersection, short lane widths, and obstructed visibility caused by parking lanes. Further investigation is needed to assess pedestrian-vehicle interactions and predict severe conflicts.

Figure 5, which displays the average speeds of vehicles categorized by direction, shows that the mean speeds align with the legal speed limit of 25 mph. However, Figure 5 shows that some drivers exceeded the speed limit. Out of the total 7,750 counted vehicles, as summed from Table 1, approximately 45% (3,518 vehicles) exceeded the speed limit. This increases the risk to pedestrians, particularly jaywalkers and those disregarding traffic lights. Research by Chaudhari et al. (2021) and Rosén and Sander (2009) confirms a strong correlation between vehicle speed, pedestrian fatality risk, and crash likelihood. As the speed increases, the PET value decreases, increasing crash probability.



(a) V1 (b) V2

(c) V3

Figure 5. Distribution of average vehicle speeds by the time of the day and direction of travel.

The validation process involved microscopic and macroscopic evaluations of trajectories and average speeds depicted in Figure 4 and Figure 5 using Kinovea software (Charmant et al., 2021). Data from the highest vehicle and pedestrian flows observed during the allocated green phase were utilized. Regarding microscopic validation, the longitudinal and transversal trajectories of vehicles and pedestrians obtained through the tracking-by-detection approach were compared with manually extracted trajectories using a paired sample t-test. All p-values exceeded 0.05, indicating no statistically significant difference between the trajectories obtained from the two methods. Moving to macroscopic validation, vehicle and pedestrian speeds were compared with the manually extracted speeds. The results were satisfactory, with R-squared values ranging from 61% to 84% depending on the type of road user (vehicle or pedestrian) and their direction of travel or crossing.

[Figure 6](#) shows the results of the pedestrian-vehicle conflict analysis conducted in this study. Figure 6a shows the distribution of the levels of severity of conflicts between pedestrians and vehicles. PET values are categorized under “no conflict” (PET: >6s), “slight conflict” (>3s & ≤6s), and “severe conflict” (≤3s). The PET threshold was set to be 6s according to the literature to determine if there was a dangerous condition for the pedestrian (Formosa et al., 2020; Radwan et al., 2016).

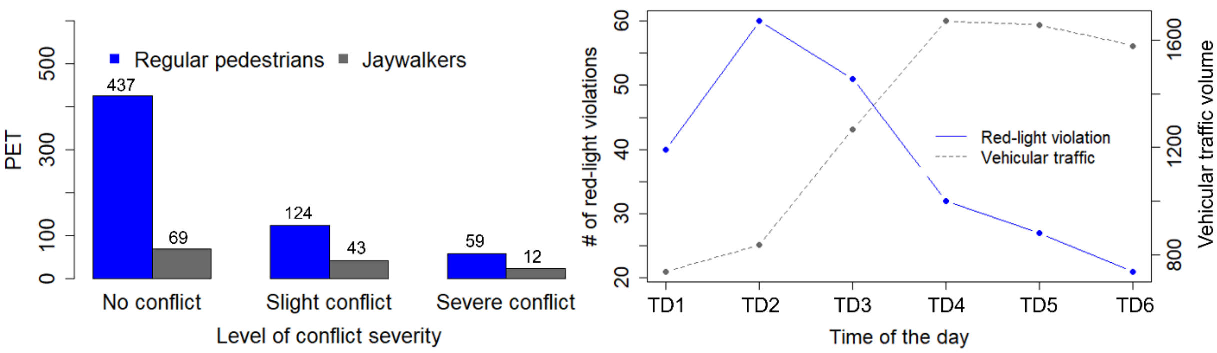


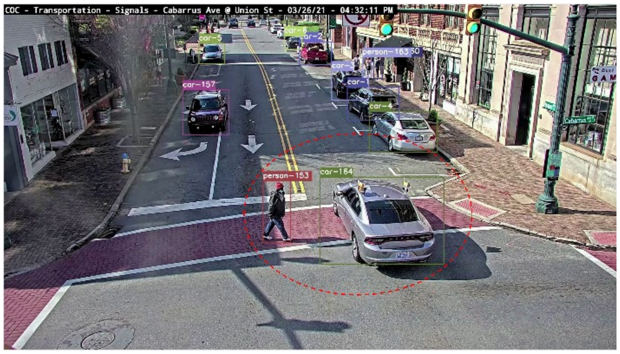
Figure 6. Pedestrian-vehicle conflict analysis, (a) Distribution of PETs, (b) Pedestrian red-light violations vs. vehicular traffic volume

Figure 6b shows that 56.6% of severe conflicts involving regular pedestrians were due to red-light violations. Previous literature supports this correlation between conflicts, jaywalking, and red-light violations. Additionally, 92.4% of jaywalkers and 82.1% of regular pedestrians identified were male, consistent with research on male pedestrians' higher tendency to violate traffic rules.

As vehicular traffic volume increases throughout the day, the incidence of traffic violations by pedestrians tends to decrease. This is depicted in Figure 6b and aligns with previous studies (Diependaele, 2019; Duduta et al., 2014) that reported similar findings. Notably, approximately 90% of all jaywalkers crossed the road against the red light, accounting for around 53% of the total red-light pedestrian violations. The remaining 47% involved regular pedestrians. There is a similarity in the behaviors of jaywalkers and visually impaired people due to their shared lack of situational awareness. Both jaywalkers and visually impaired individuals may have limited situational awareness on the road. Jaywalkers might not be fully aware of their surroundings or may underestimate the speed and distance of approaching vehicles. Visually impaired individuals may have difficulty perceiving or interpreting visual cues, such as traffic lights, road signs, or the presence of oncoming vehicles.

2.2.3. Current challenges in pedestrian and vehicle detection and tracking

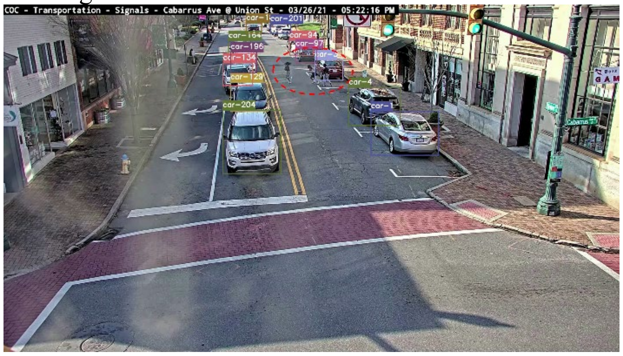
The set of illustrations in Figure 7 describes some unsafe pedestrian situations and challenges faced while detecting and tracking pedestrians and vehicles in different weather and lighting conditions within the road environment. These challenges highlight the potential risks that can arise in such situations, often leading to crashes. Adverse weather conditions like rain can reduce visibility and make detecting and tracking pedestrians and vehicles more difficult. Similarly, varying lighting conditions, such as low light, can further impede detection and tracking, increasing the likelihood of crashes. By recognizing and understanding these challenges, researchers and practitioners can develop effective strategies and technologies to improve safety measures and mitigate the risks associated with detecting and tracking pedestrians and vehicles in diverse environmental conditions.



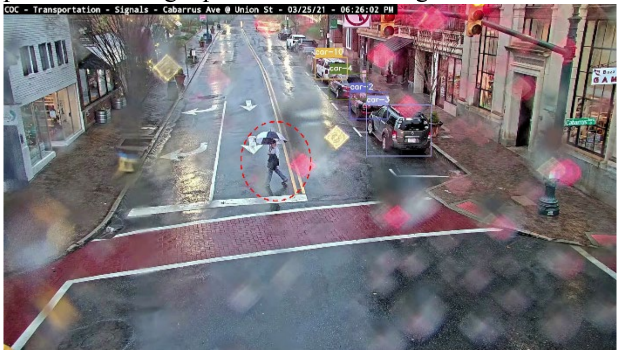
(a) A pedestrian in conflict with a vehicle during the vehicle green phase

(b) A jaywalker and a pedestrian on the phone while crossing the road

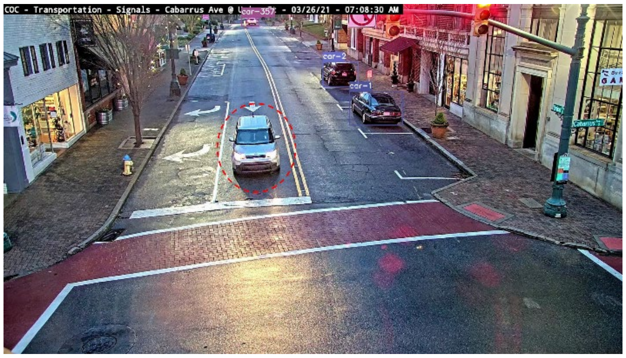
(c) A fire hydrant detected as a pedestrian and a pedestrian using a phone while crossing the road



(d) A group of jaywalkers running from the right sidewalk to the left one



(e) A non-detected pedestrian with an umbrella crossing the road under the rain



(f) A non-detected vehicle in a softly illuminated road environment

(g) An occluded and non-detected pedestrian crossing the road

(h) A detected pedestrian with a non-detected baby in a stroller

Figure 7. Challenges in pedestrian and vehicle detection and tracking

Based on cases presented in Figure 7, solutions for object detection and tracking challenges include:

- Real-time detection and alert system for pedestrian-vehicle conflicts during the green phase.
- Enhanced detection and warning system for jaywalkers, distracted pedestrians, and visually impaired individuals.
- Improved classification to differentiate other objects, such as fire hydrants from pedestrians.
- Enhanced group detection and tracking for jaywalkers with trajectory prediction.
- Robust detection of pedestrians with or without umbrellas in rainy or other adverse conditions.
- Advanced techniques for detecting vehicles in softly illuminated or dark environments.
- Robust detection and tracking with specialized warning of occluded pedestrians, pedestrians holding phones, or babies in strollers.

2.3. Building a mechanism for real-time notification/alarming of pedestrians to incoming vehicular traffic (directly to the user or through signs/signals)

This subtask involves designing and implementing a mechanism that enables real-time notifications or alerts to pedestrians regarding approaching vehicular traffic. This mechanism enhances pedestrian safety by providing timely information about potential vehicle interactions. The mechanism needs to be designed to deliver notifications directly to individual pedestrians, such as through a mobile application or wearable device or signs and signals placed strategically in the smart city infrastructure. The goal is to establish a reliable and efficient system that effectively warns pedestrians of nearby vehicles, reducing the risk of crashes and improving the overall pedestrian travel experience in smart cities. A project by Honda introduced in 2019 has sought to use V2X communication to create a SAFE SWARM™ and continues to seek collaborations (Schranz et al., 2021).

The more straightforward mechanism for real-time notification of pedestrians, particularly focusing on visually impaired pedestrians in a smart city environment, could involve the following requirements.

- Pedestrian and vehicle detection through computer vision algorithms and sensors, such as cameras to detect and track pedestrians in real-time.
- Pedestrian recognition using advanced pattern recognition techniques to identify visually impaired pedestrians among the detected individuals. This can be achieved through characteristics like walking aids (e.g., white cane or guide dog) or specific body movements.
- Communication device by equipping visually impaired pedestrians with a wearable or handheld device, such as a smartphone or smartwatch, capable of receiving real-time notifications.
- Data exchange by establishing a seamless communication network between the pedestrian detection system and the wearable devices to exchange relevant information.
- Proximity alert: When a visually impaired pedestrian is detected in proximity to incoming vehicular traffic, the system triggers an alert signal on the wearable device.
- Alert modes: The wearable device can provide alerts through various modes, such as vibrations, audible signals, or voice notifications to inform visually impaired pedestrians about potential danger.
- Navigation assistance integration: The existing wayfinding tool/app communicates route information to infrastructure and combines with detection systems to identify if crossings are safe.

By combining these components, visually impaired pedestrians can receive real-time notifications about approaching vehicular traffic and obtain assistance to navigate the smart city environment more safely.

In 2021, the U.S. Department of Transportation (U.S. DOT) released a study on phase 3 of the connected vehicle pilot deployment program (Ozbay et al. 2021) conducted by the New York City Department of Transportation (NYCDOT). The report focused on the mobile accessible pedestrian signal system (PED-SIG) application test for visually impaired individuals, implemented in New York. PEG-SIG stands for Personal Electronic Navigation Device with Spatial Information Guidance. The PED-SIG system consists of a portable device, such as a smartphone or dedicated device, equipped with sensors like GPS, inertial measurement units, and cameras. These sensors collect information about the user's environment, enabling the system to offer real-time feedback and guidance for navigation purposes. Smith et al. (2019) from Carnegie Mellon University developed a system that enhances mobility and safe intersection crossing for pedestrians with disabilities. This system connects them to adaptive signal control, improving their accessibility and pedestrian experience.

In addition to notifying pedestrians about incoming vehicles, the system should inform vehicles of pedestrians likely to cross the road. This creates an additional layer of safety awareness. Drivers can anticipate pedestrian crossing intentions by observing various non-verbal cues, including hand gestures, visual scanning (for example, looking left and right), and body posture. Many of these cues will not be communicated to a pedestrian with a visual impairment, or the vehicle operator could misunderstand the pedestrian's intentions. By incorporating this information, the system enables vehicles to be aware of pedestrians who may cross their paths, enhancing overall safety on the road. These features will become critical in the future with CAVs making up an increasing number of vehicles at intersections.

Figure 8 illustrates how pedestrian crossing intention can be detected and predicted using the algorithm FuSSi-Net (Piccoli et al., 2020). YOLOv4, DeepSORT, and DenseNet were integrated to detect and track pedestrians and their crossing intentions from a fixed camera. The original algorithm used YOLOv3 and made pedestrian crossing intention prediction from a moving vehicle's onboard camera. Therefore, it allows the system or the driver to predict pedestrian crossing intention. The end-to-end system indicates risky pedestrian intentions up to 16 frames before the actual action, corresponding to half a second before the risky maneuver. The crossing intention classifier distinguishes between not crossing (green bounding box) and crossing (red bounding box), as shown in Figure 8.

Figure 8. Illustrations of pedestrian crossing intention estimation. (a) Crossing from the left sidewalk (b) Crossing from the right sidewalk

The skeleton fitting algorithm used up to seventeen key points to detect a pedestrian and his/her crossing intent, with nine key points essential for pedestrian crossing classification. The nine key points are the left and right shoulder, hip, knee, ankle, and a point between the left and right shoulder. Three hundred and ninety-six features based on angles and distances between skeleton points are computed for classification using these key points.

2.4. Assessing potential impacts as well as acceptability of advanced technologies by stakeholders and general public

This subtask involves evaluating the potential impacts and gauging the acceptability of advanced technologies among stakeholders and the general public in the context of smart city pedestrian travel. This assessment aims to understand how introducing IoT solutions and related technologies may affect various stakeholders, including pedestrians, city officials, urban planners, and other relevant parties. Additionally, it involves investigating the level of acceptance and receptiveness of these technologies among the general public. It can include conducting surveys, interviews, focus groups, or other research methods to gather feedback and opinions. The objective is to gain insights into the potential benefits, concerns, and considerations associated with implementing advanced IoT solutions for pedestrian travel in smart cities and to inform decision-making and further refinement of the solutions accordingly.

Various technologies have been implemented worldwide to assist visually impaired pedestrians in their travel and safety. One such technology is the Smart Accessible Pedestrian Signal System (SAPSS), evaluated in Taiwan by Huang et al. (2022), to aid pedestrians, especially those with visual impairments, in safely crossing roads. Researchers from Carnegie Mellon University developed a system that connects pedestrians with disabilities to adaptive signal control for safe intersection crossing and enhanced mobility (Smith et al., 2019). Another approach, PED-SIG, was recently discussed in a report by the NYCDOT (Ozbay et al., 2021). The report, which evaluates the PED-SIG system, serves as the primary reference for discussions on the acceptability and potential impacts of advanced technologies for pedestrian travel and safety assistance. It includes the system design, data management, mobile application, experiment design, and test and field experiment results and validation. The report lacks any reference to specialized interfaces for pedestrians with visual impairments like audible output or scree reader access, although it may be assumed from the intent of the product design.

2.4.1. Potential impacts of advanced technologies by stakeholders and general public

From the perspective of city officials and urban planners, advanced technologies like detection and tracking of pedestrians and vehicles, as well as mobile accessible pedestrian signal systems for the visually impaired, can have the following potential impacts.

- Improved safety: These technologies can enhance the safety of all road users, especially pedestrians, by providing real-time information or notification.
- Enhance accessibility: Technologies such as mobile accessible pedestrian signal systems can allow visually impaired individuals to navigate cities and road crossings more independently, promoting inclusive and equitable urban environments.
- Efficient traffic management: City officials and urban planners can utilize the insights gained from accurately detecting and tracking pedestrians and vehicles to optimize traffic signal timings, design pedestrian-friendly infrastructure, and enhance overall traffic management efficiency.
- Data-driven decision-making: The data collected through these technologies can lead to more effective and targeted interventions for improving the safety of pedestrians.

From the pedestrian perspective, the following are the potential impacts of advanced technologies.

- Enhanced safety: Mobile-accessible pedestrian signal systems provide pedestrians, especially visually impaired individuals, with improved awareness of visual signalized information, including traffic cycle countdowns.
- Increase independence: These connected CAV systems could empower visually impaired pedestrians by providing real-time information and warnings.

- Improved accessibility and reduced stress: Mobile-accessible pedestrian signal systems make urban spaces more accessible by providing information on a personal device that may have customized or special interfaces enabled.

2.4.2. Acceptability of advanced technologies by stakeholders and general public

The acceptability of these advanced technologies by different stakeholders, including the general public, is impeded by several concerns despite the potential impacts or benefits. Some of the concerns people have regarding these advanced technologies were summarized in Table 2. They are briefly discussed next.

City officials and urban planners seem concerned regarding the cost and budget associated with implementing detection, tracking, and mobile accessible pedestrian signal systems in urban environments. Another concern is the integration and compatibility of these new technologies with existing infrastructure. Retrofitting and upgrading current infrastructure systems is a must for transitioning to a smart city environment. Technical expertise, public acceptance and perception, and data management and privacy are other concerns city officials and urban planners seem to face.

Pedestrians may have several concerns about advanced technologies such as the detection and tracking of pedestrians and vehicles and mobile-accessible pedestrian signal systems. There could be worries about privacy and the potential misuse of personal data, doubts about the reliability and accuracy of the technology, concerns about accessibility and inclusivity for all individuals, fears of becoming overly dependent on technology, and the potential exacerbation of existing disparities in access to these technologies. Addressing these concerns requires transparent communication, strong data protection measures, reliable technology, inclusive design, and equitable access to ensure the acceptance and trust of pedestrians in these advanced technologies.

2.5. Summary

In summary, this task focused on enhancing pedestrian travel and safety in smart cities by illustrating the use of advanced technologies. Firstly, the functional requirements for testing and implementing these technologies, considering the specific challenges faced in pedestrian travel and safety within smart city environments, were discussed.

Secondly, the functionality of novel technologies and methods for collecting data and assessing pedestrian safety was developed and demonstrated. YOLOv4 and DeepSORT were utilized to effectively collect and analyze data related to pedestrian movement and potential hazards, thereby improving the understanding of pedestrian safety within smart cities.

Thirdly, the components required for real-time notification of pedestrians, with a particular emphasis on visually impaired individuals, concerning incoming vehicular traffic are discussed. The objective was to enhance the potential benefits of implementing a system with timely notifications concerning the safety and mobility of pedestrians, especially those with visual impairments.

Finally, the potential impacts and concerns associated with the accessibility of advanced technologies such as detection, tracking, and mobile-accessible pedestrian signal systems were addressed among stakeholders and the general public. By considering the perspectives of various stakeholders, valuable insights were gained into the potential benefits, concerns, and considerations related to implementing these technologies in smart cities.

Overall, this study contributes to the advancement of pedestrian travel and safety in smart cities by providing functional requirements, demonstrating novel technologies, proposing real-time notification systems, and addressing the potential impacts and concerns associated with the accessibility of advanced technologies. The findings from this study can inform decision-making and guide further research and development in improving pedestrian travel and safety within smart city environments.

Report Body – Chapter - Project 2: Task 2

IOT Solutions for Near Horizon Challenges in Smart City Pedestrian Travel (Task 2.2)

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2.6. Communications with the signal

The processes that are present in a signalized intersection are reasonably complex. The forms of activation and control have changed over time to be more dynamic and less scripted. These changes in activation have required the intersection controls to respond to traffic patterns, intensity, and even its absence. The use of pedestrian controls adds an additional layer and extends the patterns in some situations. All this information can be simplified into a series of inputs and outputs that are managed by central processing units in a switch box. The challenge of creating a custom personal input for a pedestrian with a visual impairment should be a simple matter of reviewing the system and identifying potential points in the system for inserting information or new activation of existing protocols. This theoretically simple problem becomes more complex when one accounts for the diversity of deployments across a state ranging from recent and urban to legacy and rural. For this discussion, we will isolate the opportunities for integration and not delve into the greater system of choices and impacts. This integration will be simplified down to a binary signal, yes/no activation, that will be added to the greater system. In order to better understand the factors impacting such a deployment we will first review the current state of technology in use and training for pedestrians who are blind and visually impaired.

2.6.1. Current state of technology for Pedestrian Crossing

Crosswalk call buttons are already integrated into most traffic intersections. Notable exceptions would be intersections with no crosswalks or intersection sidewalks. Existing systems normally involve a hardwired switch connected to a post within 5 feet of the crosswalk and 10 feet from the curb (Harkey, Carter, Barlow, & Bentzen, 2010). These parameters allow for a reasonable amount of variance with attention to engineering an intersection corner. However, this variance is a confounding factor if a pedestrian is blind and needs to find the button and orient to the crosswalk. Furthermore, the visual display systems to notify a pedestrian are not accessible to many pedestrians with a visual impairment. The field of Orientation and Mobility (O&M) has developed techniques to confirm safe crossings and the evaluation of traffic patterns. In the years since these techniques became common in training the development and deployment of audible/accessible crossing signals has occurred. In that time, focused research has reviewed the impact of this technology (Salisbury, Naghshineh, & Wiener, 2009; Scott et al., 2008; Scott et al., 2014). Deployment has normally focused on areas with high population density or a significant incidence of visual impairments (significant in some cases meaning one person). With a less than saturation level use of audible signals it is still important to teach O&M skills to a high level of proficiency and execution. It is important to understand the availability of call buttons and APS does not erase challenges that are present, but merely provides equitable information to the pedestrian with a visual impairment. The pedestrian who has a visual impairment does not gain any information about the traffic that is not suggested by the phase of a particular signal.

2.6.2. Challenges for the pedestrian who is visually impaired.

The pedestrian with a visual impairment experiences several challenges when engaging the technology at an intersection. These challenges become more pronounced and are magnified when that individual is blind. To engage the problem from its more restrictive case, we will look at the factors impacting a pedestrian who is blind in a hypothetical crossing both with and without the assistance of crosswalk technology. This review will only reflect the crossing choices and not the choices and decisions related to route or navigation during the crossing. Those elements are reserved for Task 3 of this study.

Without APS technology, the pedestrian will arrive at an intersection and have only access to the audible information provided incidentally by the cars present. Audible information from cars will fall into four states: approaching, stationary, accelerating, and receding. These states are communicated by the ambient noise produced by the vehicle, usually the sound of the engine, fans/belts, tires against the pavement, or potentially the stereo system (Emerson et al, 2011). The stationary combustion engine vehicle produces consistent audible information, while the approaching and receding vehicle information is impacted and communicated through changes in decibel level and the doppler effect. The sound of an engine revving up or winding down depending on changes in acceleration will also register to the trained ear. This collection of audible information will communicate relative position, distance, and speed, though not precise enough to always get clear estimations on the size of the intersection or number of lanes. All this information is heavily impacted by traffic density. The absence of traffic in a direction or a lane, means the audible information is also absent, requiring an entirely different set of taught skills (Sauerburger, 2006).

When engaging a crossing, the trained traveler will wait on a signalized intersection until they have confidence in the traffic pattern. Left and right turn lanes are especially important to detect. The traveler may wait for two or more cycles depending on both the traffic and the patterns. Once the traveler is comfortable, they will assert their intent to cross by ensuring the nearest oncoming traffic can see their cane. This is normally completed by pointing the cane toward the center of the intersection. They will then wait for a vehicle in the nearest lane traveling parallel to their intended cross. They will listen for this vehicle to start moving forward and approach the center of the intersection This suggests the car is not moving to make a right turn on red. These vehicles are referred to as near parallel traffic or blocking traffic for short. Once the vehicle is perceived to be crossing the intersection the pedestrian will initiate their crossing, paying careful attention to additional vehicles that may make a turn once the blocking vehicle has exited the intersection. While making a crossing the pedestrian traces the trajectory of the parallel traffic to establish a line of direction that will keep them within the crosswalk. The pedestrian must trace the traffic through the middle of the intersection to be certain that the movement of the vehicle signals a walk cycle rather than a right turn on red. When the walk cycle starts, cars turning in front the pedestrian may delay the initiation of the crossing. This delay could result in the green light changing to yellow or the pedestrian being unsure of the light phasing. This uncertainty stems from the time necessary to cross and pedestrians are trained to wait for another cycle to ensure they have adequate time. This is especially important if the pedestrian is not certain about the presence of the adjacent crosswalk or the number of lanes to cross. Solutions have been tried in some countries to provide this information (Figure 9), but few examples exist in the US.

Figure 9 Tactile Intersection diagram.

When completing the same crossing with the aid of an APS there are several pieces of information that support the process. The pedestrian is aware of the changing of the light, even if traffic is not present. The phase changes of the light are communicated, warning them that they should not initiate a crossing. And finally, the audible (beaconing) sound of the APS on the opposite facing corner will help communicate the ideal path of travel. If the pedestrian requires several cycles to assess and make an accessible crossing, it will be important for the crossing button to be pressed each time since it will likely change the pattern of the traffic, timing, and lane signaling. Each time the pedestrian has to return to the pole with the cross button, the individual’s orientation to the corner is disturbed and must be re-established. The pedestrian who can see the traffic signals also has the benefit of predictive information, from viewing the perpendicular traffic signal for a yellow light, that will help prepare them for the timing of the crossing.

The information shared by an APS helps support efficient and safe crossings. The critical skills and information that ensures a safe crossing cannot be provided by an APS. However, if a means of I2P and P2I communication was established, the additional information in a connected smart city environment could greatly improve the awareness, safety and efficiency of the pedestrian who has a visual impairment. As discussed, in Task 2.1 there are several technologies growing in this area with relation to detection and prediction. The goal of Task 2.2 was to explore means of P2I communication with the assumption that a fruitful protocol will eventually yield a two-way method of communication.

2.6.3 Potential interfaces with intersection controls

Current technologies offer several options for box communications with a pedestrian. The increased adoption of Wi-Fi integration along with DSRC has provided a more robust set of options for development. These communication options are made more dynamic when the RSU (Roadside Unit) is network connected. Most mobile devices are capable of communication via Wi-Fi, Bluetooth, and WAN connection through cloud interfaces. DSRC communication is achievable as well. The two methods that offer the most direct communication are Wi-Fi and Bluetooth. Bluetooth also offers some flexibility with the range of devices available.

Bluetooth communication can be established through one-way packets and paired connections. Bluetooth beacons are a simple one-way packet communication. The small transmitter delivers a string of values that the receiving device can separate and display. It would be easiest to think of these strings as similar to a Comma Separated Value file format (CSV), but not necessarily identical. Through Bluetooth communication, a mobile or specialized device could send a specific message that would cause a Bluetooth receiver to relay a call activation. These receivers are low power devices and many beacons on the market rely on small batteries, though it would not be advised for traffic applications due to required continuing maintenance. More complex Bluetooth communication through pairing would allow a pedestrian device to both call a crossing as well as relay information from the Control Unit. The two-way communication of a paired or authorized app would provide the greatest amount of flexibility in traffic applications.

Wi-Fi communication, similar to most available networks, would allow robust two-way communication between the control unit and a pedestrian device. The function provided would be similar to what is possible with Bluetooth pairing except the device would need to have some level of access to the local network. Within the domain of orientation for individuals with visual impairments there has been a robust conversation regarding the benefits of Bluetooth vs. Wi-Fi communication. The power, networking, and security for Wi-Fi networking setups could be properly designed for traffic applications. Existing network protocols could also be adapted to include the unique needs of call requests from pedestrian devices. An existing application exists with handheld On-Board Units for intersection review and testing.

Cloud interfaces offer the convenience of Wi-Fi communication with an added buffer of security. A cloud-based system would handle the communicated requests and access on a remote server not physically connected to the traffic interface. These requests could be sent through the network connection to the individual control units for execution. In the case of the cloud system the local control unit is not being connected to or communicated with directly. This system requires both the pedestrian’s device and the intersection control unit to have network access. Current mobile devices have strong connectivity, but not all geographical locations offer the same level of access or reliability. The application of a cloud interface always requires a reliable cellular connection, which is achievable but not always present.

The three communication systems shared all have one common demand. The interface must have some form of wired Control Unit interface that mediates the messages and communicates the appropriate call and switch activation in the box. The one exception to this demand would be a one-way Bluetooth activation. As a collection of protocols there are robust options for P2I communication. Two applications were reviewed as part of this project. The cloud interface and a Bluetooth pairing interface. The system reviewed for the project was a Bluetooth interface with a custom control unit and mobile device application. This system also integrated pedestrian detection options for passive activation (Nambisan et al, 2009; Saad, Hashim, & Jabber, 2022). The Polara system was reviewed with pedestrians who were blind or visually impaired. Two installations were easily accessible in cities with intersections that met the needs of Task 2.3 as well.

2.7 System Trials

Trials of the satisfaction with an existing system that utilizes a smartphone to control the pedestrian call button were included with the other field trials. The system reviewed made use of Bluetooth beacons to facilitate communication between the smartphone and a Ped head. This approach was one of the more fertile approaches that emerged from the communication review.

Travelers who are blind or have low vision, must use the sound of parallel traffic at an intersection to determine if they are facing directly across the street so that they can walk within the crosswalk lines. They must spend several seconds listening to the trajectory of the moving traffic to determine if they are in proper alignment. Then on the next walk cycle, they must be prepared to step into the street when the parallel traffic is starting to move through the intersection. Intersections at busy crossings have actuated or semi-actuated control systems that detect the presence of vehicles and provide only the amount of time needed for the vehicle or vehicles to progress through the intersection. Pedestrians who want to cross those intersections often need more time for the walk cycle than is allocated by the automated system. These pedestrians are therefore dependent upon APS to extend the walk cycle at complex actuated intersections so that they have sufficient time to make the crossing.

Safe travel requires pedestrians to locate the pedestrian button on the pole that calls for an extended walk cycle. Best practice requires the traveler to first locate the crossing point at the crosswalk, backtrack and find the pole that is equipped with the Pedestrian call button, and then return to the crossing point (Fazzi and Barlow, 2017). Guideline presented in the Manual on Uniform Traffic Control Devices (MUTCD) and the Transportation Equity Act for the 21st Century (TEA-21) indicate that the pole with the pedestrian button should be within 5 feet of the crosswalk line if extended and within 10 feet of the perpendicular curb (figure 9).

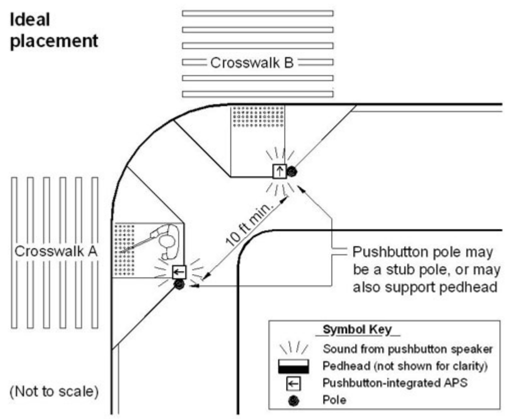

Figure 9. Harkey, Carter, Barlow, & Bentzen, (2010)

While this is the ideal situation, there are intersections where such installation is not physically possible, and the distances may be greater. Even when the poles do comply with these standards, their location still requires the pedestrian to vary from their path to find the pole. This causes difficulty as the traveler must make a detour from their original trajectory in order to locate and press the pedestrian push button. Sometimes more than once if conditions are not ideal.

It is important for travelers with a visual impairment to maintain a straight line of direction to the corner in order to make a crossing that takes them directly to the opposite corner of an intersection. Modern intersections and corner alignments have made this task increasingly more difficult (Scott et al. 2011a; Bentzen, Barlow, & Bond, 2004). Additionally, the detour to the APS can cause some disorientation and can result in the pedestrian not facing directly across the street when they return to the crossing point. Unless corrected, this may lead them to veer outside of the crosswalk and possibly into the parallel traffic or into the idling cars during the crossing (Scott et al, 2011b). Normally a correction is made by listening to the moving parallel traffic and adjusting their alignment position. However, once they press the pedestrian button and return to the crossing point, the traffic signal is already changing, and they do not have time to re-establish their trajectory by aligning with the moving parallel traffic. If they wait extra time to adjust their alignment, some of the parallel traffic may think they are not about to cross and may turn in front of them as they make right turns. The pedestrian must therefore make any adjustments dynamically as they are in the process of crossing the street. The solution to this problem would be to provide the pedestrian with a means to push the call button without physically having to locate the pole. The objective of task two was to explore mobile device user activation of the ped head through wireless communication with the traffic controller. This would avoid the need to find and press the pedestrian button. This task was significantly accelerated by the development and initial deployment of a system made by a traffic engineering vendor. At the time of this study, the Polara company had developed a system similar to that imagined by this project and had implemented its use in two key cities in North Carolina: one installation in Greensboro and two in Raleigh. This moved our research from exploratory in nature to proof of value. Rather than having to build a prototype, our project was able to utilize the existing installations to test its value with pedestrians.

2.7.1 PedApp® system functioning

The PedApp® by Polara can be used on a smartphone to request the walk phase of the traffic cycle for an intersection with a Polara Ped head system. For individuals who are blind or visually impaired, the system works with the VoiceOver (Apple) or TalkBack (Android) text-to-speech system to provide verbal information on their phones. This is accomplished through Bluetooth communication with the traffic controller and avoids the pedestrian having to locate and press the pedestrian call button.

The installations in Greensboro and Raleigh allowed our research to test its various functions and determine its impact on pedestrians who were visually impaired. The subjects were asked to determine the best time to make a street crossing after using the PedApp®. The installations allowed bypassing the physical button and announced the name of the street to be crossed. Furthermore, the capabilities of this app allowed testing of an additional parameter that was not initially considered for the study. The app displays a countdown of the time remaining for a pedestrian walk sign. The text-to-speech system allowed this information to be announced for the traveler, providing the same information a sighted traveler would see on the physical display. It was therefore possible to evaluate interest and satisfaction with this additional countdown information. Since auditory information is heavily used in making a safe crossing there has been some research investigating whether this could be a distraction from the traffic (Scott et al, 2014). The added feature allowed direct feedback and value on this impact for the pedestrians with visual impairments.

2.7.2 Trial methods

Subjects for this experiment were chosen from two populations that self-identified as pedestrians who have had experience in crossing streets independently. The first group was chosen from an Ability One Agency that provides work for individuals who are blind. The second group was selected from a State Rehabilitation Agency that provides training in independent travel and activities of daily living for people who are blind. The age of the subjects ranged between 20 years and 60 years. While all subjects were legally blind, there was a mix of individuals who were totally blind and those who had low vision. The researchers secured subjects by contacting the facilities and asking for volunteers who had outdoor travel experience.

Subjects were given an iPhone and familiarized with the use of the Ped App. Each subject was asked to walk to the intersection and use their phone to initiate the walk cycle of the APS. At the announcement of the walk cycle, the subject walked across the street using the researcher as a human guide. Upon making the first crossing, three similar crossings at the intersection were completed in a clockwise or counterclockwise direction.

At the conclusion of the four crossings, the subjects were asked the following six questions:

1. How difficult was it to activate the pedestrian phase of the cycle through your phone?
2. Do you like using Voice Over gestures on your phone to call the pedestrian phase of the light cycle?
3. Would you prefer to have the app detect you automatically and call the pedestrian phase?

4. Does listening to the timing countdown interfere with your ability to pay attention to traffic?
5. Is the countdown timing helpful to you?
6. Were you satisfied with the ease of use of the app?

2.8 Results

Most of the subjects (27 of 31) indicated that activating the crossing request with their phone was not at all difficult. They especially valued the ease of use with Voiceover and the access to the countdown timer. However, since the app was an early deployment, they encountered problems with reliability. There were times when the app did not function as expected. The countdown timer was not present, but also times when it worked perfectly. The app crashed on multiple occasions, but not with any consistency that would suggest a reason. Table 4 provides a summary of the responses of the subjects to these six questions.

Table 4 PedApp rating of usability

QUESTIONS	Not at All	Somewhat	Very Much
How difficult was it to activate the pedestrian phase of the cycle through your phone?	27	4	0
Do you like using Voice Over gestures on your phone to call the pedestrian phase of the light cycle?	6	2	23
Would you prefer to have the app detect you automatically and call the pedestrian phase?	14	3	14
Does listening to the timing countdown interfere with your ability to pay attention to traffic?	29	0	2
Is the countdown timing helpful to you?	0	0	31
Were you satisfied with the ease of use of the app?	2	5	24

2.9 Conclusion for Task Two

Regarding task two of the study, the subjects liked having control of the call button without having to change their line of travel. When a pedestrian who is blind reaches the corner, they are typically within the crosswalk and in good alignment with the traffic. This allows them to walk across the street without having to make excessive alignment corrections during the crossing. However, when they must abandon their position to travel to the pole to press the call button, their return depends on making several turns and can negatively affect their final position at the corner. Having a device that allows them to initiate the call button without changing their position greatly enhances their confidence in their orientation.

The subjects also felt that having countdown timers announce remaining time to complete the crossing helped them judge the distance remaining to finish their crossing. They indicated that the information from those announcements did not interfere with their ability to listen to the traffic. Remember, however, the crossings were made using human guides rather than crossing independently. When crossing with a guide, the pedestrian does not have to pay as much attention to the movement of the traffic during the crossing. It is unknown if listening to countdown timing information would degrade the more complex tasks of judging distance from and alignment with traffic during independent crossings. Future studies should examine any possible interference from the timing announcements while the pedestrian is crossing independently.

The conclusion drawn from the data indicates that smartphone devices used to initiate the walk cycle would improve the ease and safety of pedestrian crossings. The pedestrian would not have to walk to the pole and introduce unnecessary movement which would deteriorate alignment to the opposite corner. In some situations, by the time the pole has been located and the pedestrian returns to the corner, the walk cycle may commence and leave no time for realignment. The use of the smartphone to avoid leaving the corner, would allow the pedestrian to remain in place and not to make a split-second judgement regarding their alignment once they have returned to the corner from the pole. This additional time at the corner would allow them to determine their alignment with the traffic more accurately and thus keep their trajectory within the crosswalk lines.

The communication method reviewed for the trials was the most sophisticated of the options presented. Similar activation could be achieved with a simple Bluetooth device, but the additional value from the countdown and auto detection would not be available. It is possible in the diverse landscape of intersections in any state that there may be a place for both potential solutions. The Wi-fi and cloud-based solutions have both an expense and connectivity requirement that makes it ill-suited for some geographies and settings.

Report Body – Chapter - Project 2: Task 3

IOT Solutions for Near Horizon Challenges in Smart City Pedestrian Travel (Task 2.3)

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2.10 Information for Intersection Awareness

The first objective of this study was to determine the feasibility and effectiveness of providing information to pedestrians in a simpler and more native format. The goal was to present necessary information in clear concise language transmitted from Bluetooth Beacons through their smartphones upon reaching the intersection.

The technology behind the employment of Bluetooth beacons is similar to what is possible with a geographic information system (GIS). A GIS can allow the layering of information to be combined for practical applications, like wayfinding and routing, or unique presentation. The Bluetooth beacon system is a closed information system leveraging the beacon signal to reference specific location information stored in an app-based database. This information is then presented to the user/pedestrian who is blind to share what any other pedestrian could gather visually through casual inspection.

As part of this process, we wanted to transmit only the information that is most important to the pedestrian. There are many tasks to complete prior to a crossing and we did not want to overburden the pedestrian with unneeded information. The process of determining the importance of information entailed a multistep process. First, the researchers developed a list of pieces of information that are necessary to make a street crossing. With the desire to provide only the most vital information, we next turned to experts to identify those items that are essential. We surveyed 50 experts on the relative importance of 40 possible information items. A Qualtrics survey (Appendix A) was made available on a listserv that reaches Orientation and Mobility Specialists who teach blind and visually impaired pedestrians how to travel through the environment. We asked the listserv members to rate each of the 40 possible items using a Likert scale to determine their importance. We shared this information with traffic engineers at a statewide conference and requested their input. They concurred with the data and added one additional item relating to maneuvering around work zones. Table 5 presents the 11 highest ranking items from the survey by the experts and the traffic engineers along with mean and standard deviation scores. The means were all at or above 3.5 with reasonable standard deviations. Although 0.7 and 0.73 may be considered a high standard deviation on a four-point scale it is not unusual for expert ratings that may have specific areas of acute concern. These scores were also significantly skewed by scores of 1 compared to the other items.

Table 5. Expert rating of information

Question	Min	Max	Mean	Std Dev.	N
Names of intersecting streets at corner	2	4	3.72	0.57	50
Number of lanes to cross	2	4	3.66	0.56	47
Presence of accessible pedestrian signal	2	4	3.63	0.56	48
Presence of a channelized turn lane	2	4	3.61	0.53	46
Type of traffic control signal	1	4	3.59	0.7	49
Presence of a turn lane signal	2	4	3.58	0.6	50
Presence of a work zone	2	4	3.57	0.61	49
When a corner across the street is not in alignment with the current corner	1	4	3.56	0.73	48
Directions for negotiating the work zone	2	4	3.53	0.67	49

Location of accessible pedestrian signal	2	4	3.52	0.68	46
Presence of a Median	2	4	3.5	0.62	46

The next phase of the project consisted of running subjects who were blind or had low vision through an exercise that would allow them to evaluate and rate the information presented, as well as their experience in using their smartphones to gain crossing information. The subjects in this task were the same individuals who participated in the first task.

2.11 Method

To provide the information for the intersections and crossings an iPhone app that provided information with the assistance of Bluetooth beacons was selected. The Aware app by Sensible Innovations provided strong compatibility and design, with beacons donated to the project for the test deployment. The app allows robust use of the screen reading feature in Voiceover to read and review messages line by line. This form of reading is useful when reviewing large amounts of information. The app also allows tuning of beacons for variable range with secure post installation boxes that protect them from the weather. For the deployment, the tightest beacon radius was used to prevent beacons from being detected too early during crossing or from the wrong corner. The eleven items from the questionnaire were condensed to seven by grouping three items together and removing one item from the list. The three items that were grouped were the presence and location of an APS, the presence, and directions to negotiate a work zone, and the presence of turn lane and signal. The one item that was not included in the information was the type of traffic control signal. The type of traffic control signal was valuable to experts, but the narrative did not feel useful to a pedestrian once it was authored. As a result, it was not used in the field testing, but could be considered in future research. In addition, one final piece of information was shared, though it had no bearing on the crossing or intersection information. At the start of each message the cardinal direction of the crossing was added along with the street information. In future applications for navigation and travel, this will likely be standard for orientation and assisted in making the messaging similar to what would be received using Apple or Google Maps.

The initial language was authored in the order of ranking from the survey, presuming a hierarchal nature. The initial three subjects found that the information was shared in an order that did not compliment or group in a way that aided memory. A secondary order was chosen and used with the remaining 47 subjects. This order started from broad information like street names and the number of lanes, moved to traffic patterns, and finally the details like a median, position of the adjacent corner, and work zones. The final information was the location of the APS, since that would be the next step in initiating a crossing. In the current study the order of the information was not a detail under review, but it is possible that order impacted the favorability of certain items. An example of the two narratives is provided below. The complete final language is included in Appendix C.

Narrative #1 for Beacon: You are northbound approaching the perpendicular street of Western Blvd. traveling parallel to Advent Ferry. You are facing north with six lanes of traffic to cross.

There is an APS at this corner and the button is located to the left of the crosswalk. There is an island in the street you are crossing. The parallel oncoming traffic has a left turn signal arrow before parallel traffic starts. The far corner is in alignment with the corner you are on.

Narrative #2 for Beacon: You are approaching Western Blvd. on the east side of Advent Ferry facing North. There are six lanes of traffic with an island after two lanes. The oncoming parallel traffic has a left turn arrow before parallel traffic starts. The corner across the street is aligned with the crosswalk facing it. The APS is to the left of the crosswalk on the inside edge of the corner.

The final message order of presentation:

1. Name of parallel street & name of the upcoming perpendicular street (Direction of travel).
2. The number of lanes to cross.
3. The presence of a median.
4. The presence of a left turn lane and signal arrow.
5. The alignment of the far corner with the corner you are on.
6. The presence & location of a non-APS pushbutton at the corner.
7. The presence of a construction barrier and means to go around it.

The researchers presented the crossing information to 31 blind and low vision subjects at one of two intersections and had them evaluate the relative importance of the information they received and their satisfaction with the process. Bluetooth beacons were set up at the four corners of the two intersections, one in Greensboro and one in Raleigh. Subjects were asked to walk towards one of the intersections and use their phones to gather information about the intersection and the pending crossing. The subjects were given an iPhone with Voiceover activated and the Aware app running. Where necessary, subjects were taught how to use VoiceOver on their phones to provide the information coming from the Bluetooth beacons. The subjects used Voiceover gestures to scroll through each of the messages that described information relevant for their crossing of the intersection and were able to repeat them if they desired.

In addition to rating each of the questions, at the conclusion of this exercise the researchers also asked the subjects two questions: “Are you satisfied with the order of presentation of information?” and “Is there other information that you would like presented?” Along with a numeric rating, subjects were encouraged to provide open-ended answers to these questions.

Once the messages were understood and processed by the subjects, they were told to initiate their crossings. In order to ensure safety, subjects crossed the street using a researcher as a human guide. Four crossings were made at each intersection in either a clockwise or counterclockwise manner. After each crossing, we turned to the next crossing at the same intersection and ran through a series of information through their smartphones about the next crossing. After crossing all four streets at the intersection, the subjects were asked to rate the importance of each of the instructions and evaluate the effectiveness of the system. An open-ended question was then asked regarding the sequencing of the information provided and other information that would have been helpful.

2.14 Results from Task Three

From the items presented, it is clear that the 8 items all scored similarly high in value for participants (see Table 6). It is important to note however, that the responses of the subjects to the importance of the various items differs to varying degrees with the importance that was assigned the items by the experts. Three mean differences suggest a higher priority for participants than for the experts. These differences include 1) Presence of a Median (Mean 4.0, Diff. +0.5, SD .00), 2) Location of APS (Mean 3.87, Diff. +0.35, SD .34), and 3) Number of Lanes to cross (Mean 3.97, Diff. +0.31, SD .18). The overall standard deviation was much smaller among subjects. This may be the result of an overabundance of information presented to the subjects. Table 7 compares the survey means from the experts with the trial means of the subjects.

Table 6. Subject ratings of information

Question	Min	Max	Mean	Std Dev.	N
Name of intersecting streets at corner.	3	4	3.90	0.30	31
The presence of a left turn lane and signal arrow.	3	4	3.84	0.37	31
The number of lanes to cross.	3	4	3.97	0.18	31
The presence of a median.	4	4	4.0	0	31
The alignment of the far corner with the corner you are on.	3	4	3.81	0.47	31
The presence & location of a non-APS pushbutton at the corner.	3	4	3.87	0.34	31
The presence of a construction barrier and means to go around it.	2	4	3.81	0.47	31
Are you satisfied with the order of presentation of information?	2	4	3.55	0.85	31

Table 7. Comparison of expert and subject ratings

Question	Expert Mean	Subject Mean	Diff.	Expert SD	Subject SD
Names of intersecting streets at corner	3.72	3.90	0.18	0.57	0.30
Number of lanes to cross	3.66	3.97	0.31	0.56	0.18

Presence of accessible pedestrian signal	3.63	3.87	0.24	0.56	0.34
Presence of a channelized turn lane	3.61	3.84	0.23	0.53	0.37
Presence of a turn lane signal	3.58	3.84	0.26	0.6	0.37
Presence of a work zone	3.57	3.81	0.24	0.61	0.47
When a corner across the street is not in alignment with the current corner	3.56	3.81	0.25	0.73	0.40
Directions for negotiating the work zone	3.53	3.81	0.28	0.67	0.47
Location of accessible pedestrian signal	3.52	3.87	0.35	0.68	0.34
Presence of a Median	3.5	4.00	0.50	0.62	0.00

2.15 Conclusion for part three

In addition to providing ratings to the questions, the subjects participating in this study also shared their personal reactions and suggestions with the researchers. Several important suggestions came from the participants. During this study, participants were required to initiate the Bluetooth beacons as they approached the corner. The subjects felt that it would be better to have the beacons detected automatically by the phones rather than depending on the pedestrian to identify their presence.

While all attempts were made to simplify the beacon messages and present only the most vital information, the amount of information was still too much for many of the subjects to digest quickly. They felt that the messages should be broken down into smaller units that can be repeated as needed. It is necessary to set up the messages so that they can be read line by line.

Since the crossings took place at complex and trafficked intersections, the passing vehicles' sounds were often loud. At times the subjects strained to hear what was being said over the sounds of the cars and other vehicles. The subjects recommended that the beacons would be more useful if the messages were displayed through earphones rather than through the speakers on their phones. This is a common problem with GPS navigation devices for pedestrians who are blind, and the solution of using earphones has been problematic because they block out the sounds of the traffic that provide essential information. The recommended solution to this problem is the use of Bluetooth bone-conduction earphones. These earphones vibrate the bones of the skull and transmit auditory information without blocking ambient sounds that would otherwise enter the ear. Such devices are readily available and should be used with this type of beaconing system.

At first, the researchers were not sure that it was necessary to include the name of the street that the pedestrian was approaching since it was thought that the travelers would of course be aware of the name of the upcoming street. It was found however, that pedestrians felt a sense of relief in being reassured that they were at the desired street. Without visual cues, they must rely on memory and determine that they had arrived at the right corner. The subjects said that the announcement of the street name verified that they were at the correct corner.

Accessible pedestrian signals must produce an identifiable sound within ten to 12 feet of their location. This allows them to be identified by the visually impaired pedestrian. Subjects in this study nevertheless found that verbal description of their location was helpful in planning ahead for their location. Also, notably at some corners where actuated or semi-actuated traffic controls are present, but APS signals are not found, the location of call buttons are silent and nearly impossible to find. Yet, it is essential to find and push the call button to extend the time available to complete the crossing. The use of beacons to identify the location of these silent call buttons greatly increases the safety of the pedestrian who is blind.

The subjects in this study indicated that when they travel in a new area and approach an unfamiliar intersection, they don't have the same information that is available to their sighted counterparts. It is a difficult and time-consuming task to gather all the needed information by listening to the traffic. In many situations they cannot determine the number of lanes to cross, a median island, or other important features. Subjects in this study voiced the hope that installations such as those in this study would be made available in their communities to better acquaint them with unfamiliar intersections. The researchers believe that this would be a valuable asset at complex intersections.

Findings and Conclusions

TSAP was one of three university research programs to receive a $1 million NC Department of Transportation grant in February 2020 through the Transportation Center of Excellence Initiative to study future transportation challenges in North Carolina.

Project 2 Task 1

Task one focused on advanced data collection and assessment methods to enhance pedestrian safety. Cutting-edge object detection and tracking technologies like YOLOv4 and DeepSORT were employed to analyze safety aspects at a fixed-cycle intersection using video data analysis. The primary intent was to showcase the efficacy and functionality of these state-of-the-art technologies in comprehending traffic dynamics and behavior at intersections, ultimately striving to create safer spaces for pedestrians. Relevant requirements for mechanisms that would offer real-time notifications or alerts to pedestrians, with a particular emphasis on visually impaired individuals, were also investigated. These requirements include the capacity to equip visually impaired pedestrians with communication devices such as smartphones or smartwatches, enabling them to receive crucial real-time alerts and navigate safely within urban environments. In addition, the potential impacts and acceptability of advanced technologies among stakeholders and the general public were identified. One notable outcome highlighted concern from city officials and urban planners, particularly regarding the costs and budget needed to implement these technologies effectively. These concerns emphasized retrofitting and upgrading existing infrastructure to accommodate the transition to a smart city environment. Integration and compatibility challenges with current systems, technical expertise, public acceptance, perception, data management, and privacy emerged as critical concerns that require careful consideration. In summary, this task emphasized technical advancements in data collection and assessment for pedestrian safety and delved into the practical implications and challenges associated with implementing novel technologies.

Project 2 Task 2

Task two investigated the potential for Pedestrian to Infrastructure (P2I) communication. The goal of the task was to develop a protocol for communication to activate a walk request button at an intersection. Developments in the transportation market as well as other research projects made advances parallel to this area. The Project shifted focus to investigate implementation and use by pedestrians who are blind or visually impaired. The usability survey after trials with PedApp by Polara yielded some interesting results. It is a common concern that additional auditory information for travelers with visual impairments could be a distraction or overburden auditory needs when traveling. The survey results showed that the countdown information was valued on two different questions. This information is currently unavailable to travelers who are visually impaired on most APS. The use of the app with the built-in iOS screenreader was not as easy as the researcher expected. In fact, most users had significant gaps in their proficiency with the screenreader. This suggests that a screenreader accessible design with some built-in auditory output as well may be the most usable design. The final element of note was the use of auto detection for call button activation. This feature was evenly divided among participants, suggesting that further investigation is necessary. As pedestrian prediction and AI connected approaches are explored this feature is likely to be popular in future development. The process of preparing for a crossing can be involved and is unique to the traveler. Universal approaches could rush the traveler or create a false sense of urgency, which may increase the likelihood of a distracted crossing.

Project 2 Task 3

Task three investigated the deployment and usability of an infrastructure to pedestrian (I2P) communication system to provide more detailed orientation information for travelers with visual impairments. This portion of the project made use of the Aware App by Sensible Innovations. The application is an environmental information and routing application that has also been integrated into at least one transit system. Task three generated a list of critical features to be communicated that would aid a traveler with a visual impairment in orientation to a street corner and executing a safe crossing. This list was rated and winnowed by surveying professionals in the domain of Orientation and Mobility. A Certified Orientation and Mobility Specialist (COMS) is a Master degree level trained professional certified by the Academy for Certification of Vision Rehabilitation & Education Professionals (ACVREP). The initial list of items contained 11 features, and this list was condensed into seven messages by combining related information. Field trials were completed using the refined messaging and pedestrians with visual impairments validated the list after testing the information prior to crossing four streets. This refined seven message protocol can serve as a framework for the needed information to support travelers who are blind in feeling confident when crossing a street at an intersection. The app used in this task uses the Bluetooth beacon identifier to reference cloud-based information displayed in the app. This method allows existing and newly deployed Bluetooth resources to be leveraged to improve pedestrian access without significant physical installations. The company devices used for this task have already completed transit infrastructure collaborations and has an open API philosophy that would be necessary for a broad-based application of the methods reviewed here. The process of properly evaluating and authoring the information does, however, require the services of a COMS. This process could be automated in the future, but a significant number of intersections and scenarios would require description and validation to provide a robust database for computer learning.

This project demonstrated a new application of Bluetooth environmental information that could be integrated into future I2P design. The protocol and reliability of the information was confirmed with field trials in reasonably complex intersections with channelized turn lanes, turn signals and a construction coned off area. The video analytics describe a method to develop I2P communication with integration into smart device applications. The PedApp application and information along with Aware demonstrate that specialized applications already exist in the market for assistive technology for individuals with visual impairments. A transportation department could implement or sponsor test deployments with existing technology, but collaboration between entities would be a vital component. Platforms that share information will make the I2X (or I2E) communication far more useful to both automated vehicles and vulnerable road users.

Recommendations

Task One

Several key recommendations are proposed to enhance pedestrian safety, particularly focusing on the integration of advanced technologies and catering to the needs of visually impaired individuals. Firstly, it is essential to advocate for the widespread adoption and implementation of cutting-edge object detection and tracking technologies, such as YOLOv4 and DeepSORT, at intersections to bolster traffic analysis and create safer pedestrian spaces and easy real-time communication with pedestrians and the infrastructure. These technologies have shown significant promise in comprehending traffic dynamics and behaviors at intersections, forming a strong foundation for improved safety measures. Real-time alert systems should be developed and deployed to address the specific needs of visually impaired pedestrians. These systems should utilize smartphones or smartwatches to provide timely notifications and alerts, aiding safe navigation within urban environments. Emphasis should be placed on ensuring the ease of use and accessibility of these devices for the visually impaired. Furthermore, engaging with various stakeholders, city officials, and urban planners is crucial to build support and address concerns related to the integration of these advanced technologies. Creating awareness of the benefits and potential impacts of these technologies on pedestrian safety can facilitate smoother implementation and alleviate concerns regarding costs, budget allocation, retrofitting existing infrastructure, and compatibility challenges. Additionally, technical training programs should be implemented to enhance proficiency and technical expertise in utilizing these technologies, especially focusing on screen reader usage and other accessibility features. Lastly, a human-centric design approach should be adopted to ensure that these technologies are designed with the specific needs of visually impaired pedestrians in mind. This approach will contribute to the creation of accessible and user-friendly technologies, ultimately enhancing pedestrian safety within urban environments.

Task Two

The planning and implementation of P2I communication has become increasingly more realistic with the developments of the last decade in smartphone and traffic vendor devices. Deploying this technology is not a solution in isolation. Without collaboration with university O&M training programs, the Department of Veteran's Affairs, the Office of Special Education Programs, national advocacy organizations, and non-profits the advances in accessibility could go unnoticed. The deployment of Bluetooth Beacons six years ago in the DC Metro greatly increased orientation knowledge to specific stations, but no staff were aware of the tools or could advise on its use. It must be recognized that any P2I improvements require the training of existing professionals through continuing education, adaptations of existing instructional methods for new professionals, and a strong outreach effort. These sorts of tasks are best suited to a center level project that encourages collaboration and brings diverse partners together. The Polara tool demonstrated strong potential but may not be suited to all traffic infrastructure in both urban and rural settings. An alternative lower tech solution should also be investigated or encouraged from traffic vendors to allow broader accessibility, including those individuals living in rural or remote areas. It should be noted that the convenience of the remote activation has a potential impact to pedestrians who use wheelchairs or are otherwise disadvantaged in mobility. Time to cross and time to prepare for a crossing have an impact for both of these groups. A cost comparison to population needs would be an added advantage to a broader set of solutions using the findings from task two. It is hoped that standards might someday be developed in this domain with continued investigation and development.

Task Three

This project demonstrated the use of specific language to increase awareness of intersections and corners for pedestrians who are blind and visually impaired. The specific language developed through the project is still emerging, but the validity seems promising. There is a concern about the length and specificity of the language that should be investigated for future research. The language and deployment were also limited in traveling in only one direction from a given corner. Any street level deployment would require some method of isolating for direction of travel. Both Sensible Innovations and Right Hear interfaces allow this level of isolation through either compass information or directional beacons.

In order to deploy the I2P communication in this project agreements with a Beacon company or the collaboration for API access would be necessary. Similar to the recommendations in task 2 the best way to ensure awareness of deployments and information would be collaboration or integration with existing Apps that pedestrians use. A deployment plan would also require a survey of street corners with active Bluetooth or Wi-Fi signals be completed and mapped for saturation. Any improvements in APS accessibility that uses Bluetooth or Wi-fi technology should allow for access to App companies that provide accessibility.

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Appendix A – Beacon Questionnaire

Beacon Questionnaire

We are conducting research to determine if providing information through a phone app would be helpful to travelers who are blind or have low vision. Since we would be able to present only a limited amount of information from the app, we would like to know what information is most important in approaching a signalized intersection.

Please evaluate the importance of the following information that could be presented for improving one's ability to make an accurate and safe crossing of the street using the following scale:

5= very important
4= somewhat important
3= neither important nor unimportant
2= Not very important
1= not important

Feature

1. Street names
2. Identification of corner using compass labels
3. Changes in paving or texture leading to corner
4. Presence of curb or slope leading to crosswalk
5. Presence of detectable warning surfaces
6. Location of detectable warning surfaces in relation to the corner
7. Determination of whether it is a perpendicular, parallel, or diagonal curb ramp
8. Direction of ramp in relation to the crosswalk
9. Amount of running slope of ramp
10. Presence of sewer or grating in the street within the corner area
11. Irregularities at corner
12. Presence of protruding objects
13. Type of traffic control signalization
14. Presence or absence of actuation
15. Presence of turn lane signal
16. Type of traffic signal phasing (permissive, protected, split, lead, lag)
17. Number of phases
18. Number of lanes to cross
19. Direction of traffic on street (two way or one way)
20. Number of lanes in each direction
21. Presence of accessible pedestrian signal
22. Location of accessible pedestrian signal
23. Presence of a channelized turn lane
24. Sign indicating no right turn on red
25. Presence of a median
26. Presence or absence of detectable warning surfaces at the edges of the median/island
27. Presence of an island without cut-through pathway
28. Volume of traffic typically on the two streets

29. Volume of traffic typically on the street parallel to crosswalk
30. Width of street
31. Time allocated for crossing
32. Crosswalk direction in relation to parallel traffic direction
33. Whether corner across the street is in alignment with current corner
34. Width of sidewalk across the street
35. Presence of obstacles across the street
36. Presence of detectable warning surfaces on corner across the perpendicular street
37. Presence of accessible pedestrian signal and pushbutton locator tone at end of crosswalk
38. Presence of a work zone
39. Directions for negotiating the work zone
40. Knowledge of mechanism to alert person if veering out of the crosswalk

Appendix B – Pedestrian Reaction Tool

Street Crossing Assessment Instrument for Beacons

We will be providing you with information about the intersection you are about to cross, assuming you do not know anything about the location. After each crossing, we will be interested in learning which information is important and which information is not important to you.

Script #1 for 'Street 1' and 'Street 2': Crossing 'Street'				
Item	**Very Important**	**Neutral**	**Not Important**	**Evaluator Comments**
1. The name of your perpendicular street is:				
2. The name of your parallel street is:				
3. You are facing West				
4. The number of lanes to cross are:				
5. There is not an APS at this corner				
6. The non-APS pushbutton is located at: to the left of the crosswalk				
At the intersection:				
7. There is a signal arrow for cars to make a left turn before the parallel traffic starts				
8. The corner across the street is offset to the right				

Participants Code Identifier: ____

Name of Evaluator: ____

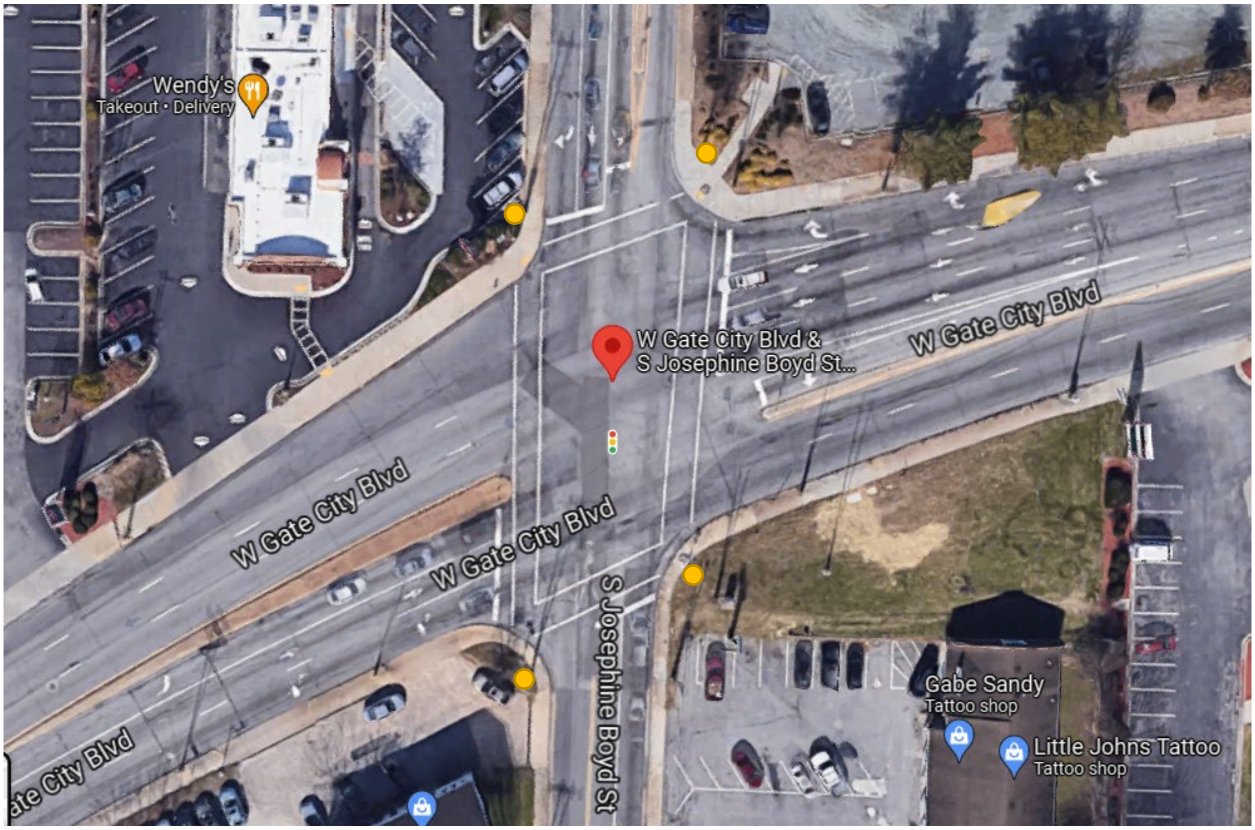
Comments from Participant

1. The name of your perpendicular street is:
2. The name of your parallel street is:
3. You are Facing:
4. The number of lanes to cross is:
5. There is not an APS at this corner
6. The non-APS is located:
7. At the Intersection (phasing):
8. The corner across the street is offset to the:
9. Are you satisfied with the order presented? a. If not, what order would you want?
10. Would you like the announcement to tell you how many seconds you have to cross the street?

Appendix C – Final Beacon Language

Gate City Blvd and Josephine Boyd St.

Greensboro, North Carolina



Northeast Corner

Narrative for Beacon: You are westbound approaching the perpendicular street of Josephine Boyd Street traveling parallel to West Gate City Blvd. There is a left turn signal arrow before parallel traffic starts. You are facing west with four lanes of traffic to cross. The far corner is offset to the right with the corner you are on. There is a non-APS pushbutton at this corner and the button is located to the left of the crosswalk.

Northwest Corner

Narrative for Beacon: You are southbound approaching the perpendicular street of West Gate City Blvd. traveling parallel to Josephine Boyd Street. There is a left turn signal arrow that activates at the same time parallel traffic starts. You are facing south with six lanes of traffic to cross. There is an island after three lanes. To navigate the work zone near the corner, walk to the left of the pylon. The far corner is in alignment with the corner you are on. There is a non-APS pushbutton at this corner and the button is located to the left of the crosswalk.

Southwest Corner

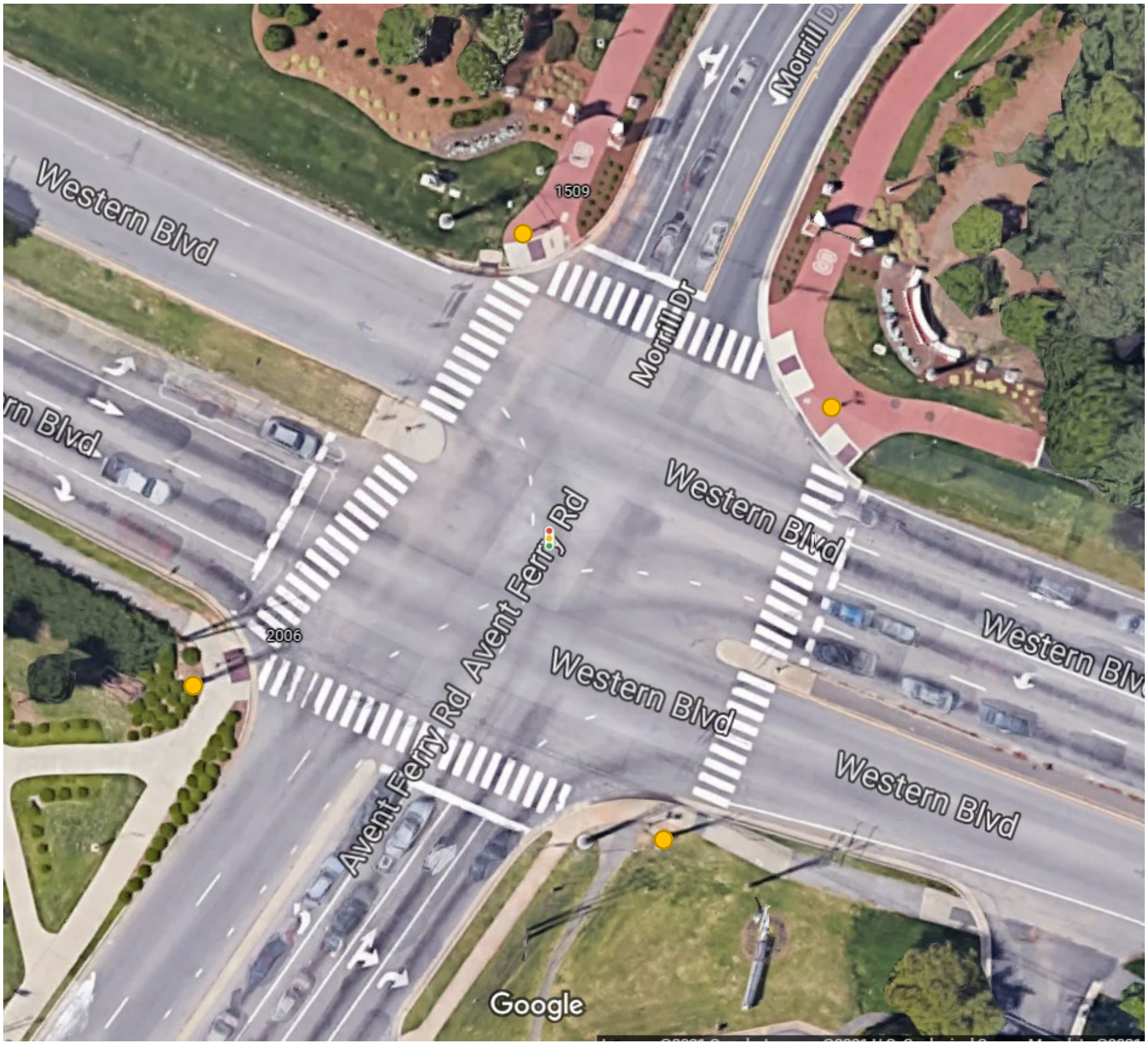
Narrative for Beacon: You are eastbound approaching the perpendicular street of Josephine Boyd Street traveling parallel to West Gate City Blvd. The oncoming traffic has a left turn signal arrow before parallel traffic starts. You are facing east with three lanes of traffic to cross. The far corner is in alignment with the corner you are on. There is a non-APS pushbutton at this corner and the button is located to the right of the crosswalk.

Southeast Corner

Narrative for Beacon: You are northbound approaching the perpendicular street of West Gate City Blvd. traveling parallel to Josephine Boyd Street. There is a left turn signal arrow that activates before parallel traffic starts. You are facing north with seven lanes of traffic to cross. The far corner is in alignment with the corner you are on. There is a non-APS pushbutton at this corner and the button is located to the left of the crosswalk.

Western Blvd. and Avent Ferry Rd.

Raleigh, North Carolina



South by Southeast Corner

Narrative for Beacon: You are northbound approaching the perpendicular street of Western Blvd. traveling parallel to Avent Ferry. You are facing north with six lanes of traffic to cross. There is an APS at this corner and the button is located to the left of the crosswalk. There is an island in the street you are crossing. The parallel oncoming traffic has a left turn signal arrow before parallel traffic starts. The far corner is in alignment with the corner you are on.

Northeast Corner

Narrative for Beacon: You are westbound approaching the perpendicular street of Avent Ferry traveling parallel to Western Blvd. You are facing west with four lanes of traffic to cross. There is an APS at this corner and the button is located to the left of the crosswalk. The parallel traffic has a left turn signal arrow as parallel traffic starts. The far corner is in alignment with the corner you are on.

North Corner

Narrative for Beacon: You are southbound approaching the perpendicular street of Western Blvd. traveling parallel to Avent Ferry. You are facing south with seven lanes of traffic to cross. There is an APS at this corner and the button is located to the right of the crosswalk. There is an island in the street you are crossing. The parallel oncoming traffic has a left turn signal arrow before parallel traffic starts. To walk through the work zone go to the left of the pylon. The far corner is in alignment with the corner you are on.

West by Southwest Corner

Narrative for Beacon: You are eastbound approaching the perpendicular street of Avent Ferry traveling parallel to Western Blvd. You are facing east with six lanes of traffic to cross. There is an APS behind the crosswalk. There is a left turn signal arrow at the end of the light cycle. The far corner is in alignment with the corner you are on.