Improving Urban Mobility for People with Visual Loss at Floating Bus Stops in Canada

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DECLARATION OF CO-AUTHORSHIP

I. Co-Authorship Declaration

As the primary author, I hereby declare that this dissertation contains material from joint research and incorporates the results of research publications conducted under Dr. Juan Pernia's supervision. I also carried out the key tasks, which included writing, data analysis, interpretation, experimental designs, and main idea generation. The co-author's contributions were limited to proofreading and reviewing the technical content of the research papers.

I attest that I have appropriately recognized the contributions of other scholars to this dissertation and that I am completely aware of Lakehead University's policy about authorship. With these credentials, I attest that the research included in my thesis is unique to me.

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ACKNOWLEDGMENTS

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Finally, I am indebted to my family for their unwavering love, support, encouragement and their belief in me provided me with the strength to persevere through the challenges I faced.

DEDICATION

This thesis is dedicated to my God, my Parents and my Supervisor.

ABSTRACT

At present time, technological advancements and emphasis on inclusive urban planning are a priority for transportation professionals to enhance urban mobility for road users, especially for people with vision loss (PWVL). Among the various modes of transportation available, cycling has emerged as an eco-friendly and efficient means of commuting. This mode of transportation also comes as a major challenge to PWVL in an already complex urban environment since cyclists cannot be detected by sound by this special population group.

This is particularly concerning at floating bus stops since buses do not pull up to the curb to load and unload. Instead, floating bus stops are placed in the center of a road on a raised island, often requiring transit riders to cross a cycling lane to access it. For PWVL, this is not only frightening but also extremely dangerous. These unique transit hubs, while serving as vital transportation nodes, present distinct navigational hurdles for PWVL since they often lack the familiar tactile cues and infrastructure that assist in safe and independent navigation.

This research study will consider a comprehensive literature review of the accessible features available for PWVL at these locations or similar as well as developing a system that will warn PWVL of upcoming cyclists at these bus stops. This system will investigate the intersection of urban mobility, technology, and accessibility with a particular focus on providing support to this group of road users when navigating the intricate landscape of floating bus stops.

The results of the comprehensive literature review and preliminary conceptual approaches for this system will be considered and included. Finally, understanding the multifaceted challenges faced by PWVL when navigating urban environments and accessing public transportation is of paramount importance since this will guide the process of determining the best possible solutions to the issues.

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LIST OF IMPORTANT ACRONYMS

Acronym	Full Form
APS	Accessible Pedestrian Signals
ILDs	Inductive Loop Detections
LED	Light Emitting Diode
PWVL	People With Vision Loss
RFID	Radio Frequency Identification
RRFB	Rectangular Rapid Flashing Beacon
TWSI	Tactile Warning Signal Indicator

CHAPTER ONE - INTRODUCTION

1.1 Background of the Study

In Canada, approximately 1.5 million people are affected by visual loss or blindness as shown in Table 1.1 and Figure 1.1 respectively. This is more than a number since it represents people whose lives, routines, and opportunities are heavily influenced by their ability to see (CNIB, 2023). This vision loss spans a wide range, from mild visual impairment to total blindness, each with its own set of issues, which are frequently exacerbated by the built environment and social attitudes. Canada has taken significant steps to provide more accessible locations and support systems for people with vision impairments. Nonetheless, the country continues to experience substantial gaps in health care, accessibility, and public awareness of this community's needs. The below key statistics are about blindness and its impact from coast to coast from the Canadian Survey on Disabilities 2017. These numbers include people with mild to very severe vision loss.

Table 1.1: Blindness by provinces in Canada data, (Source: CNIB, 2023).

Provinces	Populations	Percentage
British Columbia:	252,000	16.6%
Alberta:	160,000	10.5%
Saskatchewan: 43	43,000	2.8%
Manitoba: 57	57,000	3.8%
Ontario: 681	681,000	44.9%
Quebec: 205	205,900	13.6%
New Brunswick: 37	37,750	2.5%
Nova Scotia: 49	49,500	3.3%
Prince Edward Island	6,250	0.4%

Newfoundland and Labrador	21,700	1.4%
Yukon	1,400	0.1%
Northwest Territories	1,220	0.1%
Nunavut	1,280	0.1%

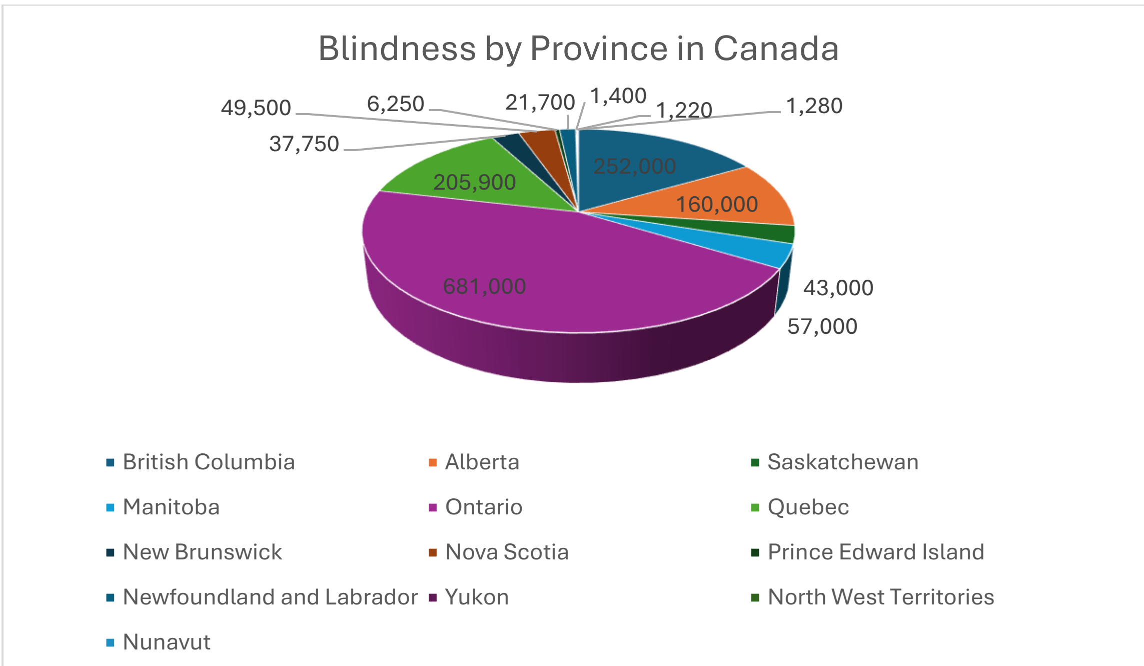


Figure 1.1: Blindness by province in Canada Data. (Source: CNIB, 2023 - https://www.cnib.ca/en/sight-loss-info/blindness/blindness-canada?region=on).

Moreover, most Canadians with vision loss are older people, with 75% of cases affecting those aged 65 and up (CNIB, 2023). Macular degeneration, glaucoma, and cataracts are common causes of visual impairment in this age range, and these figures are predicted to rise as the population ages (Statistics Canada, 2020). However, younger Canadians experience visual loss because of illnesses such as diabetic retinopathy and some genetic disorders. Because of the age and cause variations, people from different aspects of life are affected, each with specific needs that Canadian support systems are trying to address with the inclusion of how they will be able to navigate and access floating bus stops in Canada.

1.2 People with Vision Loss Challenges

People with vision loss (PWVL) have several challenges while traversing urban areas, including difficulty selecting a path, maintaining situational awareness, and recognizing hazards (Nawaz et al., 2020). Furthermore, the difficulty that PWVL faces in navigating a floating bus stop is enormous because the bicycle track is embedded at the back of the floating bus stop. This is the significant relevance of blind assistive technology devices for PWVL for urban transportation (Madake et al., 2023). These devices help PWVL with their position, orientation, and mobility needs during both indoor and outdoor activities. Moreover, these devices are especially valuable at floating bus stops, where they play a crucial role for PWVL. Furthermore, these individuals encounter practical obstacles when traveling outdoors (El-Taher et al., 2021), such as difficulties in accessing the APS buttons, and the situation awareness of cyclists when approaching floating bus stops. Due to this challenges, Popović (2013) argued that the architectural limitations of the physical environment worsen these challenges for PWVL. Nevertheless, advancements in technology, such as wearable devices and smartphone applications, are providing potential solutions (El-Taher et al., 2021; Darc et al., 2021; and Csapó et al., 2015). For instance, the incorporation of audio and tactile feedback in mobile platforms is augmenting navigation and accessibility (Csapó et al., 2015). Additionally, wearables equipped with auditory information and obstacle-detection capabilities can enhance navigation for users (Darc et al., 2021).

However, the timely processing of information remains a significant challenge. In addition, researchers are investigating the creation of on-demand mobility services to provide for the unique requirements of persons with mobility disabilities (Dorynek et al., 2022). Consequently, research and development are necessary to deal with the intricate and varied obstacles PWVL encounters in urban transportation, particularly at floating bus stops. Further, these obstacles are especially evident and complex for individuals with disabilities, including those with/ limited mobility (Banet & Stypułkowska, 2018; Kett et al., 2020) and PWVL (Popović, 2013). Therefore, the emphasis is of utmost importance for removing barriers to mobility especially for people with visual impairment. Hence, it is imperative to address obstacles PWVL encounters at floating bus stops in Canada to enhance their independence and integration into urban transportation.

1.3 Problem Statement

As discussed above, there is a crucial need to enhance safety at floating bus stops for PWVL due to their challenges regarding navigation and mobility at these specific locations. In consequence, PWVL are vulnerable users at floating bus stops and have difficulty navigating and accessing buses due to the bike lane. Therefore, the absence of adequate or proper warning systems for PWVL or the limitation of the available ones increases the risk of collision with cyclists. Moreover, these challenges may lead to collisions that may cause injuries, and/or missing the bus for PWVL. In consequence, it is essential to reduce the challenges PWVL faces when navigating and accessing floating bus stops to enhance their urban mobility. As a result, establishing viable systems that help PWVL safe access and ease navigating floating bus stops is the main purpose of this project. In consequence, the main objective of the research is to propose a technological system solution that will help PWVL access floating bus stops.

1.4 Research Objectives

The main objective of the research project is to ease the accessibility of PWVL at floating bus stops and assess the current state of the design in various parts of Canada with respect to mobility at intersections. Also, of the evaluation of existing technology system solutions is part of the research as well as proposing a new technology system at floating bus stops. A prototype to showcase the system's real-life implementation will also be presented Finally, a survey is proposed to receive feedback of the proposed system once it is tested on the field.

Then, this research project has the following objectives:

- To review existing technology systems related to interactions between pedestrians and cyclists at regular intersections and to analyze their possible implementation at floating bus stops.
- To propose a theoretical system considering existing technology to implement at floating bus stops.
- To develop and test a prototype with an Arduino-based warning to showcase the proposed technology system
- To prepare a survey to Identify and understand specific challenges faced by visually impaired individuals at floating bus stops as well as to receive feedback when the proposed technology system is tested on the field.

1.5 Significance of the study

The primary goal of this project is to enhance safety and accessibility for PWVL at floating bus stops by proposing a real-time warning system that alerts them about approaching bicycles by providing feedback through audio-haptic signals. This system integrates several advanced technologies to provide timely and effective notifications, ensuring that visually impaired users can navigate their environments more safely. The system will also be capable of detecting PWVL and facilitating their navigation by limiting the movement of cyclists through the pedestrian crossing. The audio feedback, delivered via wearable speakers or earbuds, includes text-to-speech alerts and spatial audio cues to indicate the direction and distance of the approaching bicycle.

1.6 Outline of the Report

Figure 1.2 shows the different chapters of this thesis report. Chapter one is the introduction, which comprises the background of the study, the problem statement, and the research objectives. The second chapter contains the literature review which includes existing state of the art technology and identifies the gaps in previous related studies. Chapter three presents the methodology followed to accomplish the research objectives. The fourth chapter includes the results and discussion explaining the theoretical system solutions, the proposed new technological system and the prototype development. Lastly, chapter five presents the summary, conclusions, and recommendations.

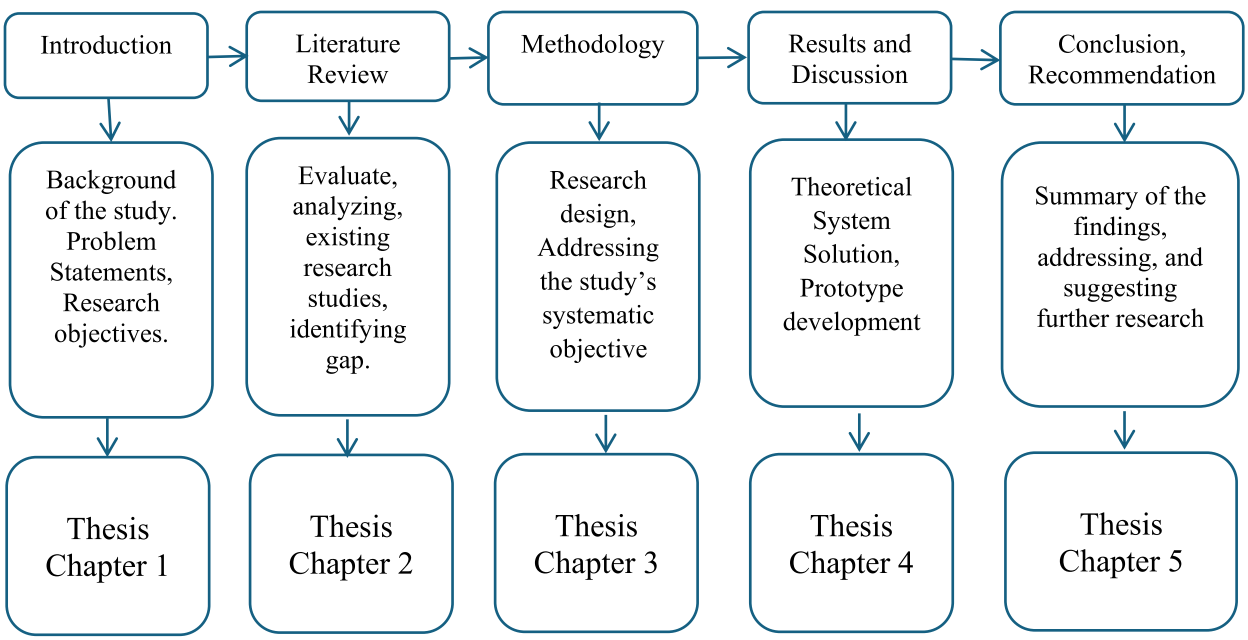


Figure 1.2: Illustration of the Outline for the Thesis Report.

CHAPTER 2 – LITERATURE REVIEW

Introduction

This chapter examines previous studies and literature identifying existing state of the art for accessibility solutions at floating bus stop as well as gaps related to PWVL. The report discusses the difficulties and impact of accessibility of PWVL when navigating floating bus stops. Furthermore, improving urban mobility for PWVL through navigation systems at floating bus stops in Canada are evaluated. Also, the latest digital tools that assist people with special needs in urban areas are reviewed.

2.1 PWVL assistive devices at the floating bus stop

Several studies have investigated the present condition of urban mobility for those PWVL Santos (2021) and El-Taher (2021) emphasized the growing utilization of wearable devices and assistance outdoor navigation systems, specifically emphasizing the provision of auditory feedback and the identification of obstacles. Many challenges exist for (PWVL) in urban mobility, including path selection, context awareness, and obstacle detection (Nawaz et al., 2020). These challenges are compounded by architectural barriers in the physical environment (Popović, 2013). PWVL face many practical difficulties when undertaking outdoor journeys as pedestrians and over the past decade, a variety of assistive devices have been researched and developed to help PWVL navigate more safely and independently (El-Taher et al., 2021). However, improving urban mobility for PWVL is crucial for their independence and safety. Wearable devices, such as those using audio information and obstacle detection, can enhance their navigation (Santos, 2021). Advancements in technology, such as wearable devices and mobile applications, are providing potential solutions (El-Taher et al., 2021 Darc et al., 2021, Csapó et al., 2015). For example, the use of audio and tactile feedback in mobile platforms enhances navigation and accessibility (Csapó et al., 2015).

Despite these advancements, there is a need for further research and development to address the complex and diverse challenges faced by PWVL when navigating floating bus stops. The importance of addressing mobility barriers is underscored by a range of factors (Joshi et al., 2021), the need for inclusive on-demand services (Dorynek et al., 2022), and the impact on participation in social and economic activities (Anderson, 2011). These barriers are particularly pronounced for people with disabilities, including those with mobility impairments (Banet & Stypułkowska, 2018; Kett et al., 2020), and visually impaired individuals (Popović, 2013).

However, researchers highlighted the need for more research and development, particularly in the areas of safety evaluation and deep learning techniques. In orientation and mobility training, particularly when utilizing the identification cane, more thorough study and methods are required. These results highlight the need for continuous improvement and innovation in urban mobility for PWVL.

2.2 Barriers at Floating Bus Stops

Enhancing urban mobility for PWVL is the main goal of this research review, which also looks at PWVL accessibility and the evaluation of bicycle navigation systems at floating bus stops. In an urban environment where accessibility is a primary concern, this review looks at the current state of research and technology, offering insights into the creative solutions and difficulties encountered in integrating bicycle navigation systems at floating bus stops to enable PWVL to navigate easily. According to Bloom and Reenen (2013), individuals with disabilities encounter challenges in participating fully in various aspects of community life due to the lack of infrastructure and transportation systems that cater to their specific requirements. This is exceptionally accurate for those utilizing mobility devices who need to navigate through constantly shifting pedestrian environments (Theodoridis & Kraemer, n.d.), accessible pedestrian signals provide auditory cues for individuals who are blind or have visual impairments. Another measure is the Pedestrian Clear Zones (PCZ) which refers to designated spaces on sidewalks that allow unobstructed passage without any temporary or permanent barriers. As per the New Construction Mitigation Guidelines, pedestrian management should provide a secure and unobstructed route around construction sites while considering the requirements of those with visual and mobility disabilities. This review aims to highlight the notable outcomes, difficulties, and prospects in enhancing mobility and independence for PWVL in urban settings.

According to Elliott (2023), Belusic (the vice-president of the Canadian Federation of the Blind), argued that public transportation is crucial for many blind individuals due to their inability to drive. However, he refrains from using floating bus stops because he considers it a risky proposition. Belusic claimed that it is impossible to anticipate the presence or absence of cyclists, and common issues with streetscape include the presence of bollards, street cafés, and parked vehicles obstructing the walkways. Swobodzinski et al. (2019) explore the range from partial to complete blindness, which significantly hinders a person's visual perception and comprehension of their surroundings, hence increasing the vulnerability of visually impaired pedestrians to accidents. Various experts present research and development efforts to create a revolutionary navigation system designed to guide PWVL. The primary goal of the recently developed system and potential solution is to enhance the mobility of visually impaired individuals by utilizing remote supervision from individuals with sight (Hunaiti et al., 2006). To assess the appropriateness of personal telecommunication technology for facilitating safe and effective navigation for PWVL, we obtained structured feedback from experts in the field and PWVL. These individuals often depend on their remaining senses and assistive equipment to ensure secure and independent navigation in their surroundings. An extensive range of visual impairments significantly impairs an individual's capacity to perceive and comprehend their surroundings, rendering PWVL more susceptible to accidents.

Lawson et al. (2022) examined the diverse obstacles encountered by PWVL and others when utilizing communal areas and other pedestrian settings. As shown in Figure 2.1, the mounting of the descriptive sign on the side of the pedestrian walkway to access the bus stop might cause PWVL difficulty in accessibility. Researchers specifically emphasized the significance of areas set aside for pedestrians, such as car-free zones, sidewalks used by both pedestrians and cyclists, and specific paths for both. Lu et al. (2023) explained that PWVL face significant challenges in their everyday lives, schooling, and jobs, Liao (2011), examined how they frequently encounter potential mental or physical obstacles because of their limited spatial awareness and frequent movement. Individuals with vision impairments sometimes encounter challenges when traversing urban areas. Cushley et al. (2022), Common issues often encountered by visually impaired pedestrians include various streetscape elements such as bollards, street cafes, and parked cars obstructing the sidewalks. and are not easily accessible. Nevertheless, these obstacles provide additional challenges for those with visual impairments to effectively navigate their environment and further limit their freedom of movement.

Figure 2.1: The descriptive signs on a pole (Source: Original Photograph by Samuel Olugbade 2024, August 8, 2024).

Therefore, enhancing accessibility for visually impaired pedestrians at floating bus stops is crucial to guaranteeing their safety and autonomy when utilizing floating bus stops. It is important to consider that the success of these solutions may vary depending on the environment and the demographics they serve.

2.3 The Concept of Urban Mobility

Urban mobility is the movement of people and goods within cities, and it has been extensively researched because of its impact on urban development, sustainability, and quality of life (Thompson & Lee, 2019; Williams et al., 2021). Urban mobility is becoming increasingly important in Canada as cities face significant population expansion, environmental issues, and technological advancements (Johnson, 2020; Chen, 2021). Also, Urban mobility lacks a universally accepted definition, with disciplines such as urban sociology, psychology, geography, economics, transport planning, traffic engineering, and mobility research each framing mobility in distinct ways (Smith, 2010; Jones & Brown, 2016). Additionally, variations exist in the classification and measurement of urban mobility (Davis, 2015). These varied viewpoints have a significant impact on how people think about urban mobility. For example, traffic flow managers prioritize ensuring high-speed, long-distance travel while maintaining safety, often overlooking the slower and more complex aspects of mobility (Williams & Lee, 2021). Terms like "rush hour" focus public attention on statistical extremes rather than everyday mobility patterns (Green, 2013). Most urban transportation activities support community-centered activities rather than simply accommodating vehicles, pedestrians, and cyclists (Chen, 2019). Density, a key characteristic of social rather than statistical traffic, highlights shared spaces where streets provide exits, not just entrances (Clark et al., 2022). For instance, during Toronto's evening rush hour, employment district sidewalks become dense with pedestrians, showing a pedestrian flow that rivals that of motor vehicles (Miller, 2021).

To address issues to create effective urban mobility in Canada, the concept of development in urban centers has gained the attention of the agencies involved, demonstrating that major urban street crossings and underground transit systems facilitate pedestrian mobility more effectively than parking centers (Roberts, 2018). This evidence of ambulatory mobility underscores the need for planners to integrate pedestrian considerations in urban and traffic planning (Evans, 2022).

2.4 Inclusive and Accessibility Initiatives for PWVL in Canada

Most recently, the Accessible Canada Act (2019) has advanced accessibility for Canadians with vision impairments by setting ambitious targets towards removing barriers across all federally regulated sectors by 2040. It is a huge step forward with ramifications for employment, digital accessibility, and public transport. Accessibility is essential to daily living and freedom for PWVL; It goes beyond simple convenience. Technology has also been essential in this situation. The advent of screen readers, GPS navigation tools, and software for magnification have altered how many PWVLs interact with their surroundings. These tools are still not available to everyone.

In the inclusive and accessibility Initiative for PWVL in Canada, various authors include accessibility and inclusion for PWVL, and the limitations are not solved yet and this is making PWVL navigate and accessibility in urban mobility.

2.5 Floating Bus Stop

A floating bus stop, sometimes referred to as a "bus stop bypass," is a design in which a bike lane divides the bus stop from the main sidewalk, and it is situated on an island. By enabling buses to stop without obstructing the bike lane, this configuration enhances pedestrian and bicycle safety by reducing disruptions for both bikers and buses (Kittleson et al., 2015). Due to its effective use of space in urban environments where several forms of transportation share a street, the design, which originated in European cities, has become more well-known in North America.

By minimizing collisions between buses and bikes, the floating bus stop design puts safety first. To prevent accidents and delays, cyclists can continue riding in the protected lane behind the bus stop island while a bus stop. According to studies, this configuration enhances overall traffic flow by removing bottlenecks frequently created when bikes and buses cross paths (Kittleson et al., 2015; Dill, McNeil, & Howland, 2019). The bus stop island also improves accessibility for people with restricted mobility by giving walkers a safe place to wait without obstructing bike lanes (Dill et al., 2019). As shown in Figure 2.2. a typical floating Bus stop at West minister BC, Canada.

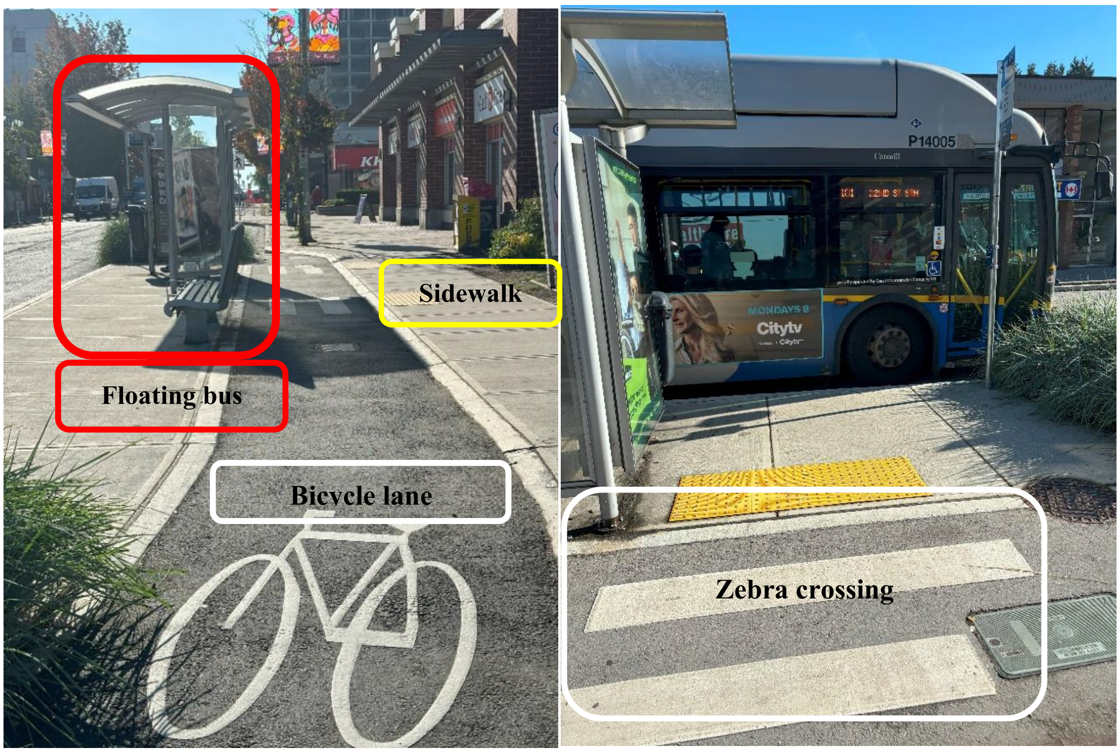


Figure 2.2: This is an illustration of a Floating Bus Stop, (Source: Original Photograph by Samuel Olugbade 2024, August 8, 2024).

Floating bus stops have been used in Canadian cities such as Toronto and Vancouver, where growing urban populations have reconsidered street space distribution (Toronto Transit Commission [TTC], 2021). In line with Canada's overarching objectives of multi-modal transit infrastructure and urban sustainability, research from Toronto's trial programs indicates that floating bus stops can shorten travel times and make it easier for people to interact with one another (TTC, 2021).

2.6 Conventional Bus Stop

A Conventional bus stop is a specific place along a bus route where people are picked up and dropped off. Usually situated on a sidewalk next to the curb, these stops give passengers easy access to board or disembark from the bus (TCRP, 2012). Conventional bus stops are placed in a way that maximizes safety and accessibility while causing the least amount of disturbance to traffic. Depending on the location of the bus stop and the anticipated number of passengers, its design frequently incorporates information displays, seating, signage, and shelter (Vuchic, 2007).

In Canada, conventional bus stops are a common feature of both urban and suburban landscapes. While they are practical, conventional bus stops can cause traffic congestion because they block one lane when stopping, which affects the flow of other vehicles, especially in dense urban areas. Congestion is frequently worse during peak hours, according to studies on how traditional bus stops affect traffic flow. This emphasizes the necessity for methods that strike a compromise between passenger convenience and traffic efficiency (Ceder, 2007). Major Canadian cities like Toronto and Vancouver have conventional stops, but they are increasingly investigating alternative designs, such as floating bus stops.

Large Canadian cities like Toronto and Vancouver have conventional bus stops, but they are also looking into alternative designs, like floating bus stops, to meet the changing needs of multi-modal transportation and ease traffic (City of Toronto, 2021). Conventional bus stops are a common feature of both urban and suburban landscapes in Canada, as shown in Figure 2.3.

Figure 2.3: A typical conventional Bus Stop, (Source: Original Photograph by Samuel Olugbade 2024, August 19, 2024).

2.7 Difference Between Floating Bus Stop and the Conventional Bus Stop

The main distinction between a floating bus stop and a conventional bus stop is how they are designed and how different forms of transportation, especially buses, bicycles, and pedestrians, interact. A conventional bus stop is directly adjacent to the sidewalk, where buses pull up to the curb to pick up and drop off passengers. This design makes it easy for passengers to enter the bus and gives them direct access (TCRP, 2012). However, buses can disrupt traffic flow by stopping in the traffic lane, leading to bottlenecks, especially on congested metropolitan highways (Vuchic, 2007). Additionally, cyclists may encounter difficulties at traditional bus stops since they frequently must swerve around halted buses, raising the possibility of collisions.

Furthermore, cyclists may encounter difficulties at conventional bus stops since they frequently must swerve around buses that are stopped there, raising the possibility of collisions (Ceder, 2007).

On the other hand, a floating bus stop, also known as a bus stop bypass, has a designated cycle lane between it and the sidewalk. Since the bus stop is situated on an island that is reachable by crosswalks, bicycles can pass behind it without hindrance while buses pick up or drop off people (Kittleson et al., 2015). Floating bus stops provide a safer waiting area for passengers, enhance traffic flow, and lessen the possibility of collisions between cyclists and buses (Dill, McNeil, & Howland, 2019). The use of these stops is growing in densely populated areas, such as those in Canada, where it is crucial to pedestrian safety and the effectiveness of multimodal transportation systems (City of Toronto, 2021). Traffic flow and safety are ultimately where the two diverge most. Floating bus stops are especially well-suited for locations with significant bus and bike traffic because they separate cyclist and bus interactions, minimizing problems that conventional bus stops may cause by disrupting the flow of vehicles and bicycles (Kittleson et al., 2015).

2.8 Design Technique of the Floating Bus Stop

Several design strategies are used in floating bus stops to guarantee everyone using the road is safe, accessible, and efficient. In addition to offering easy and secure access to the bus stop island, these design features mainly aim to reduce collisions between buses, bikers, and pedestrians.

2.8.1. The location and width of the Floating bus stop

Floating bus stops are an important part of the inclusion of the secure waiting space for PWVL and pedestrians and a shelter, which is divided by the bike lane and the pedestrian's walkway or sidewalks. Typically, the floating bus stops at a width that is designed to allow waiting spaces and passenger flow without creating crowding. Islands should be at least two to three meters wide, according to research, to provide facilities like benches, shelters, and signage with information (Dill, McNeil, & Howland, 2019). As shown in Figure 2.4, the width of floating bus stops.

Crosswalks that link to the main walkway provide pedestrians with a safe and easy way to access the island.

Figure 2.4: The width dimension illustrates the floating bus stop at North Vancouver BC. (Source: Original Photograph by Samuel Olugbade 2024, August 8, 2024).

2.8.2. Diversion and Protection of Cycle Lanes

In floating bus stops, the cycling lane usually runs between the curb of the pedestrian walkway and the bus stop, avoiding the bus stop island. By avoiding stopping or avoiding buses, this detour lowers the risk of collisions and delays for bicycles (Kittleson et al., 2015). The bike lane is divided by curbs and bollards from the bus stop shelter to clearly define and direct traffic flows and physical obstacles to increase efficiency and improve safety in cities with an increase in the number of cyclists. Figure 2.5 shows the Bike Lane position behind the shelter.

Figure 2.5: The Bike Lane position behind the shelter, (Source: Original Photograph by Samuel Olugbade 2024, August 8, 2024).

2.8.3. Pedestrian Sidewalk

As shown in Figure 2.6 the sidewalk connects to the sidewalk to the bus stop island and provides a safe means for passengers to cross the bike lane, crosswalks are essential to the design of floating bus stops. To warn pedestrians, especially those who are visually impaired, of oncoming bikes, marked crosswalks with tactile warning surfaces are frequently utilized (City of Toronto, 2021). In certain places, particularly where high bike speeds potentially endanger people, signalized pedestrian crossings are erected near floating bus stops. Pedestrians trigger these signals, which preserve bike lane movement while offering safe crossing intervals.

Figure 2.6: The pedestrian sideway that PWVL (Source: Original Photograph by Samuel Olugbade 2024, August 8, 2024).

2.8.4. Features for Accessibility

A primary consideration in the design of floating bus stops is accessibility. To accommodate passengers with impairments, many floating bus stops use elevated curbs, tactile pavement, and audible signals. Wheelchair users and people with mobility impairments can board buses level and more easily because the island's elevated curb frequently lines up with the bus entrance (Goldsmith, 2020). To make these stops more inclusive, some designs additionally incorporate Braille signage or audio information for people with visual impairments (Kittleson et al., 2015) as shown in Figure 2.7.

Figure 2.7: The Tactile pavement. (Source: Original Photograph by Samuel Olugbade 2024, August 8, 2024).

2.8.5. Landscaping and buffer zones

Sometimes buffer zones are positioned between the bike lane and the bus stop island to improve pedestrian comfort and safety. These areas may incorporate landscape elements like planters, trees, or grass strips that serve as a natural barrier between cyclists and walkers in addition to their aesthetic value. Passengers waiting on the island may feel less stressed because of these features, particularly in crowded urban areas (Dill et al., 2019). Additionally, buffer zones give bikers and pedestrians an extra degree of segregation, which improves the area's organization and safety.

2.8.6. Smart and Dynamic Integration of Technology

To enhance the user experience, some floating bus stops in cities with sophisticated transit systems include smart technologies like automated crossing lights and real-time arrival displays. Smoother interactions and increased safety are promoted by these technologies, which alert passengers to impending bus arrivals and let bicycles see when a pedestrian is crossing (City of Toronto, 2021). Smart technology integration is particularly beneficial in crowded cities where regular bus and bicycle traffic need real-time information to prevent collisions.

In summary, the design techniques of floating bus stops, from the bus stop island to smart technologies, work together to create a safer, more efficient transit experience. Each design feature supports a particular aspect of user safety and accessibility, making floating bus stops a popular choice for urban areas with high pedestrian, cycling, and bus traffic.

2.9 Deployment Location

When deciding where to locate floating bus stops, several criteria need to be considered to guarantee optimal functioning, safety, and accessibility. By affecting the positions of floating bus stops in metropolitan areas, these variables help create effective public transportation networks.

2.9.1 Areas with high pedestrian and bicycle traffic

Floating bus stops ought to be placed in places where there is a lot of foot and bicycle traffic, including close to business districts, schools, and residential neighborhoods with a high population density. High-traffic areas guarantee that the bus stop serves more people, increasing its usefulness (Dill et al., 2019). The presence of floating bus stops at these locations could also encourage more interactions among different road users that are healthy, especially in mixed-use environments.

2.9.2 Proximity to Existing Transportation Facilities

To improve connectivity and reduce the commuting pace, floating bus stations must be installed near the existing transit built in the context. According to Furth et al. (2017), the implementation of floating bus stops at strategic transfer points, like junctions with other bus lines or transit hubs (like light rail or subway stations), facilitates easy mode switching for passengers and cuts down on total trip time. Furthermore, higher use of public transit systems is encouraged by closeness to other public transportation services.

2.9.3. Traffic Patterns and Road Configuration

Road layouts and traffic patterns should be considered while choosing deployment sites. Since these circumstances reduce the possibility of conflicts between buses, cyclists, and pedestrians, floating bus stops work best on routes with defined bike lanes and slower vehicle speeds (Kittleson et al., 2015). The ideal sites are those that have sufficient road width at that location to accommodate floating bus stops without interfering with traffic. Analyzing corridor throughput is also critical to identifying peak hours of the week by vehicle types to avoid trends of clogged regions that can undermine transit functions.

2.9.4. Safety Consideration

For the provision of floating bus stops, safety is an overriding consideration when determining which sites are suitable for deployment. Improvements should be carefully considered in areas where there has been a history of accidents involving bikes or pedestrians. Floating bus stops can also be safer when traffic-calming features like speed bumps or lower speed restrictions are present. Furthermore, priority should be given to accessibility and visibility for all users, including those with impairments (City of Toronto, 2021).

2.10 The Summary

Bicycle navigation system implementation at floating bus stops is a complex issue that requires an all-encompassing approach. The systems approach must prioritize safety, particularly when it comes to cycling in metropolitan areas. El-Taher (2021) emphasizes how important it is to take visually impaired people's needs into account while developing and deploying such systems. The significance of infrastructure design, specifically highlighting how cycling affects the safety of PWVL. Finally, all these findings suggest that any bicycle navigation system utilized at floating bus stops should put safety first, consider the needs of people who are blind or visually impaired, and be created and evaluated based on input from users. This study looks at the connection between urban mobility, technology, and accessibility. Its specific objective is to assess the degree to which bicycle navigation systems facilitate the navigation of the complex network of floating bus stops by those with visual impairments. By evaluating the usability, functionality, and user experiences of these navigation devices, this study seeks to offer valuable insights and recommendations for enhancing the accessibility and inclusion of floating bus stops for this user group.

2.11 Selection Criteria for Assistive Technologies in Floating Bus Stop Environments

The literature review evaluated assistive technologies for people with visual loss in urban environments, focusing on floating bus stops due to unique challenges like shared spaces, lack of tactile or auditory cues, and potential conflicts between pedestrians and cyclists. Key challenges included navigation challenges, shared infrastructure, and limited accessibility features.

The selection process for Floating Bus Stops involved identifying key challenges such as the lack of direct curb-to-bus access, the high potential for bicycle-pedestrian interactions due to shared infrastructure, and limited accessibility features. Assistive technology was prioritized based on bicycle detection capability, compliance and behavior management, communication, and accessibility.

Research on proven technologies in urban accessibility projects included bicycle detection systems, auditory alert systems, tactile feedback devices, and IoT-enabled systems. These technologies addressed safety and accessibility concerns while aligning with the goals of creating inclusive, user-friendly, and scalable solutions in urban environments.

The final selection of technologies was based on their direct applicability to floating bus stops, ensuring that the proposed solutions were practical and impactful in addressing the specific needs of People with Visual Impairment (PWVL) at floating bus stops. These technologies not only addressed safety and accessibility concerns but also aligned with the goals of creating inclusive, user-friendly, and scalable solutions in urban environments.

2.12 Functionalities and their Limitation of different technology

Presenting a high level of theoretical solution that is inclusion of compliance, communication, and detection and checking out each technology that will be used checking their functionalities and their limitation as explained in Table 2.1 below, the research studies will use the methods.

Table 2.1: Functionalities and their Limitations of Different Technology

S/N	Company	Bicycle Detection Equipment	Pros	Cons	Diagram
1	FORTRAN	Bicycle traffic signal	Good for Operation for Detection and Compliance.	Lack of Effective Communication	
2	FORTRAN	Radar Detector	Reliable and accurate	Lack of effective Communication and Compliance	
3	ATLA PLANNING + DESIGN	Loop Detection	Detection of cyclists	Intentionally avoidance of the loop detection.	
4	Accessible Pedestrian signals (APS)	Push button	Advanced models can provide audible and visual feedback to the user	Difficult for people with vision loss to navigate.	
5	ATLA PLANNING + DESIGN	Microwave radar devices	Detection devices can collect counts, speed, distance, and classification data,	Problematic due to weather, low light, occlusion, or other factors	

6	CARMANAH MX Series- Rectangular Rapid Flashing Beacon	Communication	Clear communication / passive detection.	Audible Push Button Station is difficult for people with vision loss to navigate.	
7	ZELT EVO: Cometh Edition.	Sensor/ Loop Detection	Detection loops, Direction recognition, Speed measurement.	No communication/ compliance	
8	TELELDYNE FLIR: Trafisense AI	Detection	Detection	No communication and compliance	
9	SENSYS NETWORK	Detection VSN240-M-2 Micro Radar Sensor	Simple Installation	No communication	

The study will zoom in on some components, the bicycle traffic signal, infrared, and others, describing their functionalities and implementation in detail including their physical usage and the pictorial example of their usage. Finally, the research study will present the best theoretical usage of the best technology that will combat the challenges and allow the easy accessibility of PWVL, while cyclists is detected or controlled and forced to comply with the traffic signal for allowance of PWVL.

CHAPTER 3 - METHODOLOGY

3.1 Overview

This chapter outlines the methodology employed in this research. The study integrates bicycle detection, compliance technology, and communication systems to improve urban mobility for individuals with visual impairments at floating bus stops. It is structured into several sections that describe the technology systems evaluated, the theoretical approach to implement those technologies into floating bus stops, the proposed technological system, prototype development, and survey. The primary objective is to propose a system that warns and enhance safety for PWVL by detecting cyclists and improving their compliance with traffic laws and regulations by combining existing technology.

3.2 Technology Systems Analysis.

This part of the research involves the evaluation of existing technology systems at intersections and their possible adaptation to floating bus stops. System components, functionality, communications, compliance, schematics, and limitations of different technologies are examined. The schematics will consider the theoretical adaptation of the systems to floating bus stops. Four systems are included in this part.

3.2.1 The First Technological System Solution

This includes s description of the application of FORTRAN Bicycle Signal Head and its possible implementation at floating bus stops. The following are considered in the analysis.

- Functionality Specification,
- Features,
- Real-time application,
- Communication system

- Compliance Technology
- Schematic diagram of Bicycle Traffic signal at floating bus stops
- Limitations

3.2.2 The Second Technological System Solution

This includes a description of the analysis and application of Rectangular Rapid Flashing Beacons (RRFB) on the aspects indicated below.

- Functionality Specification,
- APS and Passive Microwave Detection system,
- Real-time application,
- Communication system
- Schematics diagram of the RRFB at floating bus stops
- Limitations

3.2.3 The Third Technological System Solution

This system considers Radio Frequency Identification (RFID). The following are included for this system

- Functionality Specification
- System Setup: REID-Enabled Tags and Devices
- RFID Signage and Sensors.
- Approaching the Floating Bus Stop: (PHASE ONE)
- When People with Vision Loss Approach the Floating Bus Stop (PHASE TWO).

- When the Cyclists and PWVL interact with each other at the same time. (PHASE THREE)
- Calculating Bicycle Speeds
- Summary of the System
- Schematics diagram of the RFID at floating bus stops
- Limitations

3.2.4 The Fourth Technological System Solution

This system is based on Inductive Loop Detection. The list below are the considerations for this part.

- Functionality Specification
- Operation of the Inductive loop detections.
- Limitations of the Inductive Loop Detection.
- Schematic diagram of the Inductive Koop Detection at floating bus stops

3.3 Proposed Technological System:

The proposed technological system is based on the combination of existing technology. This system combines detection, communication and compliance. The list below is the consideration for the system.

- System components
- Control system
- Detection system
- Communication system

- Compliance system
- System functionality
- Benefit of the proposed system
- Schematic Application of the proposed system at floating

As a substitute for the BTS detection of cyclists, the Wavetronix Bicycle Detection system by FORTRAN is examined, and its specifications are also evaluated.

3.4 Prototype Development.

The main purpose of the prototype development is to represent the proposed technological system described above. The different phases considered to develop this prototype are presented in the following subsections.

3.4.1 System Architecture.

The System Architecture will include Hardware components and software components. These components include Arduino Uno, Breadboard, Jumper Wires, Sensors, and Buzzers.

3.4.2 Development Procedure.

The Arduino Uno is used in the Traffic Light System and Bicycle Detection System to improve safety and mobility. The following phases comprise the methodology:

- Analyzing requirements: determine the goals of the system, the target audience (such as those with visual impairments), and the components (such as buzzers, RFID, LEDs, and ultrasonic sensors).
- System Design: create circuit schematics and logic flow for controlling traffic lights and detecting bicycles.

- Integrating components: assemble and connect hardware parts while making sure they work and are compatible.
- Programming: create an Arduino code that can guide users, identify pedestrians and bicycles, and indicate with LEDs.
- Testing and Evaluation: verify the system's functionality in various situations and improve the design.

3.5 PWVL Survey

This part presents the steps considered to develop a survey to obtain insights from PWVL regarding their experiences and expectations when navigating floating bus stops as well as feedback when the proposed technological system is tested on the field. This includes a questionnaire and communicating with CNIB staff to seek collaboration when the survey will be conducted with their clients.

3.5.1 Population Sample

The study populations will be CNIB clients in Ontario and British Columbia.

3.5.2 Data Collection Materials:

The survey will be conducted using google documents and shared using the online platforms, with the collaboration with CNIB staff.

3.5.3 Location Selection

The locations selected for this survey are Thunder Bay in Ontario and Westminster, Vancouver, and North Vancouver in British Columbia. Thunder Bay was selected since the research team is in this City. It will allow direct contact with PWVL in a familiar location. On the other hand, cities in British Columbia were selected due to the experiences at floating bus stops.

3.5.4 Questionnaire

The survey will contain two types of questions which includes open-ended questions and close-ended questions.

Close-ended questions use the Likert scale from strongly agree to strongly disagree.

Open-ended questions are intended to let the respondent tell their experiences with cyclist and floating bus stops and provide feedback when the proposed technological system is tested on the field.

3.5.5 Survey Distribution:

The survey will be distributed both in-person, and virtually in collaboration with the CNIB staff both in the cities in British Columbia and Thunder Bay, Ontario.

3.5.6 Data Collection Duration

It is estimated that the process will take approximately two weeks to complete.

3.5.7 Ethical Permission Procedure

The Research Ethics Board (REB) at Lakehead University is responsible for evaluating ethical considerations when conducting research with human subjects to avoid encroaching on the privacy of the respondents and protecting their rights. Obtaining informed consent from the respondents is critical, and for this research the anonymity and the confidentiality of the participants is paramount. The approval process with the REB to conduct the survey will be a step later.

CHAPTER 4 - RESULTS AND DISCUSSIONS

This chapter presents an overview of four existing systems where cyclists detection and pedestrians' interactions at intersections are considered. The overview includes the components of the systems and a schematic of their possible application at floating bus stops as well as their limitations. This chapter also includes a proposed technological system that combines existing technologies to account for presence of PWVL and the existing gap when it comes to their mobility at floating bus stops.

The study main objective is to improve urban mobility and enhance safety for PWVL at floating bus stops by focusing on cyclist and pedestrian interactions in shared spaces. The selection of systems was based on their relevance to the unique challenges at floating bus stops, feasibility, and effectiveness in addressing PWVL's needs.

The selected systems focused on key issues such as identifying approaching bicycles, reducing conflicts between pedestrians and cyclists, and providing timely alerts to PWVL. The systems were chosen based on their proven effectiveness in urban settings, such as camera-based bicycle detection and ultrasonic sensors, which provided measurable results like detection accuracy and reduced collision rates. Accessibility needs were also prioritized, with non-visual cues like auditory alerts and compliance signals for cyclists being essential for safe and inclusive navigation of PWVL.

Fast-fable prototype development systems were selected, considering factors like cost, scalability, and ease of integration with existing infrastructure. IR infrared sensor systems were included for their affordability and reliability, while auditory alert systems were chosen for their ease of deployment and immediate feedback. Stakeholder input was also considered, with systems that aligned with user needs and infrastructure design recommendations. Systems with potential for large-scale implementation were selected to ensure the research findings could be translated into practical solutions.

4.1 The First Technological System Solution

4.1.1 FORTRAN Bicycle Signal Head

The bicycle signal head is installed along bike lanes at intersections and will automatically switch the signal light across the green, yellow and red. This system includes detection/control, communication, and compliance as described below.

The image of the FORTRAN Bicycle Signal Head is shown below in Figure 4.1 and the bicycle symbol meets the latest Transportation Association Canada (TAC) specifications.

Figure 4.1: Bicycle Signal Head. (Source: Fortran Bicycle Signal, 2024).

The bicycle traffic signal is 100% Virgin polycarbonate, making it more fade-resistant than traditional aluminum signals through bad weather. This has been quite popular in the transport industries to help accessibility and navigation of PWVL at intersections and would be beneficial at floating bus stops by controlling and detecting cyclists to allow PWVL to cross. Still, the limitations of this system are that it will not communicate to PWVL the presence of cyclists and there is no certainty that cyclists will stop. Table 4.1 presents the functionality specifications and the details of the Bicycle Signal Head System.

In its most basic form, the bicycle traffic signal, as the head available in both 8” and 12” LED modules, and is designed to mix, match, and meet specific signaling requirements that can be spotted with the modular design from a distance.

Table 4.1: Functionality specifications and details of the Bicycle Signal Head System.

Functionality Specifications	**Details**
Materials	UV Stabilized Flame Retardant 100 % Virgin Polycarbonate
Visors:	Cowl (Cap), Tunnel
LEDs	Bicycle Symbol Clear Red, Amber, or Green
Color	Standard: Yellow Traffic, Black, Grey, and Green Other colors
Dimensions:	inches.
Backboards	Sold separately Fortran’s PolyFlex™ Backboard
Power	120VAC

Features

This system includes the following features:

- Bicycle Symbol that meets TAC Specifications.
- Signal Housing which exceeds ITE Specification
- Modular Design
- Lightweight
- Low Maintenance
- Strong and Durable
- Weatherproof Enclosure.

4.1.2 System Setup: Bicycle Signal Head.

When considering this system at floating bus stops, the bicycle signal head would be like the traffic light shown in Figure 4.2. The bicycle signal head will be fitted at a floating bus stop depending on their configuration. They will primarily be installed closer to the bicycle lane for cyclist's compliance and control when the lights come up. The bicycle head signal will function normally at timing, automated for the designated signal light to turn on and off.

Figure 4.2: Implementation of the Bicycle Head Signals and Bicycle Signal Head on Green Signal. (Source: Original Photograph by Samuel Olugbade 2024, August 8, 2024).

4.1.3 Communication System

The APS button is a communication system that provides auditory cues when is press. The system can also assist PWVL since it is used where visual feedback are not sufficient but limited due to different positioning when implemented at the floating bus stops. PWVL that are familiar with their immediate environment can travel by using their auditory senses to access a particular APS button system. Individuals who are blind or partially blind frequently depend significantly on this system. The time it takes for a pedestrian standing at the APS position to cross the bike lane and get to the other side of the traveled way should be used to determine pedestrian clearing times. Shown in Figure 4.3 is a typical APS button for the accessibility of pedestrians at an intersection at the University of Guelph, Guelph, Ontario, Canada.

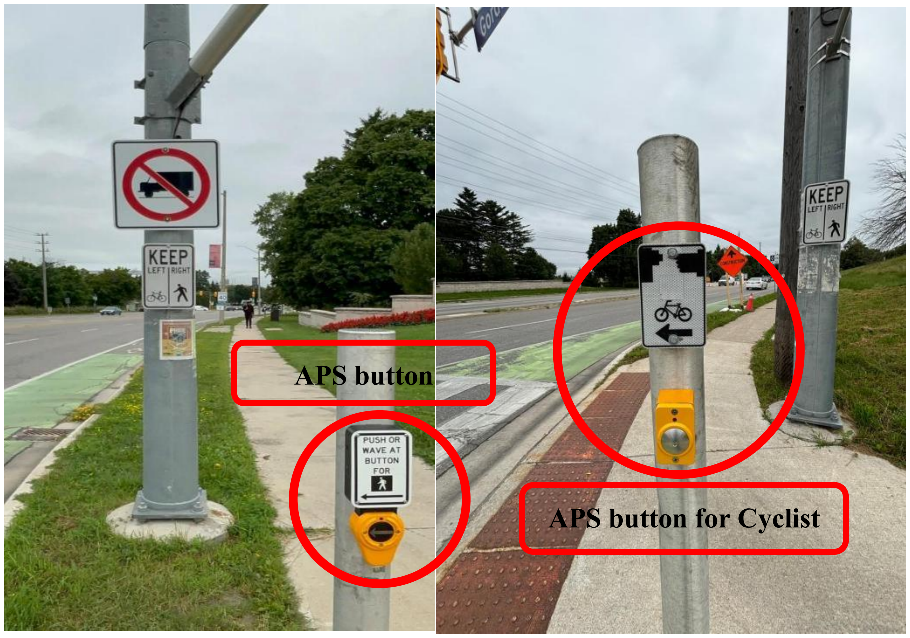


Figure 4.3: APS at an intersection. (Source: Original Photograph by Samuel Olugbade 2024, August 8, 2024).

4.1.4 Compliance Technology

Compliance technology ensures the safety of cyclists and PWVL, and the reduction of risk of collisions when they meet at common ground. Compliance technology aims to create harmonization between cyclists and PWVL by reducing conflicts and enhancing navigation and accessibility of PWVL at floating bus stops. Compliance technology may include but is not limited to stopping at crossing signs, yielding to pedestrians, and reduction of speed. An example of traffic signs that can assist in compliance is the warning sign for cyclists as shown in Figure 4.4. The compliance technology at floating bus stops will force cyclists to yield for PWVL when they approach these facilities. Cyclists must ensure that they adhere to the traffic signs for the safety of other users and should understand that failure to do so causes the risk of an accident.

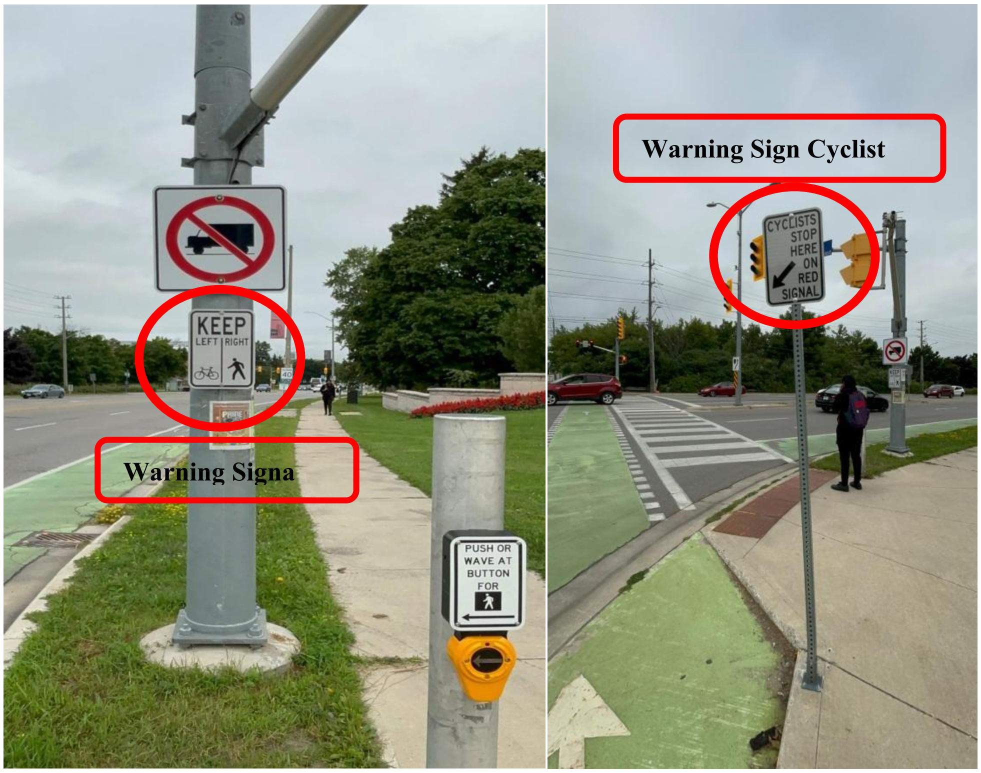


Figure 4.4: Warning signs for cyclists and pedestrians. (Source: Author, 2024, Source: Original Photographs by Samuel Olugbade, August 8, 2024).

4.1.5 Schematic Applications for the Traffic Bicycle Head System

The schematic diagram on Figure 4.5 presents the location of the bicycle signal head and interaction between PWVL and cyclists including the APS Button at a floating Bus stop. The diagram includes sections and features such as the bus stop shelter, waiting areas, traffic signal and signs, crash barriers, sidewalk, bike lane, and the IR infrared sensor.

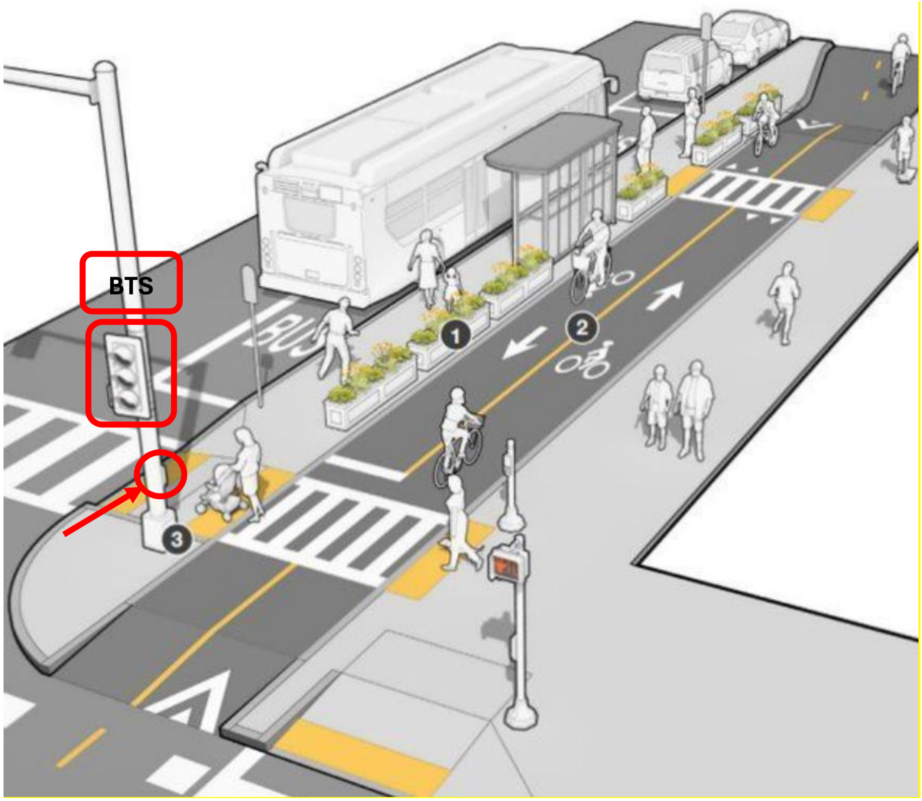


Figure 4.5: Schematic diagram of the BTS and APS buttons at floating bus stops. (Source: Tulio, 2024).

As shown in the schematic diagram above, the bicycle traffic signal head controls the movement of cyclists at floating bus stops, with a special design of lights in green, yellow, and red. The functionality of the bicycle traffic signal head is that it operates in a cycle that allows orderly movement by cyclists and pedestrians. Similar, to the vehicular traffic light, green bicycle light allows cyclists to move at a specific period, yellow light warns cyclists to prepare to stop, and red light means to stop. The use of the APS button allows PWVL to gain priority for onward movement.

4.1.6 Limitations of the system

This technology has its limitations such as the bicycle signal head poses a threat to PWVL when navigating floating bus stops due to the non-compliance by cyclists when the red light is on. Secondly, the non-clear auditory communication of the technology for PWVL at floating bus stops will increase the risk of collisions. Other limitation is that PWVL may have difficulty accessing the APS push button for navigation.

4.2 The Second Technological System Solution

4.2.1 Rectangular Rapid Flashing Beacons

Rectangular Rapid Flashing Beacons (RRFB) are similar and effective as the Bicycle Traffic Signal. The audible information devices should be installed at all crossings and triggered by passive pedestrian detection. The important features of RRFB are the high visibility flashing light pattern and the clear audible communication that assists PWVL in navigating intersections. Figure 4.6 shows the installation of RRFB at an intersection. These devices could be installed at the floating bus stop.

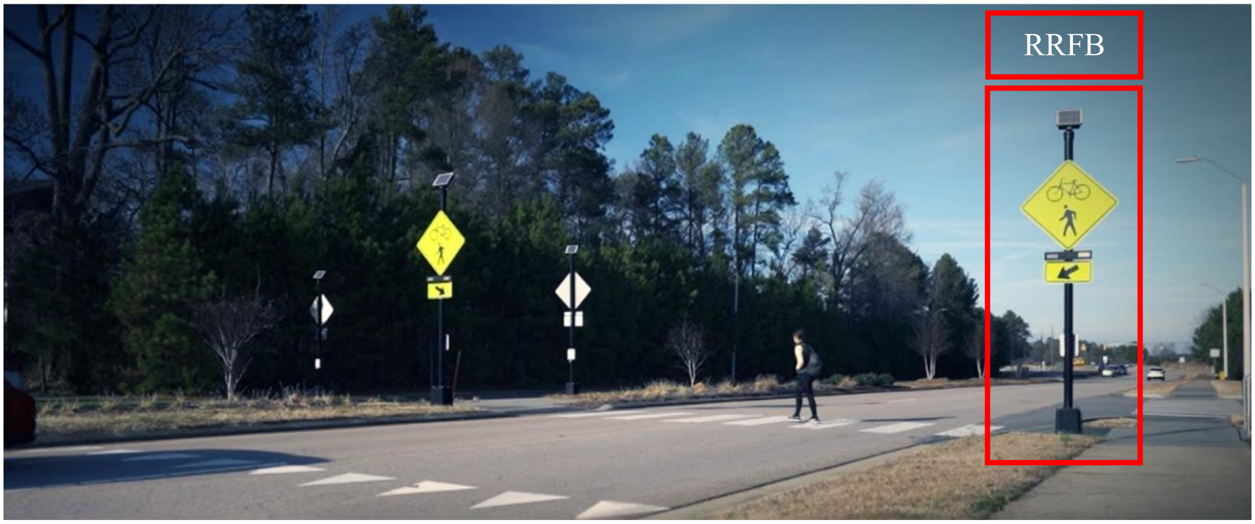


Figure 4.6: Rectangular Rapid Flashing Beacon (RRFB). (Source: Carmanah, 2024).

Moreover, Carmanah (2024) detailed that RRFB reduce pedestrian crashes at crosswalks by up to 47% with trusted MUTCD-compliant technology. Furthermore, installing passive pedestrian microwave detection systems would make it easy for people with vision loss to access and navigate. Pavement markings, regulatory signs, and RRFBs are all used in pedestrian crossovers. In addition to side-mounted and overhead-mounted regulatory signs, it is key to assist in compliance of cyclists. Examples of its use include single-lane roundabouts, double-lane roundabouts, uncontrolled intersections, and mid-block crosswalks (Marcom, 2024).

4.2.2 APS and Passive Pedestrian Microwave Detection System.

APS can be configured to provide information about street names and intersection geometry with speech messages, braille, raised print, maps, and diagrams. APS can also be configured to provide audible beacons that can help people with vision disabilities maintain their alignment while crossing long crosswalks. (Region, 2021). The passive pedestrian microwave detection system works differently from APS. Mozeliski (2018) explained that PWVL benefits from the passive pedestrian detection system's ability to recognize people and automatically send requests for the crossing phase without user intervention. A microwave Pedestrian Microwave detector, as indicated in Figure 4.7, can be used for PWVL at floating bus stops for accessibility and navigation of PWVL.

Figure 4.7: Passive Pedestrian Microwave Detector (Carmanah Technologies Corp, 2024).

4.2.3 Communication System.

RRFB have a readily installed clear and audible communication feature that can assist with accessibility and navigation of PWVL. The interaction between the system's components to maintain pedestrian safety and efficient operation is referred to as RRFB communication. A combination of internal signal processing wired or wireless connections, activation mechanisms, and visual output are used in RRFB communication.

4.2.4 Schematic Applications for RRFBs with APS and Communication

The schematic diagram is a layout of how RRFBs should be implemented and positioned for the navigation of PWVL along floating bus stops as shown in Figure 4.8. The diagram describes the location of RRFBs and how it will aid the accessibility of PWVL when they meet cyclists at a common ground to minimize the risk of accidents

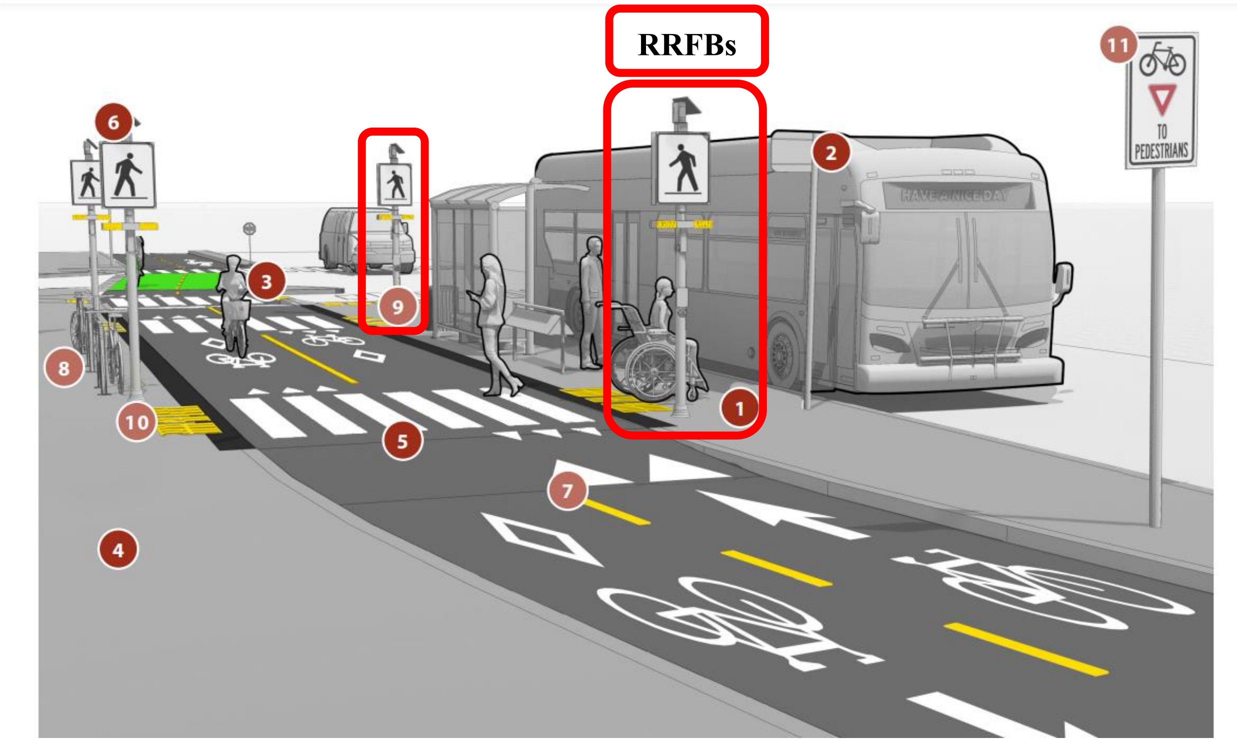


Figure 4.8: Illustration of RRFBs layout at a floating bus stop. (British Columbia Active Transportation Design Guide, 2024).

The diagram has different inscriptions, and each one represents sections and features according to the British Columbia Active Transportation Design Guide:

1. Accessible Landing Pad
2. Transit Route Identification Pole
3. Rear Clear Zone

4. Pedestrian Connection
5. Crosswalk
6. Rapid Rectangular Flashing Beacons (RRFBs) with Pedestrian Push Buttons and Acoustic Message
7. Ramp Grade
8. Bicycle Parking
9. Shelters, Benches, and Garbage Receptacles
10. Tactile Walking Surface Indicator with optional wheel gaps for mobility aids
11. Cyclists Yield to Pedestrians' Sign

4.2.5 Connections of the system.

The connection between the systems shows that when PWVL approaches the bike lane, they activate the push button and RRFBs will give a signal by flashing the amber light with clear auditory communication that gives cyclists a visible signal and a clear warning when PWVL are crossing or about to cross the bike lane, It is effective in increasing pedestrian safety because PWVL will have clear auditory communication. and the fast-flashing lights increase the chance that cyclists will yield. RRFBs are a useful tool in places where standard signals might not be available or where there are a lot of movements.

4.2.6 Limitation of RRFB

This system is an effective technology and would be more efficient if it had passive pedestrian microwave detection installed instead of APS button. This system provides the opportunity for consistent standard timing that will be sufficient for PWVL to navigate the bike lane towards the floating bus stop and the provision of auditory countdown timer. Another limitation of the system is that it does not guarantee compliance of cyclists once it indicates that pedestrians will be crossing

4.3 The Third Technological System Solution

4.3.1 Descriptive Application of Radio Frequency Identification (RFID)

The RFID technology system is a wireless sensor based on detecting electromagnetic signals according to McCarthy et al. (2003), RFID detects and identifies people, and objects using radio waves. It comprises readers, tags, and auxiliary systems that cooperate to communicate data and provide identification. The features of the different types of RFID are shown in Table 4.2. According to Kevin and Wesley (2024), Fundamentally, every tag functions similarly: a RFID tag's microchip contains data waiting to be read. The antenna of a RFID reader sends electromagnetic energy to the tag's antenna. The tag transmits radio waves to the reader using internal battery power or electricity collected from the reader's electromagnetic field. The radio waves from the tag are picked up by the reader, who decodes the frequencies into helpful information. The RFID tags that are used for the development of the systems are listed below

Table 4.2: Features of different types of RFID.

Features	Active RFID	Semi Passive RFID	Passive RFID
Power Source	Internal Battery	Internal Battery	No battery
Range	Between100 to 300 feet	Between100 to 300 feet	Up to 20 feet
Frequency	850-MHz to 950 MHz frequencies	850-MHz to 950 MHz frequencies	This varies depending on the system.

Application	The long-range tracking	Slightly less strong, but like the active RFID	Not strong
Data Strong Types	Read-Write, Read-Only, or WORM (Write Once, Read Many).	Read-Write, Read-Only, or WORM (Write Once, Read Many).	Read-Write, Read-Only, or WORM (Write Once, Read Many).

• Bicycle's RFID tag.

• PWVL radio frequency tag.

• Floating bus stops RFID scanners.

• Traffic light signals for bicycles.

• PWVL Auditory Alert.

RFID tag activation process and RFID reader use radio waves to create an electromagnetic field. Active tags use their power source to send signals, whilst passive tags in the field are strengthened, and a tag's antenna sends back stored information to the reader when it is activated, such as a unique identification number. This information is captured by the reader, who then transforms it into a digital format for processing.

RFID technology can increase safety and accessibility for all users, including those who are blind or visually impaired, in the context of floating bus stops. Visually impaired people can use Active RFID to follow buses in real-time and be alerted when a bus is coming. By detecting the presence of bikes or pedestrians, passive RFID tags can improve communication amongst all users of the road in shared areas. An extra degree of functionality and safety can be added by using semi-passive RFID, which can provide improved sensing capabilities to track pedestrian movements and environmental conditions. When combined, these RFID devices can increase accessibility, safety, and navigation at floating bus stops.

4.3.2 Schematic Applications for the RFID

The schematic diagram in Figure 4.9 is a layout of how RFID could be implemented for the navigation of PWVL along floating bus stops. The diagram describes the location of the RFID readers, RFID frequency, and RFID tag that will be attached to bicycles or cyclists and PWVL, and the interaction will occur when they meet on a common ground.

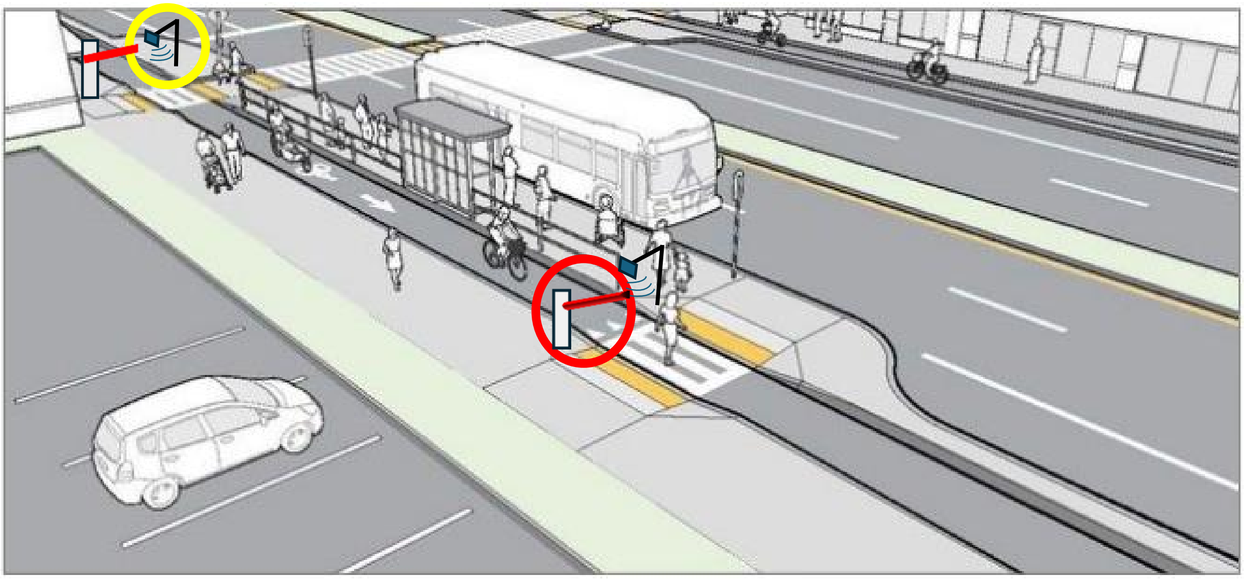


Figure 4.9: Illustration of RFID layout at a floating bus stop. (Arlington County Virginia, 2025), modified by Olugbade Samuel

RFID systems will monitor cyclists, and PWVL at floating bus stops to guarantee efficient operations. Readers can identify bikes with RFID tags and tracked them. For safety and real-time updates, pedestrians who have RFID-enabled cards or gadgets are tracked and warn of cyclists close by when the data from RFID readers is transmitted to a central server that interfaces with management systems for the safety of both cyclists and PWVL. All things considered, RFID guarantees effective communication between bicycles, and pedestrians, at floating bus stops.

4.3.3 RFID Signage and Sensors:

RFID Sensors are placed strategically beside the bike lane and walkway for pedestrians. These sensors provide real-life information about the pedestrians getting closer to the bike lane and cyclists getting closer to the pedestrian zebra crossing. The interaction signage that occurs when RFID signals are received, reacts to notify pedestrians and cyclists of another presence and provide safety instructions.

4.3.4 Cyclists Approaching Floating Bus Stops (PHASE ONE)

The RFID system recognizes cyclists approaching the pedestrian walkway or zebra crossing on the bike lane close to floating bus stops and sends audio warning signals to pedestrians including PWVL.

Furthermore, the audio alert sends a signal to cyclists saying words like "Slow down, you are closer to a pedestrian crossing, or pedestrian area ahead. Cyclists will have to slow down, stop, or be ready to navigate the area carefully for pedestrians, including PWVL.

4.3.5 People with Vision Loss Approaching Floating Bus Stops (PHASE TWO).

Pedestrian Alert System.

When PVWL utilizing a RFID-enabled gets closer to the crossing by floating bus stops, the gadget will help the user navigate by emitting warnings to PWVL on the situation awareness with words like. "Ahead is a bus stop area; stay to the left to avoid cyclist's lane,'" or "Turn right as PWVL moves across the zebra crossing on the bike lane". PWVL must always react to the technology directive as cyclists approach floating bus stops and remain or continue to follow the pattern or remain in the desired lane.

4.3.6 Cyclists and PWVL interact with each other at Floating Bus Stops. (PHASE THREE)

When pedestrians and cyclists meet at a common area at a floating bus stop within crucial proximity at about 5 meters or less; the RFID system will give pedestrians, including PWVL, priority over cyclists. For this purpose, the system will inform cyclists to slow down or yielding so pedestrians can pass through. The sample system component that can be replicated at a floating bus stop as shown in Figure 4.10 includes RFID scanner, antennas, and guardrails.

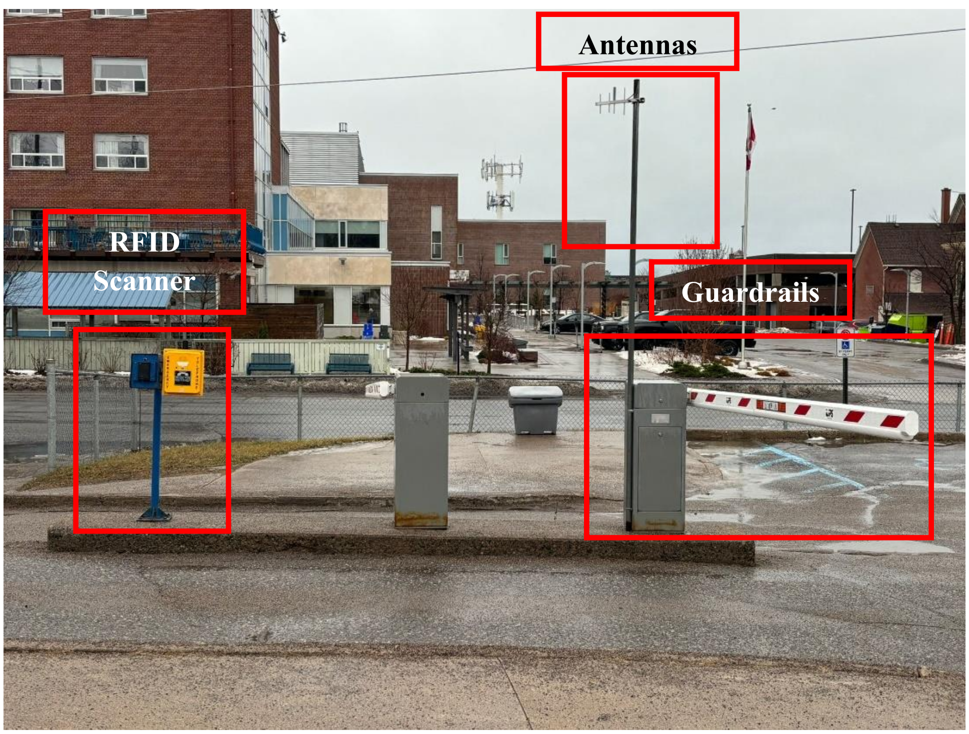


Figure 4.10: Illustrates the RFID system that can be replicated at floating bus stops (Source: Original Photographs by Samuel Olugbade, December 20, 2024).

4.3.7 Calculating Bicycle Speeds

The Dual RFID Scanner will allow to determine the speeds of cyclists. For this system setup, two RFID scanners should be placed at a fixed distance apart along the bicycle path. Then, the system can calculate bicycles' speeds by measuring the time it takes for the RFID tag to be read by both scanners and using the formula below.

Speed = Distance Between Scanners/Time taken to pass between scanners (1.1)

For this system, more auditory alerts could be triggered if a bicycle is moving above a certain speed to ensure pedestrians are extra cautious. This high speed can also trigger an additional warning signal for cyclists to slow down.

4.3.8 Limitations of RFID

The system assists PWVL in navigating floating bus stops but has limitations and challenges for PWVL. One limitation is the short detection range in an outdoor space like floating bus stops and the immediate feedback due to the placement of the tag and the reading. Also, environmental interference can influence the reader and tag detection.

Another limitation is RFID Tag Dependence. RFID-based systems do not identify users without RFID tags. That leaves a gap in user detection that could make increases risk of collisions if PWVL rely on the efficacy of detection of all users.

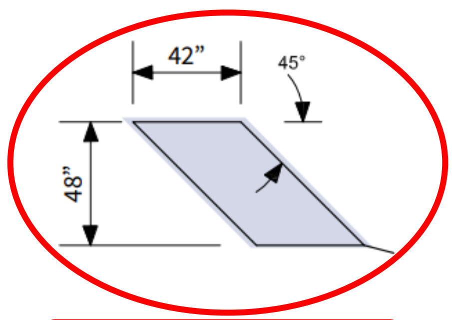
A very crucial limitation of this system is the lack of tag identification on non-tagged users. The system currently cannot identify other road users such as wheelchair users, skateboarders, animals etc. And finally, the limitation of type error. If tags do not work or are misread, RFIB won't trigger and will jeopardize the lives of tagged individuals.

4.4 The Fourth Technological System Solution.

4.4.1 Overview of the Inductive Loop Detection.

This is a system that only detects metallic objects such as bicycles using an electromagnetic field. Inductive loop detection uses magnetometer-built detecting devices that are also regarded as intrusive detection because they require pavement cutting for installation.

When inductive loop detectors are properly constructed and configured, they can easily identify bicycles with metal rims, whether they are made of steel or aluminum. The inductive loop is made from a wire that has been wound into a loop in a common shape, like a circle, square, or rectangle. A change in the magnetic field is sensed and the loop's inductance is reduced as a vehicle or bicycle passes over it (Monsere et al., 2021). Figure 4.11 shows the wiring loop and the Sawcut.



Sawcut for Bike Lane

Figure 4.11: The Sawcut Detail for Bike Lane with the dimension (Gilpin et al. 2021).

4.4.2 The Features

The categories and specification of inductive loop detection as shown in Table 4.3. the specifications are part of the detection systems and when bicycle passes over the loop or stop at the loop.

Table 4.3: Overview of the Inductive detection system (Orange Traffic, 2024).

Categories	Specifications
Type of Loop	Parallelogram, rectangular or circular
Sensor type	Electromagnetic detection system
Installation	Inground or embedded in the Bicycle track
Response time	Fast response time
Application	Bicycle detection
Power	Low voltage
Connections	Connected to a control unit.

4.4.3 Operation of Inductive Loop Detectors

An inductive loop detector (ILD) works based on electromagnetic induction at its most basic level (Matan, 2023). An ILD is made up of a detector unit attached to a wire loop that is buried in the bicycle track or bike lane. The loop can produce an electromagnetic field since it is a component of an oscillator circuit. This field is disturbed when a bicycle travels over the loop, altering the inductance. The unit detects this change, indicating cyclists' presence. The sensor loop and loop detectors are the main components of the ILDs, as shown in Figure 4.12.

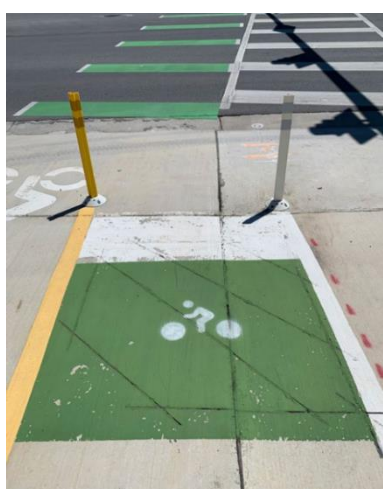


Figure 4.12: Sensor loop is painted green. (Gilpin et al. 2021).

Inductive Loop Detection for PWVL Safety

The **inductive loop detector** is designed to detect cyclists in advance as they approach a floating bus stop. This early detection allows the system to regulate cyclist movement and enhance the safety of individuals with partial or total vision loss (PWVL) navigating the area.

When a cyclist is detected, the system can trigger **audible alerts** or **traffic signals** to inform both cyclists and PWVL of each other's presence, reducing the risk of unexpected encounters. Additionally, the **inductive loop detection system** can measure the speed of approaching cyclists. If a cyclist is moving too fast, the system could activate **warning signals** or adjust **barrier gate controls** to encourage safer speeds, ensuring that PWVL have adequate time to cross the bike lane safely.

By integrating inductive loop detection with other accessibility-focused technologies, the system enhances real-time communication between cyclists and PWVL, improving navigation, safety, and overall traffic flow at floating bus stops.

The inductive loop detection as illustrated in Figure 4.13 system can also be used to measure the speed of cyclists when approaching the floating bus stops.

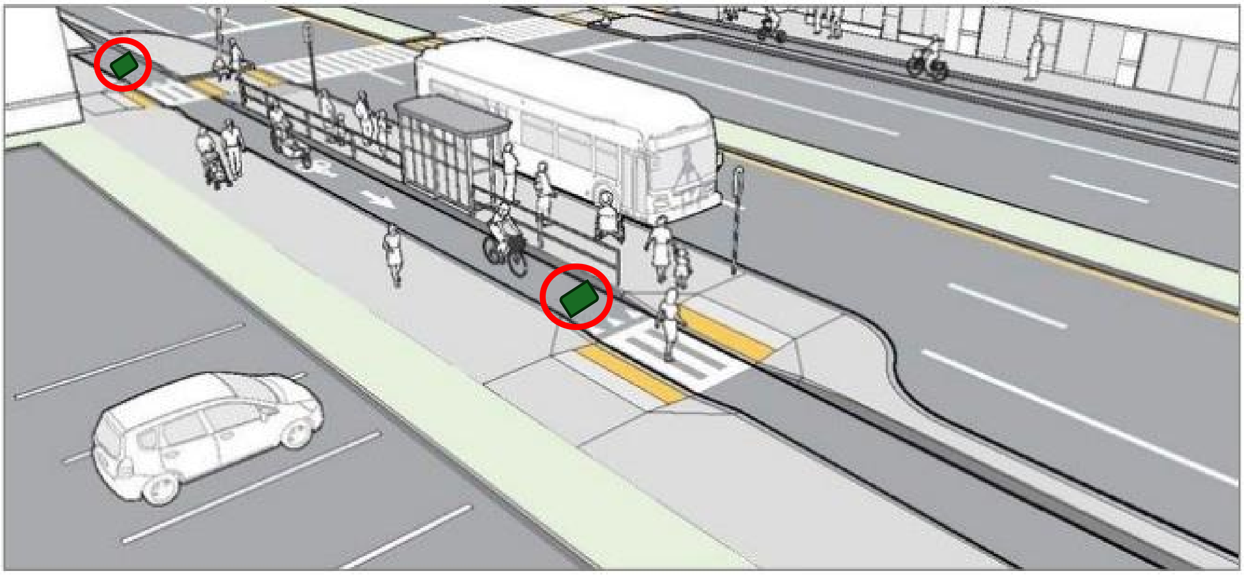


Figure 4.13: The Illustration of inductive loop detection layout at a floating bus stop. Sources (Arlington County Virginia, 2025).

For (PWVL) and cyclists, Inductive Loop Detection (ILD) improves safety and cooperation at floating bus stops. All things considered, ILD at floating bus stops maximizes traffic flow, enhances safety, and offers a predictable environment for all users of the road.

4.4.4 Limitations of the Inductive Loop Detections.

First limitation of this system is it cannot detect humans including PWVL. Secondly, cyclists intentionally avoid loops to prevent being detected. ILDs are susceptible to damages when the bicycle track is damage, leading to detection failure.

4.5 Summary of the Systems.

The summary of the technological systems provides details of the systems including highlight key detection, communication, and compliance. Table 4.4 presents the summary.

Table 4.4: Summary of equipment including detection, communication, and compliance/control.

	Equipment	Detection	Communication	Compliance/Control
1	Bicycle traffic signal	Yes	No	Yes
2	Loop Detection	Yes	No	No
3	Accessible Pedestrian signals (APS)	No	Yes	Yes
4	Microwave radar devices	Yes	No	Yes
5	Rectangular Rapid Flashing Beacons (RRFB)	No	Yes	Yes
7	ZELT EVO: Cometh Edition.	Yes	No	No
8	TELELDYNE FLIR: Trafisense AI	Yes	No	No
9	SENSYS NETWORK: VSN240-M-2 Micro Radar Sensor	Yes	Yes	No

4.6 Evaluation Criteria for Assessing Assistive Technology System Limitations.

This research focused on assessing several key factors of different systems to evaluate their potential impact on urban mobility. These factors included communication, detection, accuracy, accessibility, integration with existing infrastructure, user experience, environmental robustness, and compliance.

Furthermore, accuracy and reliability were assessed for their ability to detect bicycles and provide feedback to both cyclists and pedestrians. Response times were measured when alerting users. Moreover, accessibility was assessed by the ability of the systems to warn visually impaired users through non-visual feedback, such as auditory or haptic signals. Scalability and adaptability of the systems were also considered, with reference to the complexity of installation, compatibility with existing infrastructure, and adaptability to diverse conditions. In addition, cost-effectiveness was evaluated by considering the balance between the system's cost and the value it provides in enhancing safety and accessibility for PWVL. Another important aspect considered was the Integration of the systems with existing infrastructure, with some systems requiring significant infrastructure changes. And for compliance, some systems do not have mechanisms to enforce compliance which limited success in ensuring safe interactions between users.

In summary, the evaluation process highlighted the strengths and weaknesses of the systems, providing actionable insights for improvement and guiding recommendations for the development of a new technological system. This new integrated system purpose is to enhance safety, accessibility, and user experience for PWVL by combining the strengths of various technologies. The selection and integration process involved identifying core challenges at floating bus stops, such as shared spaces between cyclists and PWVL, lack of visual cues, and limited accessibility features. Technologies were chosen to address these specific challenges including detecting bicycles, providing timely alerts to PWVL, and ensuring compliance by cyclists.

4.7 Technological Selection and Integration: Challenges in PWVL Assistive Systems

State of the art technologies were evaluated to determine their feasibility to assist PWVL, including ultrasonic sensors and cameras for bicycle detection, auditory and tactile alerts for real-time feedback, compliance mechanisms with visual and auditory prompts for cyclists, and seamless communication between components.

During the evaluation, different challenges were encountered for the integration of the technologies such as technical compatibility, reaction time, user-centered design, environmental limitations, cost and scalability, and compliance to resolve some of these challenges, standardized communication protocols were considered to ensure smooth data transfer and simplified integration by addressing technical compatibility. Furthermore, prioritizing synchronization and reaction time, iterative prototyping and testing were used to improve the user-centered design.
The final integrated system addressed the main needs of PWVL and offered a framework that is flexible, scalable, and able to enhance urban mobility at floating bus stops by effectively integrating bicycle detection, auditory alerts, and compliance mechanisms.

4.8 The Proposed Technological System Solution:

This theoretical system solution proposed a combination approach using existing technologies. It is critical to understand the systems analysis of two or more technologies that will access the identified gap at floating bus stops when PVWL intends to cross bike lanes. The purpose of the development of the proposed technological solution is to combine systems that will aid in improving safety and enhance accessibility for PWVL at floating bus stops by:

- Detecting the presence of cyclists and/or approaching PWVL.
- Auditory cues for PWVL and cyclists when approaching the floating bus stops
- Cyclists should comply with speed limits as they approach bus stops and stop if needed.

Utilizing technology that is sufficiently advanced to address the difficulties PWVL encountered at floating bus stops will enhance their urban mobility in these areas. The detection, communication, and compliance/control components are all part of the system. The following subsections will describe these components of the proposed technological system.

4.8.1 The System Components.

These system components form a comprehensive system that addresses the challenges PWVL faces when navigating floating bus stops and ensuring seamless system functioning.

- The Bicycle Traffic signal
- Ultra sonic or IR Infrared
- The RFID
- Automatic Barrier gate arm

4.8.1.1 Controlling system

Bicycle Traffic Signal Head

Cyclists are guided by the BTS head as they approach floating bus stops, where they could interact with PWVL. BTS uses the bicycle symbols yellow, red, and green and works independently to provide right of way to PWVL to cross bike lanes where they may come together with cyclists. For safety at floating bus stops, the BTS is situated in a prominent spot that cyclists may see as they approach the floating bus stops. BTS is responsible for regulating bikers and permitting PWVL to navigate to the floating bus stops.

4.8.1.2 Detection system:

Two different detection systems will be part of the proposed technological system. Each one contributes to enhance safety for PWVL.

IR infrared:

When approaching the cycling lane at floating bus stops, this IR infrared system detects PWVL and sends a signal to the microcontroller, which in turn controls the BTS and the gate to close the bike lane to ensure cyclist compliance to stop.

Furthermore, the detection of PWVL by the IR system at floating bus stops improves safety without requiring human input by the implementation of an APS Button.

Moreover, this system can identify PWVL without the RFID tag (Manzolillo, 2024). Additionally, passive sensors are more common in motion sensor lights and alarms because they have a longer range than active sensors. Their pyroelectric sensors detect the difference when something new enters a space. Therefore, when the pyroelectric sensors record a high enough heat signature, an audible warning will sound. The main contribution of the infrared sensor is to detect motion of untagged PWVL and cyclists.

RFID System

A wireless communication technology called radio frequency identification (RFID) uses electromagnetic or electrostatic coupling in the radio frequency region of the electromagnetic spectrum to identify a person, animal, or object uniquely (Amsler and Shea, 2021). A scanning antenna, a transceiver, and a transponder are the three parts of every RFID system. A RFID reader or interrogator is the term used to describe the combination of the transceiver and scanning antenna. The RFID System is a system that uses RFID tags to detect PWVL that have these tags. The tag is used for identification when approaching the floating bus stops

4.8.1.3 Communication System

The XAV2E non-contact activation

The XAV2E Led system push button is a system that illuminate when used by the pedestrians. This crossing signal, which requires a push mechanism from the pedestrian, has great LED visibility and is both tactile and loud. For PWVL to utilize this method, PWVL utilize the button's arrow and the push button station's (PBS) face to find their direction of travel (Polara, 2023), In the direction of travel, the arrow should point across the street, and the PBS sign should be parallel to the crosswalk when it is erected. XAV2E-LED System push button is a good system for PWVL but its need human input by pressing the APS button which prone too difficulties for PWVL when navigating the floating bus stop the alternative to this system is XAV2E non-contact activation that doesn’t require human input.

The XAV2E non-contact activation can be designed and set up to function without a push button, automatically detecting PWVL as they approach floating bus stop, due to the challenges PWVL face in accessing the APS button. The system works with detection systems like the IR infrared and the bicycle traffic signal. It will automatically detect the presence of PWVL while removing the need for physical interaction. It will also activate the voice message by playing prerecorded messages like "wait cyclists is crossing" and "safe to cross now." This technology increases PWVL's independence when navigating through floating bus stops and improves safety and accessibility.

4.8.1.4 Compliance system

Automatic Barrier Gate arm

The purpose of the automatic barrier gate arm system is for compliance and guidance of cyclists when the IR Infrared or the Ultra Sonic system detect PWVL. The guardrail system automatically closes when the red light comes up due to the detection of PWVL. The guardrail system is for compulsory compliance for cyclists. For the arm gate with automatic detection and shutting features, the opening and closing controls are often located on a control panel. But if needed, there are additional controls to manually override it and control the entire system.

4.8.2 System Functionality

The following presents the basic functions of the proposed system.

- RFID tags or sensors detect PWVL and cyclists approaching floating bus stops, while IR infrared or ultrasonic sensors identify non-tagged users.
- Auditory communication signal to PWVL crossing readiness.
- Once the crosswalk or bus stop area is cleared, audible warnings are deactivated, resetting the system.

4.8.3 Benefits of the Proposed System

The main benefits of this proposed system are listed below

- Inclusion serves both identified and untagged users, enhancing everyone's safety and accessibility.
- The scalability can be established in multiple locations with minimal modification.
- Sustainability is the idea of reducing environmental effect using renewable energy.
- Real-time flexibility allows for dynamic upgrades and optimization by integrating with intelligent traffic systems.

4.8.4 Schematic Applications for the Proposed Technological System

A schematic diagram of the proposed technological system for PWVL navigation at floating bus stops is shown in Figure 4.14. The diagram illustrates the location of the BTS in relation to the XAV2E non-contact activation, the RFID antenna for detecting PWVL and cyclists who are carrying the RFID tag, the RFID tag that will be attached to the bicycle and PWVL for detection upon contact, the Automatic Barrier gate, and the IR infrared for detecting PWVL who are not carrying the RFID tag while navigating floating bus stops.

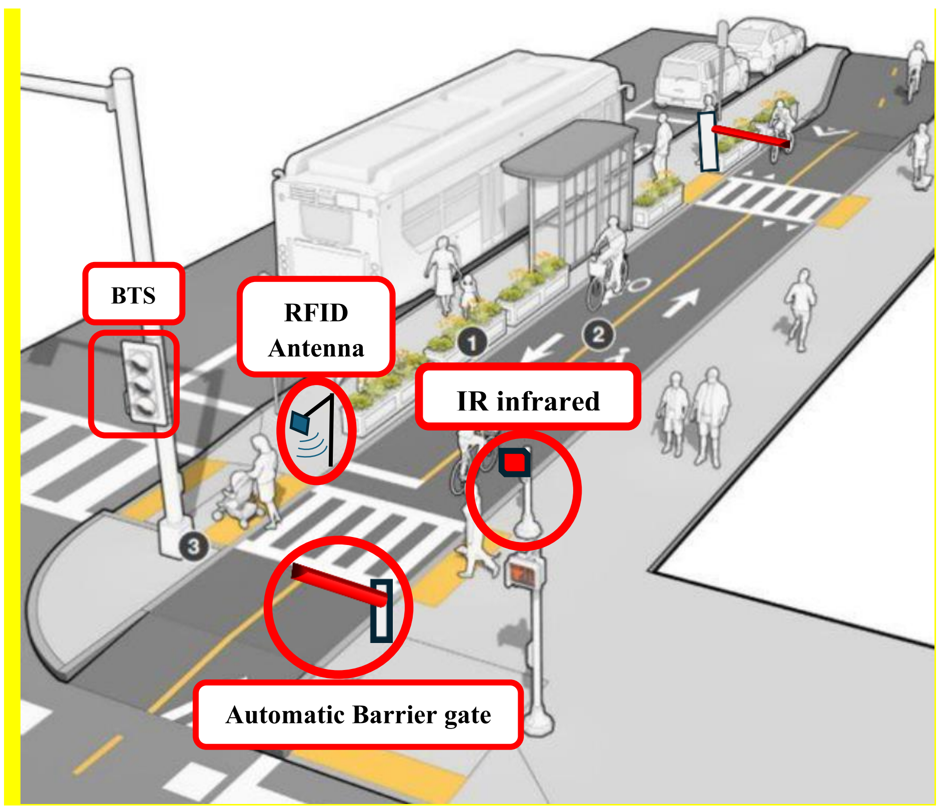


Figure 4.14: Schematic diagram of the proposed technological system solutions layout at floating bus stops.

4.9 Wavetronix Bicycle Detection by FORTRAN

This system will complement the bicycle traffic signal head by detecting cyclists approaching the signal and warning PWVL about them. Table 4.5. shows the functionality of this system. The Wavetronix Smart Sensor Matrix, known for its accuracy in vehicle detection, excels at detecting cyclists regardless of their bike's composition. Unlike in-ground detectors that struggle with lightweight bicycles, the Matrix uses radar to detect mass in all weather and lighting conditions, offering consistent performance without the need for maintenance as shown in Figure 4.15 and the schematic diagram in Figure 4.16. In summary, this Sensor Matrix is:

- Non-intrusive radar detector
- Reliable and accurate detection of cyclists
- Works with mixed traffic lanes, designated bike lanes, and bike boxes
- One Smart Sensor Matrix
- Detects both cyclists and vehicles

Table 4.5: Functionality specifications for the FORTRAN Wavetronix Bicycle Detection.

Specifications	**Details**
Radar Matrix	16 radars for two-dimensional coverage
Field of View	Tracks Vehicles through a 90-degree field of view that extends out 140 ft (42.7 m)

Visors Technology:	Includes Radar Vision Technology to detect and track in two dimensions
Detection	Standard detector-rack contact-closure interface
Lanes Dimensions:	Supports curved and angled lanes
Cabinet size	Compatible with Click 65x all-in-one cabinet interface device
Manufacturing Process	Automated manufacturing process

Figure 4.15: A typical implementation of the Wavetronix Bicycle Detection and FORTRAN Wavetronix Bicycle Detection (Source: FORTRAN, 2024).

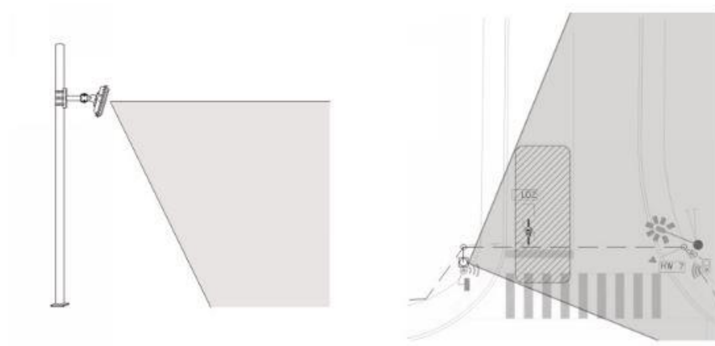


Figure 4.16: Schematic diagram of the detection range of the Wavetronix Bicycle Detection. (Source: FORTRAN, 2024).

Features:

This system includes the following features:

- Vehicle Detection: Detects and tracks both move and stop vehicles in real-time
- Auto-Configuration: Patented auto-configuration process.
- Radar Technology: Patented Digital Wave Radar II technology for enhanced radar performance.

4.9.1 Limitations of the Wavetronix Bicycle Detection

The system limitations include the difficulty in detecting accurately when there is a large inflow of traffic and in adverse weather.

4.10 Prototype Development

This prototype is developed to showcase the proposed technological system that will assist PWVL with accessibility and navigation at floating bus stops and to provide audio communication when the sensor detects them. The prototype was designed on a board that contains the creation of the main road, the shelter for floating bus stops, bike lane, and pedestrian walkway as shown in Figure 4.17. This is a typical real-life representation of a floating bus stop design across the country.

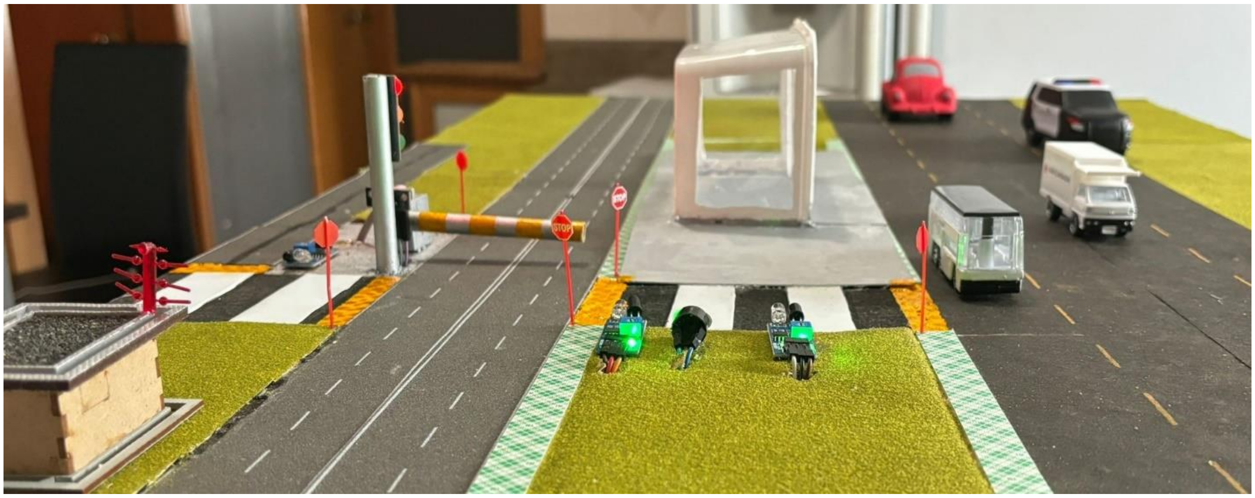


Figure 4.17: Prototype Development (Source: Original Photographs by Samuel Olugbade 2024).

When transitioning from the proposed technological system to a working prototype, several key factors were considered to ensure its functionality and alignment with the needs of PWVL. These considerations were crucial in designing a prototype that was practical, effective, and user centered.

4.10.1 Key Factors Considered in the Development of the Prototype.

The following are the key factors considered in this development process.

Accessibility for PWVL: The prototype emphasizes practicality and ease of use, employing tact ile cues and audio notifications to provide unambiguous direction to PWVL.
Because it avoids visual elements and ensures safety and risk minimization, it accommodates peo ple with visual impairments. It is intended to be an intuitive and user-friendly system.

Safety:

To provide prompt responses to any conflicts, the prototype includes a bicycle detection system t hat warns

pedestrians of oncoming cyclists. Realtime notifications, such as alarms or spoken instructions, a re used.

Selection of Technology: To ensure precise bicycle detection and effective communication without straining users or infrastructure, technology components such as IR infrared sensors, and microcontrollers (such as the Arduino Uno) were chosen based on their affordability, and dependability.

Cost-effectiveness: The prototype was made to be low-cost by using widely accessible off-the-shelf components.

Alignment to needs of PWVL: The prototype development was designed considering the needs of PWVL when navigating and accessing floating bus stops.. The prototype was created prioritizing user needs, safety, and practicality guaranteeing efficient operation and significant support for PWVL navigating floating bus stops.

4.10.2 System Architecture

The system components consist of the following

- Hardware: the hardware consists of the Input and Output components.
- Software, and
- The Integrated Development Environment.

4.10.2.1 Hardware:

Components utilized for the prototype are listed below:

1. Arduino Uno board
2. Microcontroller Breadboard.
3. IR Sensor
4. Modular Traffic Light
5. Jumper Wires
6. Buzzer
7. Power Supply
8. Servo Motor

Arduino Uno

Arduino Uno is a microcontroller that helps control electronic devices and intermediate between the Input and Output devices. Arduino Uno with sensor technology is used and has relative ease of setup. According to Sudhan et al. (2015), the Arduino ATMEGA-328 microcontroller consists of 14 input and output analog and digital pins (6 pins are PWM pins), 6 analog inputs, and the remaining digital inputs. The Arduino Uno and the Breadboard were implemented using Jumper wire and other outputs. The Arduino Uno are pre-constructed prototype boards that are designed to demonstrate the IDE systems and Code. The Arduino Uno was constructed using a combination of holes and a microcontroller as shown in Figure 4.18.

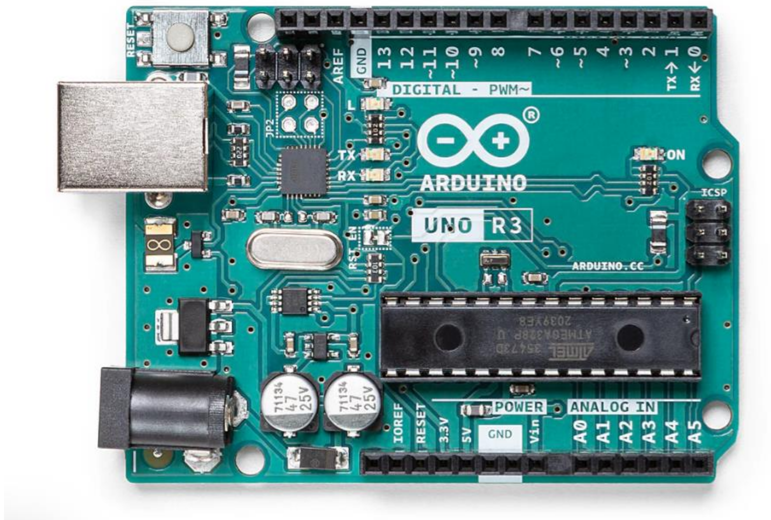


Figure 4.18: A close-up of a circuit board of Arduino Uno (Sources Arduino Uno Rev3, 2024).

IR Infrared Sensor:

This component detects the presence of PVWL approaching and sends the signal to the microcontroller on the Arduino Uno. The IR Infrared sensor is set up at the zebra crossing to identify items, specifically pedestrians as shown in Figure 4.19. If no pedestrian or PWVL is detected, the system defaults to blinking the red light every 500 milliseconds.

If a pedestrian is detected, the system starts the traffic light sequence (sensor output = HIGH).

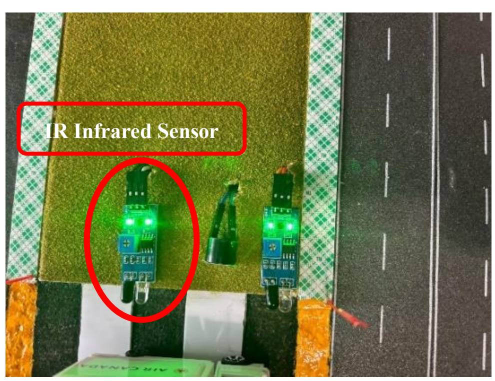


Figure 19: IR Infrared Sensor.

Traffic Lights:

In Figure 4.20, the LED red, yellow, and green traffic lights are set up as outputs. The data will activate the light sequence. PWVL detection delay causes the red light to turn on for about 20 second, without PWVL detection the red light turns on for about 10 seconds. Then, three seconds after the red light goes out, the yellow light switches on, and three seconds after the yellow light goes out, then the green light comes on for 10 seconds.

Figure 4.20: The Traffic Light signal.

Servo Motor and Guardrail:

The gate opens and closes at the sequence of the light either at 0 degrees or 90 degrees. The servo motor is at its starting position, which is 0° with the gate closed, and 90° will open. The servo motor (gate control) opens the gate slowly rotating from 0° to 90° over approximately 1.5 seconds after the green light goes out. The gate is left open for three seconds. The gate is subsequently closed by the servo motor rotating back to 0°. Figure 4.21 shows the Servo motor and the guardrail for compliance of cyclists at floating bus stops.

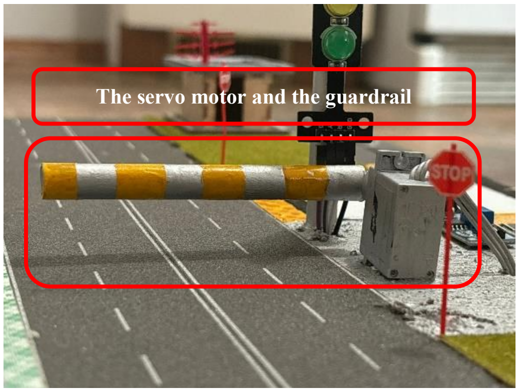


Figure 4.21: Servo Motor and guardrail.

Buzzer:

The buzzer is set up and prepared to sound an alert and to provide directional instruction. The buzzer is an alert signal for 0.5 seconds after the gate closes. At this point, the gate cycle is complete. The buzzer in Figure 4.22 is an example of audio communication., used in the development of the prototype.

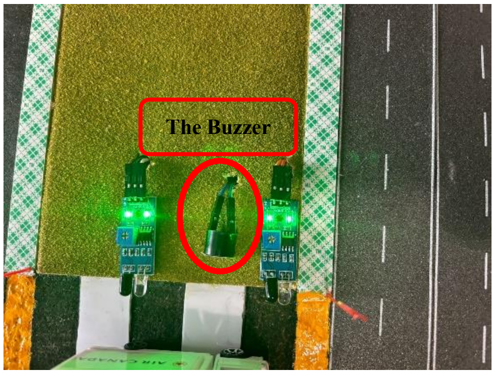


Figure 1.22: Buzzer

4.10.2.2 Software:

The Arduino Uno code software is used to write code by compiling and uploading that code onto the microcontroller, the Arduino Uno is a simple editor that has inbuilt libraries and various port selections and tools.

The software of the Arduino Uno is a serial monitor and interacts with the wide range of the Arduino Uno board. The software is open source in nature and has extensive library support. This is used for the prototyping of the project. The software section can not be touched and felt, it is a set of instructions that are written to meet specific needs and perform specialized tasks. This information requires the hardware to function but assists the hardware on how to operate the input instructions. The software uses a set of written programming languages, and the instruction will be converted to the language the computer understands to execute.

4.10.2.3 3 Integrated Development Environment (IDE):

The IDE interface allows the software to write the code, compile code, and upload code to the microcontroller. According to the Arduino Uno website, Arduino Uno IDE is Open source. C/C++ is the program that Arduino Uno uses Features of the IDE are the code editor, compiler, uploader, and serial monitor that are used in the Arduino Uno interface.

4.10.3 Circuit Setup:

To utilize an Arduino Uno for bicycle detection utilizing an ultrasonic distance sensor and facilitate communication with those who have visual impairments, auditory feedback system that delivers immediate information regarding incoming bicycles may be established.

Appendix A contains a detailed description that includes simplified wiring instructions and the schematic connection of the circuit setup of the system prototype development. and the Connection of the Wiring and the tabular circuit setup as shown in Table 4.6

Table 4.6: Connection of the Wiring and the tabular circuit setup.

Component	Arduino Uno
Red LED	Pin 2
Yellow LED	Pin 3
Green LED	Pin 4
IR Sensor VCC	5V
IR Sensor GND	GND
IR Sensor OUT	Pin 7
Servo Signal	Pin 9
Servo VCC	5V
Servo GND	GND
Buzzer (+ve)	Pin 8
Buzzer (-ve)	GND

4.10.4 Powering the Arduino Uno:

The Arduino Uno with USB is connected to the USB port on a system, or another means of connection is by a power source with an adapter. Some components draw more current during operation, such as the Servo Motor, and this must ensure that the current is stable.

4.10.5 Logical Operation of the Prototypes:

Normal Operation

- The traffic light functions normally.
- The green light is on a normal sequence for about 5 seconds.
- The yellow light moves from red to yellow for about 3 seconds.
- The red light is on, then the gate closes for the normal movement of PWVL for about 10 seconds.
- The light moves from red to yellow for about 3 seconds.
- The gate opens when the light is green and closes when the red light is on.
- To warn bicycles and pedestrians of the approaching gate closure, the system sounds like an alarm for about 5 seconds

PWVL Detection

- A pedestrian is detected by an infrared detector.
- To warn bicycles and pedestrians of the approaching gate closure, the system sounds like an alarm for about 5 seconds.

- To enable PWVL to safely cross the bike lane, the red light stays on for a longer period and blinks for another 10 seconds until PWVL clears the bicycle lane, given PWVL priority.
- To alert cyclists for onward movement, the yellow light is on for about 3 seconds.
- The system starts to function normally.

4.10.6 Fail-Safe Procedures for the Prototype at Floating Bus Stops.

If the bicycle traffic light systems at floating bus stops malfunction, fail-safe procedures govern their default behavior to maintain safety and reduce collisions. The system is temporarily managed by traffic authorities using manual control. and the traffic authorities also perform frequent maintenance to lower system failure rates, perform routine testing and maintenance. Solar power or UPS is used as a backup power source to avoid disruptions.

User functioning and safety are given priority by fail-safe procedures in the event of a system failure. Reliability and risk reduction are ensured at floating bus stops by implementing strong fail-safe designs and maintenance procedures.

4.10.7 Limitations of the Prototype:

Due to time constraints and a lack of coding experience, it is difficult to write the code that provides a maximum time for the gate to be close to allow cyclists to continue their journey on the bike lane while handling the high amount of PWVL. This is a small-scale prototype that cannot be used in real-life implementations, The prototype is to showcase the proposed technological system solution.

4.11 Summary of the Prototype Operation.

The proposed prototype is designed to enhance the safety and mobility of individuals with partial or total vision loss (PWVL) at floating bus stops by creating an integrated system that ensures controlled interactions between cyclists and pedestrians. Cyclists travel using the designated bike lane, but when approaching the bus stop, they must exercise caution to accommodate PWVL.

The system functions by utilizing IR infrared, which identify the presence of PWVL. Upon detection, the sensor sends a signal to the BTS head and activates the servo-controlled barrier gate, allowing the gate to open or close as needed based on the system's programming. This mechanism provides PWVL with sufficient time to process their surroundings and safely navigate across the bicycle path to the sidewalk without unexpected conflicts.

By coordinating pedestrian detection with bicycle signaling and physical barriers, the prototype aims to enhance accessibility, ensure a safer crossing experience for PWVL, and minimize disruptions to cyclist movement while maintaining overall traffic efficiency.

4.12 Research Survey

The research survey was prepared and completed with the collaboration of the Canadian National Institute for the Blind (CNIB) both in Thunder Bay and British Columbia. This survey will be used in the future to obtain valuable insight from PWVL regarding their experiences with floating bus stops and cyclists in general. It will also be used to collect feedback when the proposed technological system is tested on the field. At the present time, it is going through the approval process at the Research Ethic Board (REB) of Lakehead University. Appendix B, and Appendix C, contain the research informed consent and the research survey, respectively.

CHAPTER 5 – SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

Transportation experts prioritize inclusive urban design and technical developments to improve road user mobility, particularly for people with vision loss (PWVL). Cycling is one of the most effective and environmentally friendly forms of transportation accessible for commuting. In an already complex metropolitan setting, this form of transportation poses a significant obstacle to PWVL because this population group cannot detect cyclists because of their vulnerability.

At floating bus stops, this is especially challenging because buses do not draw up to the curb for loading and unloading. Rather, transit users must frequently cross a bike lane to reach floating bus stops, which are positioned in the middle of a road on an elevated island. This is not only alarming, but also quite dangerous for PWVL. Despite being essential transportation hubs, these particular transit hubs pose specific navigational challenges for PWVL because they frequently lack the physical and tactile cues that are normally associated with safe and independent travel.

In addition to creating a system that will alert PWVL to approaching cyclists at floating bus stops, this research study thorough investigate four technical systems, with their characteristics, specifications, applications, communication systems, compliance technologies, schematic diagrams, and limitations. Communication, performance, accessibility, compliance, and detection are the main criteria utilized to choose the technological systems. This made it easier to determine which technological solution would best address the difficulties PWVL had at floating bus stops.

Building on this extensive research, a new technological system was proposed that combines the existing systems to improve on their flaws and overcome the difficulties PWVL encountered when navigating floating bus stops. The proposed system was design on the functionality that combine the detection system, communication and compliance considering system component, control system, ensuring improved performance of the existing technological system.

In addition, a prototype was created to show the feasibility and validation of the suggested technical system. The prototype is made up of multiple phases that integrate the communication system, detection/control, and cycling compliance. By using the Arduino Uno in conjunction with systems, the prototype's iterative development was able to be recreated in a real-world setting.

Finally, this research study addresses the difficulties PWVL encountered navigating floating bus stops by offering technical solutions that eliminate the need for human input and improve accessibility, hence promoting urban mobility. The prototype's creation demonstrates that the suggested technology solution is workable and replicable in a real-world setting. The suggested technological system has the potential to address the difficulties PWVL encountered at floating bus stops, and it is still possible to make improvements.

5.2 Conclusions

Conclusions from evaluating and analyzing existing technology systems related to accessibility at intersections and their theoretical implementation at floating bus stops as well as the development of a new technological system that combines existing technologies are presented below. Moreover, insights of the development of a prototype to showcase the proposed system re also included.

The first technological system considered is the bicycle signal head, which is a specialized system that is designed to manage and improve safety of cyclists. When considering its implementation at floating bus stops, it will assist PWVL in navigating safely. Furthermore, the analysis indicated that the bicycle traffic signal head system can be implemented effectively at floating bus stops if its limitations such as absence of clear auditory communication and non-compliance by cyclists can be addressed.

The second system analyzed was the RRFB, which is very effective and could be implemented at floating bus stops due to its high visibility and clear audible communication. The major limitation of this system is the risk of non-compliance by cyclists which could be hazardous to PWVL.

The third technological system reviewed was the RFID system. This system is widely used to track and detect objects and humans using RFID tags and a RFID reader. The RFID uses radio waves to detect the tag via an antenna. This system could be implemented at floating bus stops but will need to be combined with other systems to be effective. The main limitation of this system includes the difficulty in accessing the RFID reader due to the positioning. Secondly, the RFID only recognizes PWVL, and cyclists carrying the tag and cannot detect non tag users which raises safety concerns.

The fourth technological system considered was the inductive loop detection system which is designed to detect metallic objects such as bicycles and could be used at floating bus stops. A limitation of this system is that it could only detect metallic objects which may not detect some bicycles which results in higher collision risk for PWVL. Another limitation is the possible avoidance of the loop by cyclists to avoid detection.

With respect to the proposed technological system, it integrates several advance systems analyzed during the research to improve mobility of PWVL at floating bus stops. The proposed system comprises of the installation of an automatic barrier gate arm to ensure the cyclists comply by stopping for pedestrians when navigating floating bus stops. The system will also provide clear communication that is prerecorded and audible from a non-contact activation device such as the XAV2E which enhance navigation for PWVL by alerting about the situational environment. Furthermore, IR infra-red will be implemented in the system to detect the presence of PWVL in real time to ensure the integration and improvement of safety with the activation of the BTS to alert cyclists of PWVL. The key importance of this system combination is to create safer, more efficient environment at floating bus stops eventually enhancing independence of PWVL when navigating floating bus stops. A prototype was developed to showcase the proposed technological model This prototype combines communication, detection and compliance technologies.

Finally, a survey was developed as part of the research work to gather information from PWVL and stakeholders. The objective is to determine current challenges that PWVL are facing when navigating floating bus stops. The intention of the survey is also to obtain feedback of the proposed system when it is tested on the field. This data gathered from the survey will be instrumental in refining the design and improving the experience of the users.

Furthermore, the results of the study highlight the possibility for innovation in urban transportation systems. By assessing current technologies, proposing new technological system to improve overall performance and user experience of PWVL navigating floating bus stops. The developed prototype offers an actual representation of how these innovations might be used in practical situations, proving the feasibility of these enhancements. Also, the outcomes of this research not only address immediate concern but also lay the groundwork for future advancements in accessing urban transportation.

5.3 Limitations

The scope and accuracy of this research conclusions were impacted by several constraints. Developing and testing a real-world prototype in an actual urban setting was one of the main limitations. Due to time and cost limitations, the study was limited to development of prototype and proposed technological system instead of a full-scale implementation. The prototype was also built using simple hardware components, which had built-in limits regarding processing power, precision, and real-time responsiveness. Due to the system's lack of large-scale implementation optimization, its performance under actual circumstances such as changing weather patterns, traffic volumes, and user interactions remains unknown.

To improve system dependability and usefulness in various urban contexts, future research should address these limits by integrating cutting-edge hardware, practical pilot testing, and extra user detection procedures.

5.4 Recommendations

The research study recommends that the prototype be developed into a real-world implementation, and it should be tested at various conditions and environments. Secondly, the proposed system should be developed and tested or improve on so that it will be able to combat the challenges of PWVL faced at floating bus stops. Finally, PWVL should be included when developing future design of infrastructures to improve the independent of the PWVL at floating bus stops.

5.5 Future Work

Future research should focus on the real-time implementation of the proposed technological system. Furthermore, the system should be tested at different urban settings to ensure that the system will be effective in every environment and weather conditions. Moreover, the system should include a multi-modal feedback system such as clear and concise auditory messages. with large groups of users to provide a clear understanding of the system’s functionality and complexity.

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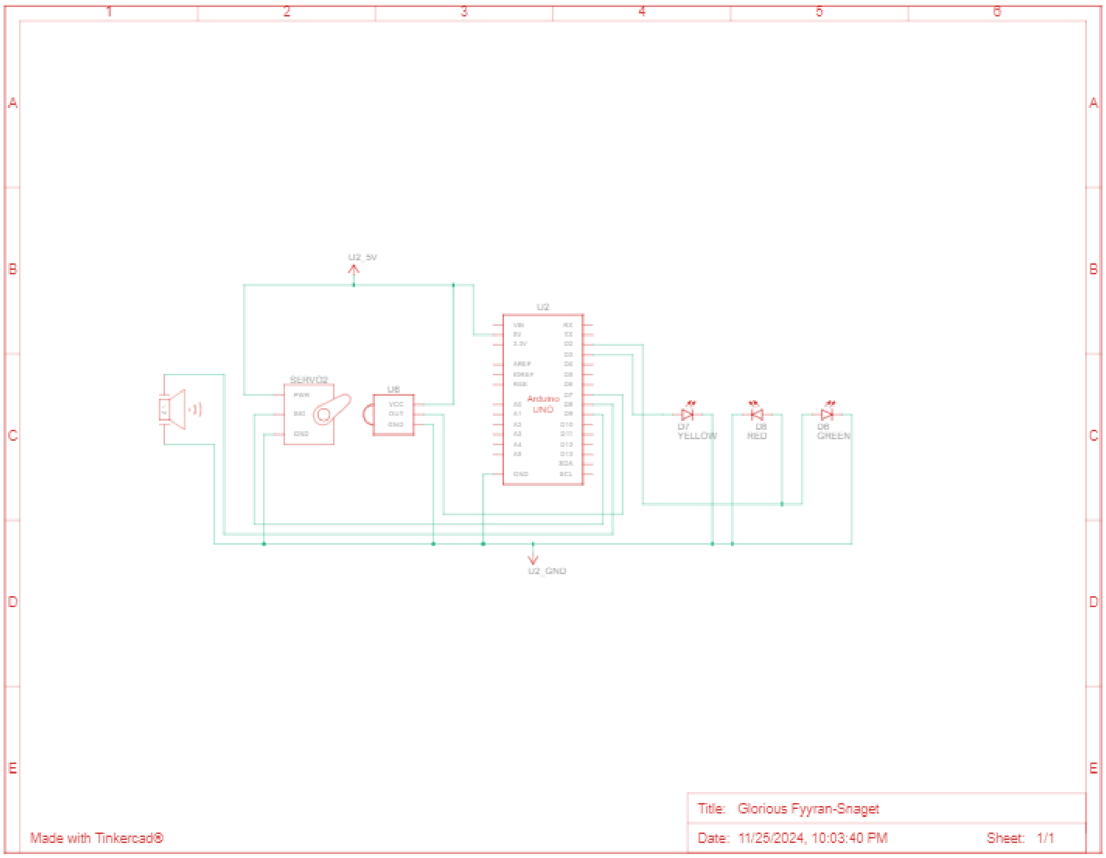
APPENDICES

Appendix A

The Schematic diagram of the Circuit setup system.



Appendix B

Informed Consent

26th November 2024.

Dear Potential Participant:

You are invited to participate in the project related to People with vision Loss (PWVL) and Accessibility. You are being considered a participant since this study's focus is on visually impaired/blind people and their concerns regarding safety when accessing and navigating floating bus stops in Canada.

Taking part in this study is voluntary. Before deciding whether you would like to participate in this study, please read this letter carefully to understand what is involved. After you have read the letter, please feel free to ask any questions or voice concerns you may have regarding the content of the document.

PURPOSE

This study aims to identify concerns that visually impaired and blind people may have about accessibility and navigating floating bus stops. The research team consists of Dr. Juan Pernia and Mr. Samuel Olugbade, associate professor and graduate student, respectively, in the Department of Civil Engineering at Lakehead University. This project is Mr. Olugbade’s thesis for his Master of Science in Civil Engineering.

WHAT INFORMATION WILL BE COLLECTED?

For this project, a survey will be conducted to gather information regarding participants' concerns about accessibility and navigation at floating bus stops. Questionnaires will be administered to the clients of the Canadian National Institute of the Blind (CNIB) in Thunder Bay, Ontario, and West Minister, British Columbia, regarding improving urban mobility for People with vision Loss at Floating Bus stops in Canada.

WHAT IS REQUESTED OF ME AS A PARTICIPANT?

As a participant, you will be asked to fill out the survey. The survey will be anonymous. The study population that will be used will consist of the CNIB clients and key stakeholders that have access to the floating bus stop. The survey for the clients of the CNIB in British Columbia will be virtual. For clients of CNIB in Thunder Bay, the survey will be done in person.

WHAT ARE MY RIGHTS AS A PARTICIPANT?

As a participant, you:

- are under no obligation to participate and are free to withdraw at any time up until the point your responses are submitted.

WHAT ARE THE RISKS AND BENEFITS?

There are no associated risks with participating in filling out the survey.

Potential benefits of this project are the identification of concerns and issues that visually impaired/blind people might have with reference to floating bus stops, as well as the evaluation of accessibility features at floating bus stops across Canada.

HOW WILL MY CONFIDENTIALITY BE MAINTAINED?

Surveys are anonymous, only the research team will have access to information identifying the participants during the study, but data will be aggregated for the research project. In other words, the data will not be related to any specific participant when used for the project.

WHAT WILL MY DATA BE USED FOR?

Data will be used to identify concerns at floating Bus stops in reference to accessibility and navigation for people with vision loss.

WHERE WILL MY DATA BE STORED?

Data will be stored with Dr. Pernia. Digital information will be on his computer and backup data kept on a portable hard drive, with information being solely accessible in his office at Lakehead University

HOW CAN I RECEIVE A COPY OF THE RESEARCH RESULTS?

Once the project is completed, a final report will be prepared and made available for the public to read.

WHAT IF I WANT TO WITHDRAW FROM THE STUDY?

You can withdraw from the project at any time up until the point your responses are submitted. All surveys are anonymous once submitted.

RESEARCHER CONTACT INFORMATION:

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Samuel Olugbade, Graduate student

Email: solugbad@lakeheadu.ca

RESEARCH ETHICS BOARD REVIEW AND APPROVAL:

This research study has been reviewed and approved by the Lakehead University Research Ethics Board. If you have any questions related to the ethics of the research and would like to speak to someone outside of the research team, please contact Sue Wright on the Lakehead University Research Ethics Board at 807-343-8283 or research@lakeheadu.ca.

Consent Form

MY CONSENT:

I agree to the following:

- ✓ I have read and understand the information contained in the Information Letter
- ✓ I agree to participate
- ✓ I understand the risks and benefits to the study
- ✓ That I am a volunteer and can withdraw from the study at any time up until the point the responses are submitted and may choose not to answer any question

- ✓ That the data will be securely stored with Dr. Pernia for a minimum period of 7 years following completion of the research project
- ✓ I understand that the research findings will be made available to me upon request
- ✓ I will remain anonymized.
- ✓ All my questions have been answered

By consenting to participate, I have not waived any rights to legal recourse in the event of research-related harm.

For anonymous surveys: *I have read and agree to the above information and by completing and submitting the survey, agree to participate.*

Appendix C

Research Survey

<u>Floating Bus Stops Accessibility Survey</u>

<u>Part A:</u> Likert Scale Questions (1–5 scale: Strongly Disagree to Strongly Agree)

		Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
1	The pathways to the floating bus stop are clearly defined and easy to navigate.					
2	Sufficient tactile and auditory cues guide me to the floating bus stop.					
3	I feel safe crossing bike lanes and roads to the floating bus stop.					
4	The current floating bus stop design effectively accommodates the needs of individuals with vision impairments.					

5	I can easily locate the entry and exit doors of the bus while using the floating bus stop					
6	The waiting area at the floating bus stop is accessible and comfortable for me.					
7	Assistance is easily available if needed at floating bus stops.					
8	Real-time information related to floating bus stops is accessible through audio systems or mobile applications.					
9	I am generally satisfied with the experience of using floating bus stops.					

<u>Part B:</u> Open-Ended Questions

1. Can you describe your experience when navigating to and from floating bus stops? Please include any challenges that you encounter.

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2. Are there any current features of floating bus stop that work well for you? What specific aspects help or hinder your mobility?

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3. What are the primary challenges/barriers you encounter when traveling independently to floating bus stops?

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4. What changes or improvements would you suggest making floating bus stops more accessible for people with vision loss?

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5. Do you use any assistive technologies while commuting? Is it integrated with floating bus stops?

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6. Please indicate what kind of support would make using floating bus stops more manageable for you

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7. Do you have any comments on a communication system that will help at floating bus stops?

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