IDEA

Innovations Deserving
Exploratory Analysis Programs

Transit IDEA Program

Location Aware Networks Optimizing Use of Transit Systems by Blind Travelers

Final Report for
Transit IDEA Project 85

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Location Aware Networks Optimizing Use of Transit Systems by Blind Travelers

IDEA Program Final Report

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EXECUTIVE SUMMARY

As part of the smart city vision, the *LookingBus* Transit IDEA project improves public transportation services for riders with disabilities. Specifically, *LookingBus* addresses the challenges of riders with disabilities in boarding and disembarking (getting on/off) the bus. *LookingBus* developed sensors that are placed on bus-stops and work with mobile apps to alert drivers of riders with disabilities waiting at subsequent bus-stop, ensuring that the drivers can assist the riders board the correct bus. Likewise, the driver gets a notification when the rider needs to get off the bus. In this way, *LookingBus* is looking out for every rider – the technology allows the drivers to be aware, prepared, and cognizant of the needs of the rider. This approach has been proven to help both drivers, who have the time to clear priority seating and prepare for the upcoming riders, and the ADA (American with Disabilities Act) riders who now have the services they need along with the confidence that the drivers will be ready for them.

LookingBus addresses the challenges of boarding and disembarking (getting on/off) the bus. People with visual impairments heavily depend on public transit as an essential service for engaging in daily life and social activities. By utilizing Smart City technology, the bus-stop sensors and the user mobile app work in synchrony to enable travelers with visual impairments to find the correct bus-stop and then to guide them there with high precision. Next, *LookingBus* provides drivers with notifications of riders with disabilities at their upcoming stops to ensure that drivers can assist the riders as they board the bus. Likewise, the driver gets a notification when the rider needs to get off the bus.

LookingBus is a Smart City accessibility solution for public transportation riders with disabilities — including those with visual impairments — to give a renewed sense of freedom to these individuals: a large group of riders traditionally limited to advance-reservation transportation services. Having a variety of mobility options allows the individual to be physically active, socially engaged, and economically productive. For riders with disabilities, *LookingBus* reduces a barrier for employment, increases rider independency, and improves quality of life.

Throughout the research and development of this IDEA project, a variety of location aware sensors were developed and installed as a permanent attachment to make bus-stops smart and buses smarter. The sensors identify that riders with visual impairments are waiting in the vicinity of the bus-stop and alerting upcoming bus drivers that they have to stop. In addition to hardware, a slew of software applications was developed, including driver alerting apps, user portals, user apps, administration portals, and cloud services.

The project conducted pilot testing with volunteer riders (with and without visual impairments) in collaboration with the Suburban Mobility Authority for Regional Transportation (SMART), a public transit operator serving suburban Metro Detroit in Michigan. The Pilot highlighted a range of valuable findings that will serve to guide the continual refinement of the technology while moving ahead into the future. Overall, findings from the pilot were very positive regarding the value of the *LookingBus* service to stakeholders and its potential to integrate into and enhance current transit systems.

LookingBus currently undergoing deployment in Lansing, MI at the Capital Area Transportation Authority (CATA) through funding provided by the $8 Million Michigan Mobility Challenge. Having discussions with over 25 bus agencies, *LookingBus* is excited to continue growing and providing accessibility services to more communities across the nation. *LookingBus* is proud and committed to provide technology that makes public transportation more accessible for riders with disabilities. *LookingBus* aims to become the flagship solution for cities and transit agencies and to become a standard solution in every transit agency nationwide.

The LookingBus technology to date has progressed far past expectations regarding development, testing outcomes, and commercialization potential. However, there is still more work to be done, and additional funding is critical for the undertaking of development efforts that will take the LookingBus solution to the next level of commercial potential.

IDEA PRODUCT

This Transit IDEA project developed and tested the feasibility of *LookingBus* as a Smart City solution that improves the accessibility of public transportation for people with disabilities, including people with visual impairments. Specifically, *LookingBus* addresses the challenges of boarding and disembarking (getting on/off) the bus. People with visual impairments heavily depend on public transit as an essential service for engaging in daily life and social activities. However, they often face challenges with (1) finding the correct bus-stop, (2) determining which bus to board, especially at busy bus-stops when multiple buses approach, (3) boarding the correct bus in a timely fashion before the bus leaves the stop (**FIGURE 3**), and (4) getting off the bus at the right bus-stop (**FIGURE 2**). By utilizing Smart City technology, *LookingBus* provides drivers with advanced notifications of riders with disabilities at their upcoming stops to ensure that drivers can assist the riders as they board the correct bus (**FIGURE 1**). Likewise, the driver gets a notification to alert them when the rider needs to get off the bus.

FIGURE 1: LookingBus in action

LookingBus developed location aware smart sensors as a permanent attachment to make buses smart and bus-stops smarter. Installed on the bus-stops, the sensors identify that riders with visual impairments are waiting in the vicinity of the bus-stop and alerting desired bus drivers that they have to stop. Unlike beacons, the sensors identify the phone of the users and relay relevant information to the bus driver. Then, the *LookingBus* terminal on the bus retrieves and presents the information to the driver.

With the help of the *LookingBus* smart sensors (**FIGURE 7**), travelers with visual impairments can find the correct bus-stop and guide them to the stop with high precision, thus reducing travel errors, wasted time, and missed buses. The ability to find the exact location of the stop out of many nearby poles is critical for riders with visual impairment that often miss the bus just because they are not close enough to the correct bus-stop pole (**FIGURE 2**). *LookingBus* technology not only improves safety and reliability, but also customer experience, specifically for those who rely on fixed-route services. The *LookingBus* service contributes to the growing efforts in the industry in creating Smart City applications by developing sensors that provide connections between bus drivers and riders with visual impairments waiting at their bus-stops.

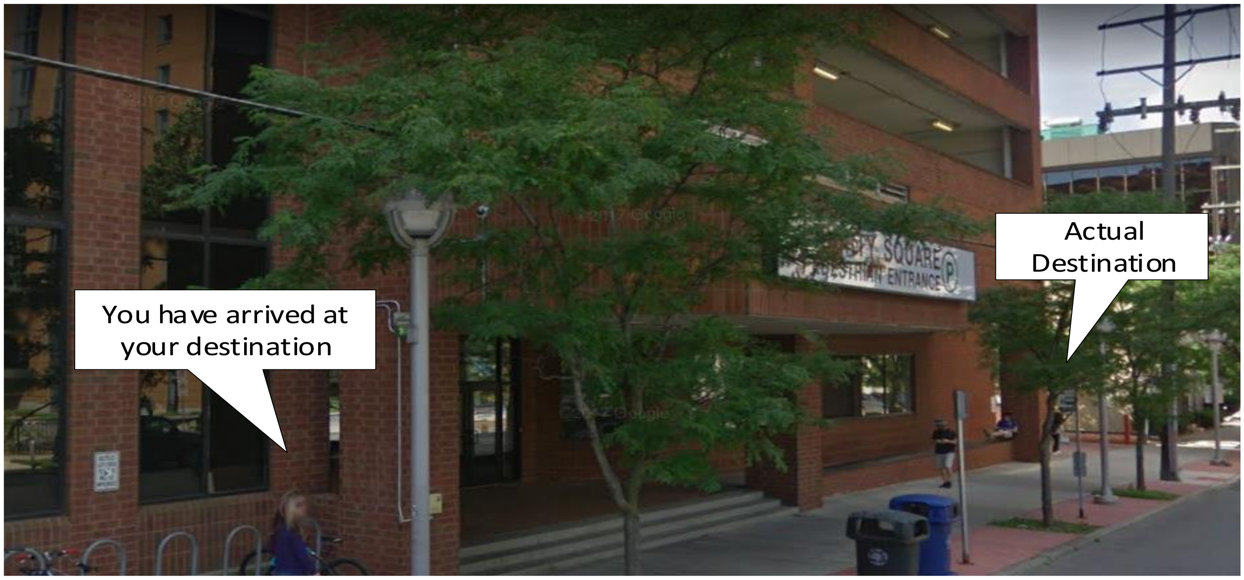

FIGURE 2: Where is the bus-stop?

The *LookingBus* team developed and tested the system to innovate a prototype for implementation and potential commercialization. Pilot testing took place on bus routes at The Suburban Mobility Authority for Regional Transportation (SMART). Elaboration on the product, significance, and research and development tasks continue throughout this report.

CONCEPT & INNOVATION

LookingBus is a Smart City solution used by public transportation riders with disabilities - including those with visual impairments - to give a renewed sense of freedom to said individuals: a subdivision of riders that is traditionally limited to advance-reservation transportation services. *LookingBus* aims to improve the accessibility, safety, and reliability of public transportation services for people with disabilities. Practically, the system takes an extra step to engage the driver of the desired bus, even before the bus arrives to the stop, by notifying the drivers that there are users waiting at their next stop (**FIGURE 9**).

The Americans with Disabilities Act (ADA) requires public transportation authorities to provide services for people with disabilities [1]. There are over 45 million people that are blind and visually impaired (BVIs) worldwide [2] and the unemployment rate for adults who are blind is about 70%, despite a higher college graduation rate than any other disability group [3]. For the BVI population, one significant barrier to employment is their ability to commute. People with visual impairment cannot drive motor vehicles and are therefore reliant on public transportation to both obtain and retain gainful employment. Moreover, the reliance on paratransit systems, with its unreliability and need for advance booking is not ideally suited for use for getting to and from employment. *LookingBus* will improve public transportation accessibility by facilitating communication between bus drivers and smart bus-stops when riders with visual impairment are waiting at the stop (**FIGURE 3**), getting off the bus (**FIGURE 5**), or finding the exact location of the bus-stop (**FIGURE 2**).

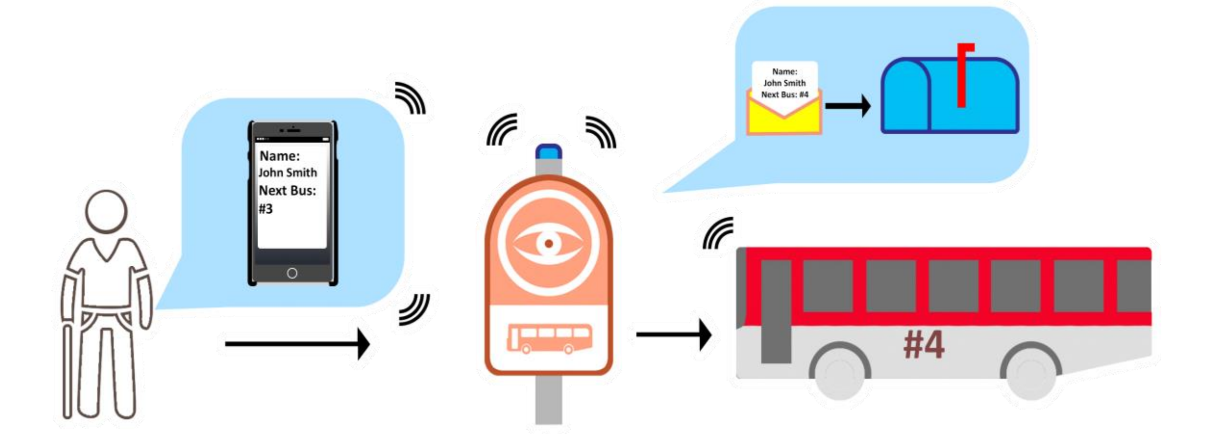

FIGURE 3: Getting on the bus

The *LookingBus* system provides alerts for bus drivers. At the beginning of each trip, a person with visual impairment that is registered with the *LookingBus* service (or their caregiver) reserves a trip in the user app. Once the user (ADA rider) arrives at the bus-stop, the sensor detects the rider at the stop and alerts the approaching bus driver about their presence (**FIGURE 3**). Next, an alert message with the name and picture of the rider that is saved in their profile is presented to the driver via the *LookingBus* terminal. The *LookingBus* system alerts drivers again when the user arrives to the destination stop, enabling public transportation agencies to provide a more efficient service for riders with disabilities while reducing requests for paratransit rides.

FIGURE 4: Driver terminal

FIGURE 3**,** demonstrates the operation of *LookingBus* when a person with visual impairments approaches their desired bus-stop. The location-aware smart sensors (**FIGURE 7**) relay the trip information to the relevant bus drivers. The sensors, a Driver Alerting Unit (DAU) (**FIGURE 4**), and a mobile app work in synchrony to ensure that drivers are aware of riders with visual impairments within the vicinity of the bus-stop. After a reservation is placed, the sensor sends an advanced notice to the designated driver that a rider with visual impairments is waiting at the stop.

LookingBus also assists riders with visual impairments to get off at the correct bus-stop. As seen in **FIGURE 5**, toward the end of the ride, the system will alert both bus drivers and riders with visual impairments about the destination stop ahead. Bus-stop sensors, a driver terminal, and a mobile app work in synchrony to ensure that drivers are aware of the destinations of riders with visual impairments on their bus.

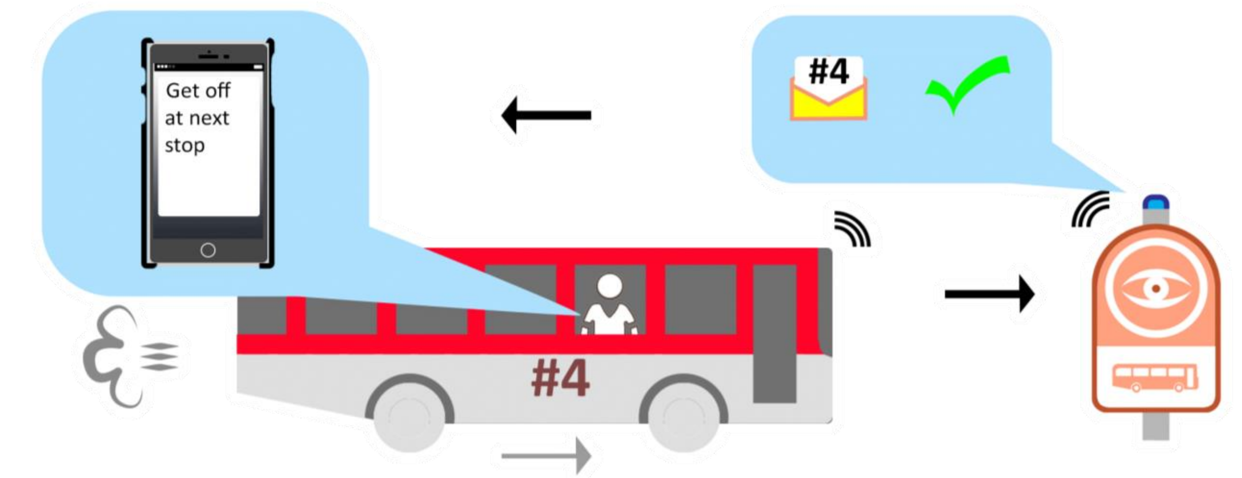

FIGURE 5: Getting Off the bus

In **FIGURE 2**, the GPS announces 'you have arrived at your destination' 40ft from the actual bus-stop. *LookingBus*' smart bus-stops enable travelers with visual impairments to find the correct bus-stop and then to guide them to the stop with high precision, thus reducing travel errors, wasted time, and missed buses. The ability to find the exact location of the stop out of many nearby poles (e.g., stop sign) is critically important for riders with visual impairment that often miss the bus just because they do not wait near the right pole.

As part of the Smart City vision, *LookingBus* enhances connectivity of public transportation systems through greater communication between riders and drivers by means of smart sensors and Internet of Things (IoT) Technology. Through implementation of smart bus-stops (**FIGURE 7**), as well as a user app (**FIGURE 12** and **FIGURE 13**) and driver app (**FIGURE 11** and **FIGURE 10**), *LookingBus* enables people with visual impairments to use public transportation reliably and safely with minimal required user operation.

SIGNIFICANCE

As an accessibility technology, *LookingBus* enhances methods that drivers use to identify disabled riders at stops. Currently, bus drivers heading in the opposite direction often notify fellow bus drivers when they notice a disabled rider waiting at their upcoming stop. However, this approach does not easily recognize blind riders that have disabilities that are not visually obvious. Also, this approach is unreliable because it depends on bus drivers noticing disabled riders while managing their other duties as well as manually contacting other drivers through intercom services. Moreover, riders with visual impairments attempting to get off the bus at their desired stop rely on the bus driver remembering their stop. With all of their required tasks, drivers often forget and miss announcing a specific passenger's destination stop. *LookingBus* provides a technological solution that reduces the unreliability of this and other current techniques.

LookingBus technology enhances the experiences provided by public transportation services while improving short, simple trips as well as long journeys for both residents in their daily commutes and travelers visiting the city. People with disabilities and especially people with visual impairment are limited with their ability to ride public transportation. *LookingBus* improves the ability to travel from one place to another providing riders, specifically those with visual impairments, seamless navigation of public transportation services.

LookingBus answers the call of the American with Disabilities Act (ADA), which requires cities to tend to the transportation needs of people with disabilities. As the nation prepares for the large number of aging baby-boomers, the number of people with associated visual impairment continues to rise. Persons with visual impairments are heavily dependent on public transit as an essential service for engaging in daily life and social activities. By providing advance notice to bus drivers, *LookingBus* improves public transportation accessibility, which by law must meet the needs of people with disabilities. In August 2017, the International Agency for the Prevention of Blindness (IAPB) reported that 36 million people are blind and an additional 217 million people have moderate to severe vision impairments. By improving the accessibility of public transit for persons with visual impairments, *LookingBus* increases demand for fixed-route services and provides public transportation agencies with a cost-effective alternative to paratransit [4].

Having a variety of mobility options allows an individual to be physically active, socially engaged, and economically productive. The ability to travel independently within an environment, especially by way of mass transit system, has been shown to be strongly linked with the ability of a person with visual impairments to work and live a productive life. In fact, 67% of the responders regarded transportation problems as a major barrier to employment [5-8]. Transportation challenges are one reason contributing to the increasingly high unemployment rate among persons with visual impairments [3]. In 2014, 4.4 million people in the United States, aged 18 to 64, were living with a visual disability [9]. Within the blind population, 70% could be more employable if they had ready access to transportation. The poverty rate for this group was 28.7%, over twice as high as the 13.6% rate, for non-disabled adults [9]. Unless services that improve access to transportation for persons with visual impairments are implemented, poverty rates will continue to grow as the population ages.

EQUALITY AND ECONOMIC IMPACT

All bus and rail companies, in order to comply with the ADA Act, provide paratransit services to riders whose disabilities prevent them from using scheduled public transportation [1]. This service costs the agencies at least six times more than the regular transport service. A rigorous customer discovery interview process with over 150 in-person interviews with people with visual impairments and their families, as well as with public transportation key stakeholders including drivers, dispatch operators, and orientation and mobility personal revealed that riders with ADA status are looking for alternative solutions to paratransit services, not only because of the cost but also because of stricter scheduling needs. For example, riders may need to schedule trips up to or over a day in advance to secure availability. This can be problematic with unpredictable return times. Also, due to the prolonged wait times, persons with visual impairments cannot depend on paratransit services for regular trips such as daily commutes to work. Additionally, riders with disabilities highlighted frustrations with how long ride-share trips can take for relatively short distances. Further, interviews revealed that paratransit services may not even show up for pre-scheduled trips leaving riders with no transportation. Many riders with disabilities are seeking greater independence and flexibility, which will be enabled by use of *LookingBus* and fixed-route buses.

For persons with visual impairments, the option of using fixed-route public transportation poses several challenges at each step of the journey. The most common challenges are identifying the bus-stop, getting on the correct bus, and getting off at the right stop. For example, while a sighted person can increase their pace to catch a bus about to leave a stop, persons with visual impairments might not be aware of the departing bus and thus, miss the bus. Similarly, persons with visual impairments might face difficulty when locating bus-stops, determining which bus to board, and identifying the proper stop to exit. Such challenges could lead riders to get on the wrong bus or miss the bus entirely.

LookingBus is an accessibility technology for improving fixed-route services to reduce costs associated with paratransit (a special transportation services for people with disabilities) by making fixed-route services more accessible to riders with disabilities. These paratransit services consume over 20% of the budget and serves only 4% of the ridership [4]. *LookingBus* enhances fixed-route transit for riders with ADA status, which will improve the perception and image of transit companies. Validated through the customer discovery process mentioned earlier, many people with ADA status have expressed concerns with their paratransit experiences and desire improvements that would make fixed-route services more accessible and an alternative option. While public transit companies are required by law to provide accessible transportation to riders with ADA status, *LookingBus* is the accessibility solution for the transportation service offered to these riders.

To improve the accessibility of public transportation services for persons who are blind, visually impaired, and the increasingly large number of aging baby-boomers, it is necessary to develop technological tools that allow these individuals to carry out activities safely, independently, and reliably. As we continue to learn more about how people with disabilities utilize technology, it is vital to use this information to develop accessible and beneficial technology [10,11]. *LookingBus* uses verbal commands, vibration cues, and micro navigation to provide an accessible service.

The *LookingBus* service benefits both riders with disabilities as well as Transit companies through a service that improves public transportation. For riders with disabilities, *LookingBus* reduces a barrier for employment, increases independency, and improves quality of life. For Transit companies, *LookingBus* save money on paratransit and improves the accessibility and the perception of their service.

INVESTIGATION

The project tasks and work performed were divided into eleven major tasks in two stages.

STAGE I: DEVELOP HARDWARE AND SOFTWARE

Task 1: Vibrotactile Wristband

During the project, several vibrotactile wristband and smartwatches were evaluated. The bands were tested in controlled conditions for communication integrity, functionality, and performance (**FIGURE 6**). Vibrotactile guidance has the advantage of being robust in situations where spoken instructions may be difficult to hear, or where visually impaired pedestrians need to listen for other cues such as the sound of moving traffic. The team found that most of the commodity smartwatches and fitness bands (e.g., iWatch, Moto360, Samsung Gear, and Fitbit) are capable of conveying vibrotactile cues that are triggered from an app installed on their paired smartphone.

FIGURE 6*:* Vibrotactile wristband

Task 2: Smart Bus-Stops

Location aware sensors were built as a permanent attachment for single-pole bus-stops (**Error! Reference source not found.FIGURE 7**). A variety of sensors were designed as IoT sensors with battery or solar recharging elements to sustain long independent operation in the field under a range of conditions. These sensors were tested in the field to evaluate their durability and survivability in variable Michigan

FIGURE 7*:* Smart bus-stop

weather. Pole mountable casing was also developed to provide waterproof housing for the sensors, as well as serve as the implement for mounting them on bus-stops in positions that facilitate strong and reliable wireless communication. **FIGURE 8** shows tests conducted in Ann Arbor, Michigan during winter 2018. These tests

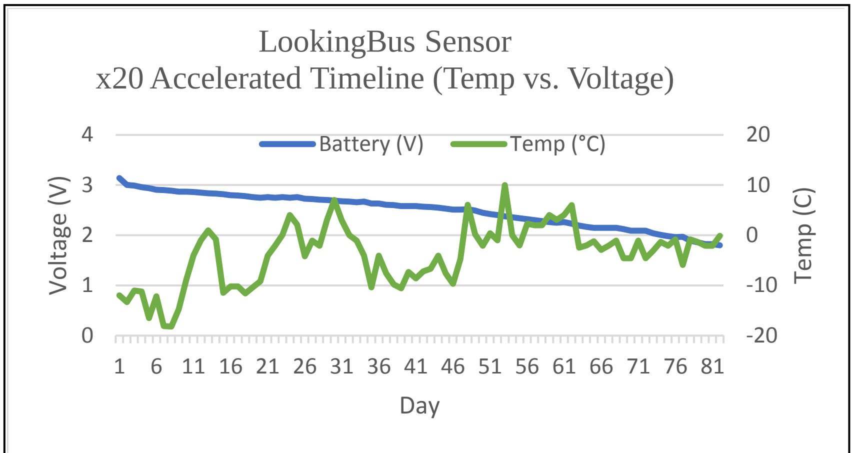

FIGURE 8: Energy performance of the LookingBus sensor

included sensors powered by a smaller battery of 1,200 mAh, operating at 20 times higher frequency than the intended use. The motivation behind the experiment design was to accelerate testing from months to years.

Task 3: Driver Alerts (DAU)

A proof-of-concept Driver Alerting Device (DAU) was developed as an android app for tablets. **FIGURE 9** provides a timeline of notifications to the driver on the DAU during the lifetime of a trip reservation.

FIGURE 9: Timeline messages on the DAU

FIGURE 11 exemplifies a pickup message while **FIGURE 10** exemplifies a drop off message on the DAU. The DAUs communicate with the APIs of Clever Devices, the *LookingBus* Cloud, and the sensors from Task 2 in order to provide reliable advance notice to drivers about the riding events of individuals with visual impairments.

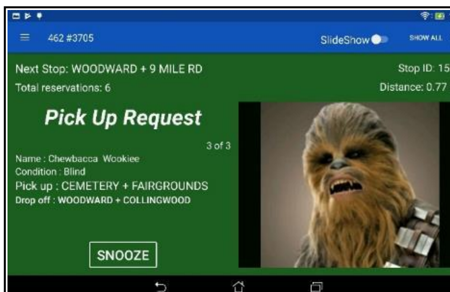

FIGURE 11: Pickup messages on DAU

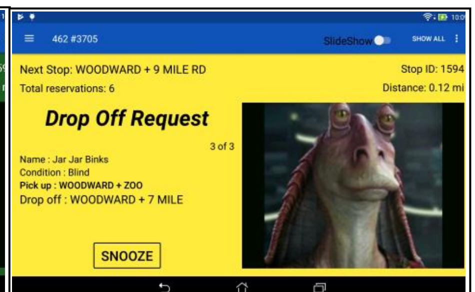

FIGURE 10: Drop-off messages on

Task 4: User Portal

A proof-of-concept user portal was developed as part of the cloud service (**FIGURE 12**). The portal allows users to register, manage their profile, and select favorite travel destinations.

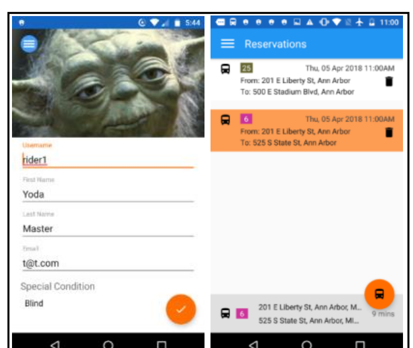

FIGURE 12: User portal

Task 5: User App

A mobile app was developed to (a) allow micro-navigation to bus tops with the *LookingBus* sensors and (b) reserve public transportation trips (**FIGURE 13**). The mobile app is the primary manner in which users interact with the system. It relays location information and provides fine navigation instructions. Vibrotactile feedback can be provided through the wearable wristbands of Task 1. The app was designed for trip planning, selecting origin, destination, and favorite places, where similar to other transit apps, users are able to plan a trip that includes getting to the bus-stop. Optimal public transportation routes are suggested by querying Google Transit.

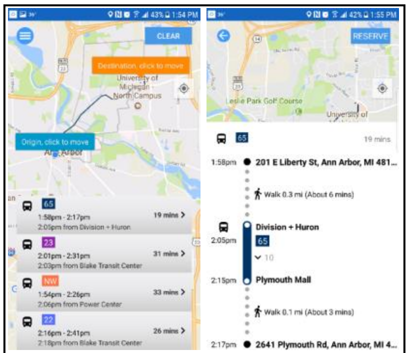

FIGURE 13: Reserving a trip

Task 6: Administration Portal

An administration portal was developed as a Web Service for the Microsoft Azure (**FIGURE 14**). The portal enables management, monitoring, and control tasks. The portal is also required for testing processes that involve multiple steps, such as alerting services.

Task 7: Cloud Service

The *LookingBus* cloud service was developed to manage location-aware networks, public transportation agencies, and users (**FIGURE 14**). The service was designed to support large volume service requests from multiple mobile apps at different geographical locations simultaneously. A documented licensable application program interfaces (API) was provided in the Stage I report and is available for licensing.

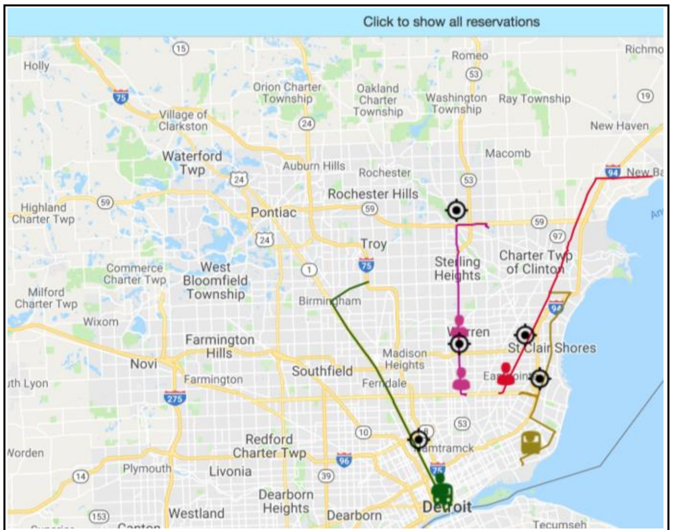

FIGURE 14: Central dispatch center (CAD)

Task 8: Stage I Report. Submitted and approved.

STAGE II: SOFTWARE OPTIMIZATION AND PILOT TESTING

Task 9: Optimize the Performance and Robustness of The System.

Final testing and subsequent modification were performed to optimize robustness and performance. System testing was performed in a control environment prior to deployment of the system on the Suburban Mobility Authority for Regional Transportation. Data was collected from the test to evaluate the performance of the system, including false positives and false negatives.

Task 10: Performance and Functionality Tests.

Based on the initial results, final software modifications were made. During this stage, testing at SMART was conducted with volunteer students, to evaluate and optimize the system before large scale testing with blind and visually impaired (BVIs) riders. Testers were introduced to the training task and use of the wearable device prior to experiments, to minimize novelty effects to the training task, and to establish a baseline performance level.

After initial testing with volunteer students, a small group of people with visual impairments were recruited for pilot testing on specific tasks of traveling along SMART routes. The tasks included planning a route, finding a specific bus-stop, identifying a specific bus, identifying a specific stop on a bus line, and finding a destination within a transit terminal. As these were pilot tests, the location aware sensor system was not fully deployed throughout the transit system but only as needed for specific tasks in order to assess performance of the components for that task. The alerting system for both getting on the bus and getting off the bus were tested for functionality and usability. Throughout the project, refinements and improvements to the software and hardware were implemented according to data and feedback from the tests. Volunteers with visual impairments generated qualitative data regarding system performance, and were also asked to give personal evaluations of positive and negative aspects of using the system. Results from all testing will continue to inform future development, and guide both general and specific refinements intended to improve performance and reliability of the technology.

Pilot Testing

Prior to the conducting of performance and functionality tests, extensive planning and preparation was conducted to prepare the technology and participants for safe live runs. In preparation for the pilot, the *LookingBus* team worked in collaboration with SMART to provision routes, schedule, and real time vehicle locations into the *LookingBus* servers (**FIGURE 15**). As part of this process, information about the specific Intelligent Transportation Systems (ITS) including the Automatic Vehicle Location (AVL), has been integrated into the *LookingBus* service and Driver Alerting Unit (DAU). Preparation also included extensive discussions with key stakeholders from SMART staff,

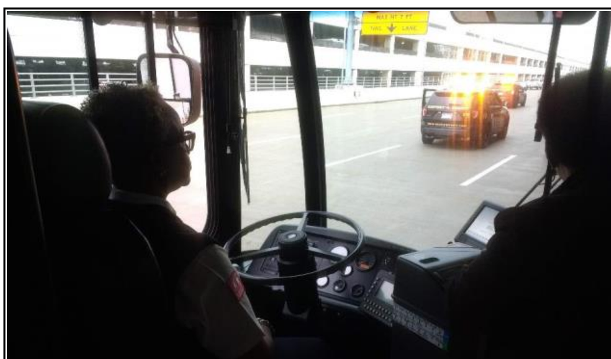

FIGURE 15: Pilot in Detroit

such as IT and operations management personnel, to ensure safe trials. The discussions addressed practical aspects such as locations for placing DAU on buses, placement of sensors, and safety for trials participants.

Prior to the test runs with volunteers from the community who are blind or visually impaired, two technical pilot tests were conducted in controlled environments (**FIGURE 15**). The first initial technical pilot was conducted with SMART drivers, SMART operations personnel, and *LookingBus* development team members. This test was conducted with no test riders for safety reasons, in preparation for the second run. A second technical pilot was conducted with a small group of healthy volunteers with no known disability in further preparation for the live pilot. All the volunteers were older than 18 years old. Both trials have been conducted with no test riders, and both tests incorporated feedback gathered from stakeholders involved in the technical pilots.

Participants in the test runs included a range of engineers, developers, bus drivers, operation personnel, travel trainers, evaluators, and volunteers who are blind or visually impaired. All volunteers were older than 18 years old, both men and women and from a range of ages. Professor Wall Emerson, the external evaluator working with the development team, is a Blindness & Low Vision expert and research professor at Western Michigan university. He was responsible for recruiting the volunteers with visual impairments from the local community. Participants from SMART included multiple bus drivers, operations managers, travel trainers, and IT personnel (**FIGURE 16**).

FIGURE 16: Pilot in a dedicated vehicle

The test runs conducted during multiple sessions over a few weeks period. Each test run was conducted with a small group of volunteers, all with visual impairments, and on a different day. During the first day of testing, only one of the volunteers participated in the trial. In the next days, additional volunteers participated, at least two volunteers in each session. A different driver was used on each of the independent testing days. All development staff, evaluation staff, and SMART personnel participated during all days of testing. Dedicated buses were used during the test, with no other passengers on the buses other than the test participants and pilot stakeholders. The tests were conducted this way for safety purposes.

Testing was conducted along a fixed-route bus line that is frequently used by riders with ADA status, and included grocery stores, business offices, and entertainment attractions along the line. Specifically, testing route started at Detroit Metro Airport (DTW) to best simulate crowded and noisy environments that are typical of crowded real-world bus transit areas, particularly ones where there are multiples lines and multiple bus-stops in very close proximity and operation to one another (**FIGURE 15**).

This environment served as a challenging testing grounds for the technology. Additionally, the built structures around the DTW facilities, including parking structures and airport infrastructure, provided the real-world issue of GPS interference that the technology will face during implementation, and allowed for testing with this condition. The trial test consisted of a series of points along a 'route' that volunteers (**FIGURE 17**) had to navigate using the *LookingBus* technology.

FIGURE 17: Visually impaired volunteers

1) The volunteer began by reserving the ride on the mobile app. The volunteer then traveled 100 ft from the starting point to the bus-stop following the app's guidance. The bus driver received an alert with the volunteer rider's details (including picture and desired destination) when they were two stops away from the volunteer. An additional alert was delivered upon the driver's final approach to the user's stop. At the stop, the rider was provided with up to date information on the status of the bus, including how many stops away it was from their location, and until the bus arrived at their stop.
2) When the bus arrived at the stop, the volunteer boarded the bus. The rider then rode the bus for about six - ten stops. The LookingBus application continued to provide regular updates during the ride, including what the upcoming stop was as well as how many stops remain until the desired destination. Using the application, the volunteer disembarked at the correct stop.
3) After disembarking at the stop, the volunteer followed the app's directions to the end point.
4) Following a debriefing, the volunteer used the app to return to the origin.

To complete the test, full application functionality was required, and all features were tested and evaluated by all participants. From the starting point to the destination, volunteers with visual impairments were accompanied by the evaluator. Throughout the duration of the test, the volunteers talked to (think aloud style) the evaluator about what they were doing and their thought processes while using the application. The evaluator took notes and asked questions regarding their experience and perceptions throughout the duration of the test. During the test, the *LookingBus* team engaged with the driver and observed their interactions with the system, as well as gathered perception data from them during their operation of the bus and using of the technology. SMART personnel rode the bus during the test and observed the operation of the technology in conjunction with regular bus technologies. SMART operations personnel also monitored the data being received by the central dispatch system.

Following the completion of each test run, participants gathered to partake in focus group-style discussions. Perception data was collected from both volunteer riders and volunteer drivers, and extensive feedback was noted based on their experience using the system. Toward the end of the pilot, the *LookingBus* team also met with SMART key stakeholders to gauge perceptions of the solution. Questions of interest included the potential of *LookingBus* to improve the quality of service that SMART and its operators can provide. For example, an estimation about the ability of the system to assist riders with disabilities to ride safely and confidently on fixed-route buses, a decrease in missed buses, a reduction in pick-up time of riders with disability, or a reduction in wait times by riders with visual impairments. All feedback data gathered will contribute to the refinement of the *LookingBus* deployment moving forward (post-pilot sustainability).

Driver Input

Overall, drivers were very pleased and excited about the development of a system that could enhance the experience of transit users with disabilities, including riders with visual impairments. The drivers, in addition to riders with visual impairments, expressed a strong need for such a technology with the capability to improve transit use for all riders with disabilities, and are eager for its implementation. For example, they emphasized the need to have an alert when a rider with a wheelchair is waiting at the bus-stop, so they will be able to prepare accordingly, even before they reach the bus-stops. They also mentioned that because they are limited to only two-wheel chairs in a bus, an early alert will help them to notify the dispatch center in case that they can't accommodate more wheel chairs.

Drivers also provided valuable practical suggestions about visual, timing, and audible aspects of the system notifications to ensure that they are able to understand and address them. It was noted that the number of required clicks, or interaction with the system, should be limited so that drivers are not required to take their attention away from other important systems and responsibilities while they are operating the bus. Alongside this point, drivers noted that it was important that alerts be provided in a timely fashion, and that two stops in advance, upon approach to the target pickup stop and target drop-off stop, and at the arrival of the target stop were good times to deliver alerts through the *LookingBus* driver device. The drivers noted that audible noises would be useful to emphasize alerts, and also said that the audible alerts should not be too intrusive.

Drivers also provided feedback on the positioning of the *LookingBus* terminal in the driver pit (**FIGURE 4**). For example, they requested that the terminal would be oriented within the driver space to not be too intrusive over other systems and responsibilities, and at the time being, prevalent enough to get their attention when an alert is received. Smaller points of feedback included visual details like how it would be helpful if different fonts, colors, and designs could be used to differentiate between different notifications. Drivers also suggested that it would be helpful to not have too much information on the screen and to avoid visual clutter so that the device is easier to use while they are operating the bus.

User Input

A prototype of the application on an android phone was used to canvas input from focus groups of potential users (people with visual impairments). Riders with visual impairments reviewed elements of the application and discussed the potential benefits of the *LookingBus* system. Critical perception feedback from pilot test participants was also gathered during live tests and in a post-trial focus group style setting. While there were many suggestions for ways to improve the system, mainly in terms of interactive functionality of the interface, the basic idea of a travel application that assisted a pedestrian with a visual impairment in finding a bus-stop and organizing a route that incorporated a bus trip was seen as positive. All participants were positive about the features of the system involving having bus drivers alerted about the presence of a traveler with a disability and the sense of security that this extra level of trip knowledge gave travelers.

Several travelers with visual impairments also took part in simulated travel routes using the prototype app and a dedicated training bus equipped with the *LookingBus* terminal. Routes traveled were on the FAST bus route within the larger SMART transit system. Routes went from the Detroit Metropolitan Airport to a selected stop approximately 30 minutes from the airport and back. The current prototype is on the android platform and this presented some challenges for users. Further, user testing once the application is available on the iOS platform will be needed to assess usability by people familiar with one or the other technology platform. Nonetheless, it is evident that some training will be needed by most users before they will be comfortable in planning and logging routes and continuing to use the app while riding the bus. Pilot users offered several suggestions on improvements to the app although all focus group members and pilot users indicated that the core idea of the project was very exciting and promising.

Main benefits:

User input assisted in the further refinement of the identified primary benefits of the *LookingBus* technology. One of the standout points of interest from focus groups was that the technology provided improved accuracy in finding bus-stops compared to GPS devices and other smartphone applications. Use of the technology also provided an added sense of security due in part to knowing that the bus driver is expecting the user at the stop, and that the driver will be available to provide assurance of safe boarding.

Users also indicated that *LookingBus* was beneficial in how it was able to accept address or destination inputs and plan an entire route for the user, while also reducing the need for users to know all of the bus routes themselves. Users highlighted that the technology was helpful in how it allowed both typing and voice input for information entry into the interface, and that it was convenient that *LookingBus* bundles walking and bus riding into one route application. Overall, users indicated that the benefits of the technology may incentivize persons who otherwise do not typically use the bus to try using it.

Suggestions:

LookingBus users also provided valuable feedback and suggestions through prototype use and focus groups. They suggested possible improvements to the *LookingBus* app to enhance its usability including read aloud functionality for lists of directions, use of vibration at the completion of each step, and continuous audible feedback and reminders of steps. Suggestion were also given regarding additional information about each step, such as information about crosswalks, upcoming traffic intersections, and walking bridges. Some users requested that the app would provide trip start time for when the user should start walking in order to reach the bus-stop before the bus arrives but preventing the user from spending excessive time waiting for the bus. Users also made the great suggestion of including updates on when the bus is scheduled to depart from the stop so that they will know whether they are going to make the bus on time or should plan accordingly to wait for the following bus. It was also suggested that safety and security of the rider could be improved by including a system check asking for confirmation from both the rider and driver that the rider is on the correct bus, and also provide regular updates on the time remaining until arrival at their desired stop.

Regarding voice-based functionality, users suggested enhancements based on their experience with voice-based functions of the app during the trial. Users experienced some confusing outcomes based on their vocal inputs and noted that there should be clear commands that do not produce other outcomes like interference with notifications and navigation to incorrect menu options.

Other suggestions regarding functionality included specific details that will be addressed during refinement of the technology. Suggestions included the importance of deactivating a smartphone's screen-sleep functionality so that the user does not have to worry about their device screen ignoring their inputs due to it being locked. Some users noted that it was important that their swipes or other screen inputs did not direct them to other menus or lists within he app that would be difficult to navigate out of. An additional and very important point was that users need to receive clear feedback from the device indicating that their inputs were registered. Users also commented on the actual phrasing/wording of the prompts such as confusions by the phrase “your trip is about to begin”, which means that they need to start walking to the bus-stop and not that the bus is approaching.

Agency Operations Input

In addition to feedback from volunteer test participants and drivers, valuable feedback was received from operations personnel while they accompanied and observed the pilot. Feedback focused mainly on the integration of *LookingBus* with existing Intelligent Transportation Systems (ITS). In general, operations personnel were pleased with the position of the *LookingBus* terminal in the driver pit and that the orientation of the terminal is set in a way that it is complementary to other critical bus systems while they can still be used effectively. Operations personnel also commented on the user interface of the device, which requires minimal input from the driver (for functions like login, menu navigation, etc.) so that their hands and eyes can remain focused on driving. Operations personnel also discussed various hardware options for the *LookingBus* terminal considering its robustness, communication capabilities, and its resistance to water.

Operations personnel also made some suggestions on additional technology features that would improve the function of the *LookingBus* solution and its integration with existing systems. It was suggested that additional independent Automated Vehicle Location (AVL) features be developed on the *LookingBus* end that would be used in parallel and back up for the legacy AVL systems already installed. It was also suggested that Artificial Intelligence (AI) would be used for better predictions that riders receive through the *LookingBus* app.

Other suggestions regarding functionality included specific details that will be addressed during refinement of the technology.

PLANS FOR IMPLEMENTATION

NEED FOR FURTHER TESTING

The *LookingBus* team was highly encouraged by the results of the pilot. The purpose of this pilot was to test and demonstrate the feasibility of the *LookingBus* solution with the goal of further development as well as full deployment. Furthermore, time and funding from the IDEA project allowed for not only for the execution of the pilot, but also for preparing the technology for long-term deployment. Longevity of the *LookingBus* solution, following the pilot period, will rely on implementation in stages to ensure intelligent growth. Following the pilot, further data collection and analysis will continue to optimize the system for full bus system integration. With the goal of system-wide deployment, the technology will undergo extensive testing so that it may operate sustainably and provide value well into the future. This testing period will contribute to a smooth expansion to full-scale implementation and was a critical next-step in the preparation of the *LookingBus* solution for long-term, sustainable integration into various bus networks.

Several areas of focus have been identified as important for testing and development progresses. For example, the system needs to be tested in a greater variety of technology platforms and real-world environments. Regarding the mobile application, *LookingBus* has been initially developed for testing and use on the Android operating system, and further development and testing is necessary for expansion onto the Apple-based iOS operating system, which is used by a large portion of smartphone users.

LookingBus needs to be tested with additional transit agencies, as operations technologies (including AVL systems) differ between organizations. The technology also needs to be tested with additional volunteer riders and drivers to collect more user feedback data that is crucial for development. Last but certainly not least, further testing of the technology in different cities and regions is necessary as no single transit authority's jurisdiction is the same, and the technology must be able to function in a wide range of environments.

FUTURE DEVELOPMENT

As *LookingBus* continues to develop through iterative refinements, we plan to improve the service through testing and evaluation of user suggestions, both of which continually inform the enhancement of the technology's performance and reliability. Development of the product will continue with the goal of providing the best possible service to public transportation riders with disabilities.

LookingBus intends to further provide riders with disability the ability to utilize fixed-route bus systems using our services through implementation of improved ride reservation functionality and features. This aspect of the service will expand in several ways. Firstly, recurring reservation functionality will be developed and implemented to improve long term user experience with the application. For example, a user will be able to set the application to recurrently reserve rides on recurring days and times (e.g., Tuesdays at 10am. and on Thursdays at 11am,) or set the application to reserve rides for going to work each day with programmed exceptions for non-work days like Saturday and Sunday. Secondly, the technology will be developed to allow family members and caregivers to set up paired accounts and make reservations for their family from their own devices. This will enable more flexible assistance without the need to enter reservation information directly into the rider's device, and allow them to receive mobile updates on the progress of the user's trip. Thirdly, a feature will be developed to allow additional 3rd party individuals, such as doctors, to make reservations on the behalf of the rider with a disability to assist them on their travel to and from appointments. This feature will be supported on an independent system so that 3rd party individuals can make reservations without having to do it on the riders' own device.

Future developments are also planned on porting the mobile app from Android to iOS. Adding support for an additional major mobile operating system will extend the service to iPhone users within the ADA community.

Another aspect of the technology that will continually be developed is security and privacy of the service. It is of the utmost importance to secure and protect the data of LookingBus users and their privacy in compliance with the Health Insurance Portability and Accountability Act (HIPAA), and as such these security features will continue to be developed and refined.

Looking into the future, *LookingBus* also plans to continue and develop features such as Automated Vehicle Location (AVL) for better integration with transit systems, Artificial Intelligence (AI) based prediction technology for improving reliability of the service, and Vehicle to Infrastructure (V2I) Application Programing Interface (API) for communication with other Intelligent Transportation Systems (ITS).

PLANS FOR IMPLIMENTATIONS

LookingBus is currently being deployed in Lansing, Michigan on the system of Capital Area Transportation Authority (CATA), with funding from the $8 Million Michigan Mobility Challenge. *LookingBus* is excited to continue growing by implementing our system in additional cities across the nation and is currently in discussion with over 25 bus agencies in the USA. The team is confident in its ability to quickly and affordably scale the *LookingBus* Smart City solution and is eager to further extend the *LookingBus* accessibility services to enhance public transportation experiences of users across the nation. The team aims to become the flagship accessibility solution for cities and transit agencies, and they will be proud to highlight the *LookingBus* innovative accessibility service in their annual reports. The long-term vision for *LookingBus* is to become a standard accessibility solution in every transit agency and mobility on demand provider nationwide.

CONCLUSIONS

OVERALL FINDINGS

Pilot testing of *LookingBus* highlighted a range of valuable findings that will serve to guide the continual refinement of the technology while moving ahead into the future. Findings were primarily derived from feedback gathered from key stakeholders, including volunteer test users, bus drivers, and transit authority personnel. Overall, the stakeholders involved felt very positive and excited about the technology and believed that it would be a valuable technology to improve the experiences of people with disabilities who use public transportation systems. Regarding improvements while moving into the future, one of the major findings from testing and feedback from drivers and transit personnel was that the driver device needs to be optimally placed so that it is readily accessible but not intrusive to the driver. This same feedback was given about the functionality of the user interface of the device, that it should be easy for the driver to operate and not take their attention away from their primary duties. Feedback from transit personnel also included insight into how the technology could be better integrated with existing Intelligent Transportation Systems (ITS). Operation personnel requested support for other technologies such as additional Automated Vehicle Location (AVL) and Artificial Intelligence (AI) systems that enable improved performance and operation in conjunction with transit service systems.

Volunteer riders also provided highly valuable findings from pilot testing and focus groups that are fundamental to the *LookingBus* technology moving forward. User feedback was very positive and indicated that *LookingBus* provided value and functionality beyond available technologies such as GPS devices and other smartphone applications. *LookingBus* also provided an additional sense of security due in part to the knowledge that drivers would be expecting them at stops and would be able to provide assistance. User feedback also included suggestions on improvements that would enhance their experience, including refining how users navigate the user interface and how they receive verification of their inputs into the application. Overall, findings from the pilot were very positive regarding the value of *LookingBus* to stakeholders and its potential to integrate into legacy transit systems.

LESSONS LEARNED

The *LookingBus* journey exceeded all expectations set during the IDEA proposal. The completion of the proposed objectives led to even further developments that were necessary to take the project further and ultimately led to expanding future goals to a variety of additional transportation applications.

The *LookingBus* team also learned that both riders with disabilities and transportation providers are eager to adopt new technology to improve accessibility of public transportation. With the rising rideshare offerings, riders expect to receive from their public transportation agency accurate information regarding bus arrivals, reliable pickups, and higher accountability. At the same time bus operators, similar to rideshare drivers, expect to receive information about riders needing accommodations ahead of time so that they will be able to prepare and provide a great service. Additionally, operation and IT personnel at the transit agencies were excited about closing information gaps that the legacy systems pose.

Toward the end of the project, the team was contacted by several active safety groups from global car manufacturing companies to explore collaboration with the *LookingBus* system in order to alert pedestrians with visual impairments about quiet electric vehicles. Further conversations are also taking place with engineers from the autonomous driving groups about informing the car about pedestrians in order to adjust the vehicle behavior.

Looking into the future, the LookingBus team plans to expand the service to other modes of transportation, such as Mobility on Demand (MOD) services, which are rarely accessible, for the most part because of the point of pickup and drop-off which are random curbside along the street. By having LookingBus sensors installed in accessible curb side areas, LookingBus can further expand the transportation options available to individuals with disabilities. The goal of LookingBus is to provide people with disabilities, including those with visual impairments, more opportunities to fully engage in every-day aspects of society by improving the accessibility of public transportation.

GLOSSARY

- ADA – the American with Disabilities Act
- AI – Artificial Intelligence
- API – Application Programing Interface
- AVL – Automatic Vehicle Location
- BLE – Bluetooth Low Energy
- BVIs – Blind and Visually Impaired Individuals
- DAU – Driver Alerting Unit
- GPS – Global Position System
- HIPPA – Health Insurance Portability and Accountability Act
- IAPB – International Agency for the Prevention of Blindness
- IoT – Internet of Things
- IT – Information Technology
- ITS – Intelligent Transportation Systems
- MOD – Mobility on Demand
- RF – Radio Frequency
- V2I – Vehicle to Infrastructure

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