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## Crowdsourcing the Collection of Transportation Behavior Data

Christopher Bone  
*University of Oregon*


Seth Kenbeck  
*University of Oregon*

Ken Kato  
*University of Oregon*

Jacob Bartruff  
*University of Oregon*

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*FINAL REPORT*

## **Crowdsourcing the Collection of Transportation Behavior Data**

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NITC-RR-653 ■ September 2015

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university transportation center for livable communities.*



# **CROWDSOURCING THE COLLECTION OF TRANSPORTATION BEHAVIOR DATA**

**Final Report**

**NITC-RR-653**

by

Christopher Bone, PhD.  
Seth Kenbeek  
Ken Kato  
Jacob Bartruff

University of Oregon

for

National Institute for Transportation and Communities (NITC)  
P.O. Box 751  
Portland, OR 97207



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## **DISCLAIMER**

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## **EXECUTIVE SUMMARY**

Understanding the travel behaviors of individuals who use public transit is essential for enhancing the performance, sustainability and efficiency of public transportation. Contemporary methods for collecting data on transportation behavior are focused on manual or automated procedures for counting the number of individual passengers entering or exiting transit vehicles. While such methods provide useful data for understanding transit demand throughout a network, they ignore the important details of how passengers travel to and within a network as well as their personal experiences during their commute, all of which can enrich the ability of transit agencies to provide sustainable transportation. To address this issue, there has been a proliferation of location-based services (LBS) that allow for new methods of data collection involving passengers volunteering data about their commute. In this light, passengers engage in a crowdsourcing effort to generate data about experiences across the network. This project's objective is to implement and test specific LBS in a bus transit network to better understand their potential and limitations for improving the crowdsourcing of travel behavior data.

Our project developed a mobile phone application that utilized two forms of LBS technologies referred to as Bluetooth Low Energy (BLE) beacons and geofencing. Participants were recruited to use the application for a three-week period on Lane Transit District's EmX bus line located in the Eugene-Springfield area in western Oregon. At the end of the study period, data was collected from the participants' applications. Participants were then asked to complete a survey about their experience using the application.

Results from the study reveal that both BLE beacons and geofences have the potential to be widely used to facilitate the crowdsourcing of travel behavior data. Most participants indicated that the application was easy to use, and our application was found to collect accurate data for the majority of trips. The collected data expanded knowledge about transit riders, as our database includes places of departure and destination for each trip, the length of time it takes transit riders to arrive at their bus stop, and the mode of travel used to arrive at the bus stop. Both technologies did exhibit some errors, which were mostly in the form of the application not accurately recording when a transit rider exited a vehicle. However, these errors were in small proportion with respect to the total number of trips during the study period. Overall, our project demonstrated that LBS have a role in the future of how transit agencies collect data in order to improve rider experience as well as system efficiencies.



# 1.0 BACKGROUND AND RESEARCH OBJECTIVES

## 1.1 INTRODUCTION

Understanding the travel behaviors of individuals who use public transit is essential for enhancing the performance and efficiency of public transportation (Konig, 2011). This requires collecting and analyzing data about when and where individuals enter and exit public transportation, what other modes of transportation they utilized to get to those access points, and their experiences while using public transportation. These data are relevant to planning decisions about improving the ridership, efficiency and sustainability of public transportation.

Currently, data collection methods focus on counting riders who enter and exit public transit at a particular location. Traditionally, this involved individual data collectors who observed counts of the number of individuals entering and exiting vehicles (Boyle, 2008). However, manual counts are expensive, requiring high long-term labor costs, and do not provide representative samples as data collection is limited to short timeframes (Konig, 2011). More recent innovations, such as Automatic Passenger Counting Systems (APCS) developed in the late 20<sup>th</sup> century, have provided automated methods for collecting these data. APCS are an improvement on manual counting methods, as they are capable of counting the number of riders at multiple system levels, including entire routes, route segment, specific stops, and the time of day and the day of the week (Baltes and Ray, 1999). APCS are useful for determining which stops are over- or underutilized, providing for more efficient distribution of resources (El-Geneidy et al., 2011). However, some transportation agencies (especially smaller agencies with fewer vehicles) cite upfront costs of APCS technology as an impediment to utilizing automated technologies (Boyle, 2008). In addition, some studies suggest data collected from APCS can bias results on routes or at stops where ridership counts are significantly higher than others (Strathman and Hopper, 1991).

While APCS and manual data collection methods remain in use, both ignore key aspects about the commuter population. For example, where is a given rider going? Where are they coming from and how did they get to that access point? How has their experience been while using transit? One way to obtain answers to these questions is crowdsourcing data collection of riders' commutes. This process builds upon current practices that utilize public participation for informing transportation planning (Chaves et al., 2006; Badenhope, 2010). However, rather than bringing members of the public together to solicit their sentiments on transportation, crowdsourcing data collection obtains sentiments and behaviors experienced during a rider's commute.

Methods for crowdsourcing travel behavior data are slowly emerging, and have thus far taken advantage of existing social media applications. The microblogging application Twitter, for example, solicits posts from users stating their thoughts or experience at a given time and location. Specific sentiment-analysis software can be used for collecting those posts that relate to

travel behavior, and then analyzing the text to generalize riders' experience (Mai and Hranac, 2013). Another social media application, FourSquare, has been used to track movement of its users during their commute, thus providing information on where and when individuals are travelling at all times (Goers, 2013). While the data is free and abundant, there are several shortcomings with using social media for crowdsourcing travel behavior data. First, social media applications are typically only used by certain demographics of the population, which creates sampling bias (Morstatter et al., 2013). Second, data collection is considered to be unstructured because the data does not relate to any specific questions of interest to an agency. Also, collecting and analyzing social media-generated data is oftentimes beyond the scope of work that can be performed by agency employees (Evans-Cowley and Griffith, 2012).

An additional challenge of using social media as an industry standard of source data is the commuter's willingness to volunteer information on their location (Cottrill, 2014). Numerous researchers (see Goodchild (2007) and Elwood and Leszczynski (2011) for examples) have articulated the concerns of locational privacy with volunteered geographic information, with individuals balancing the tensions between wanting to utilize LBS technologies and concerns about maintaining their locational privacy. LBS capture and store geographic coordinates of users, infringing on their privacy (Harvey, 2013).

Rather than relying upon existing applications for providing data on travel behavior, mobile applications can be developed in a way to facilitate the crowdsourcing of data collection while not infringing on a commuter's privacy. Applications can be developed to collect data on the length of one's journey, how one travelled to a transportation stop (e.g. walking, biking), and the positive or negative aspects of the commute. Furthermore, riders can use smart phone applications to collect alternative data formats such as digital photos that document safety concerns and other potential problems. In summary, crowdsourcing travel behavior via targeted mobile applications can provide agencies with strategic data that will improve efficiency, infrastructure and safety. Crowdsourcing data collection has flourished in many areas (Goodchild, 2008); however, it remains in its infancy in the area of transportation. The objective of our research project is to address this gap and assist agencies in their potential to maintain sustainable transportation.

## **1.2 RESEARCH OBJECTIVE**

The overall objective of the research was to evaluate the effectiveness of LBS technologies to assist in collecting data that provide more information about transit riders than existing approaches. Specifically, we develop a mobile application that can be used for crowdsourcing travel behavior data in order to assist public transportation agencies in providing sustainable transportation while maintaining the privacy of its riders. Specifically, we develop and evaluate two different LBS technologies, Bluetooth Low Energy (BLE) and geofences, for their ability to capture the location of where transit riders enter and exit the network, how they arrived at the network, where they came from and where they are going, and any additional comments that riders wish to provide. Furthermore, the LBS technologies are designed to minimize the infringement upon individual rider's locational privacy.



## 2.0 METHODS

### 2.1 SETTING

The study was set in the Eugene-Springfield area of Lane County in western Oregon. Specifically, the study focused on Lane Transit Districts' (LTD) Emerald Express (EmX) line (Figure 2.1). The EmX is a bus rapid transit system that currently connects downtown Eugene with downtown Springfield and the Gateway Mall in Springfield. It has 27 stops. The EmX provides a useful test case for this system because it is a contained route with specified buses, which allows us to test the LBS technologies without having to concern ourselves with an entire bus fleet or an entire bus network.

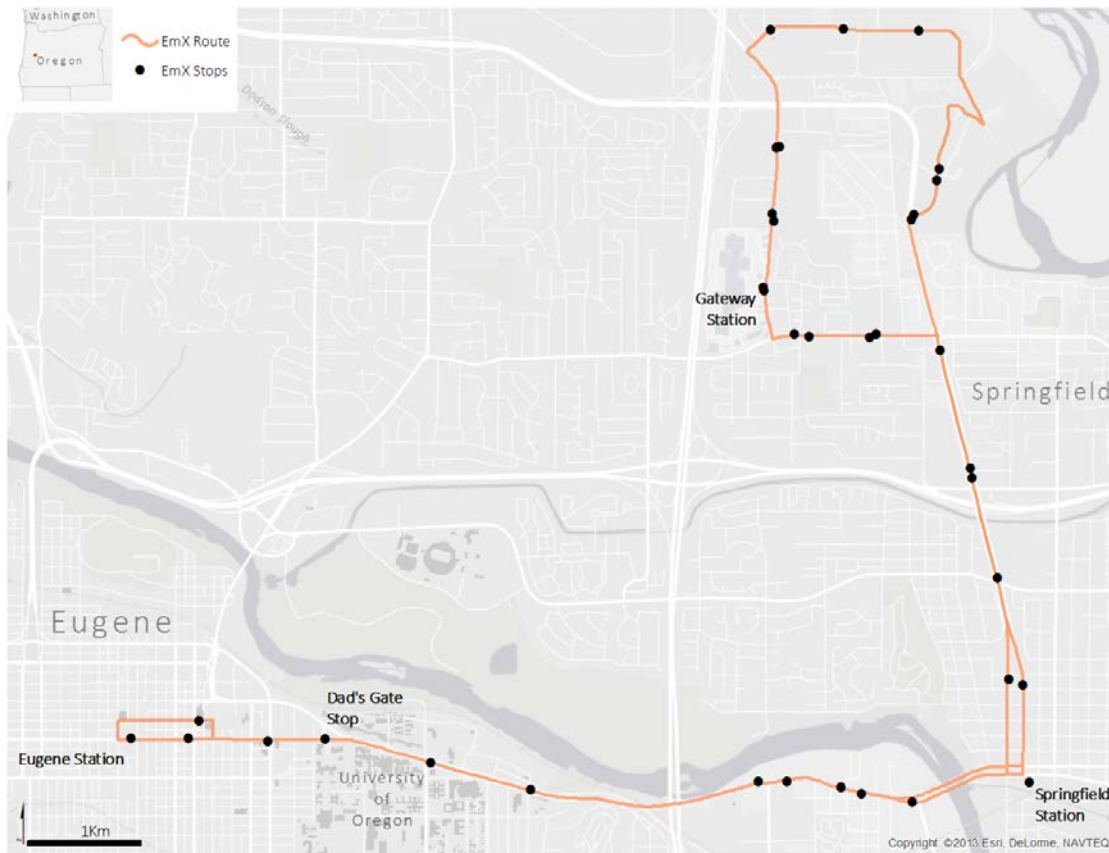


Figure 2.1. Map showing the EmX bus line and stops.



## 2.2 APPLICATION

A custom mobile application was designed to record location and survey data from the user. The general procedure enacted by the application is as follows: once the application realizes that the user is on or about to get onto the bus, it records the location of the user and asks the user to take a brief survey. The user completes the survey, and the data is recorded for that specific trip. The application then remains active, sensing whether or not the user is still on the bus. Once the user leaves the bus, the application asks the user for the confirmation. An exit location is recorded if the rider confirms that the trip has terminated. The survey questions from the application are shown in Appendix A. The application interface and survey are shown in Figure 2.2.

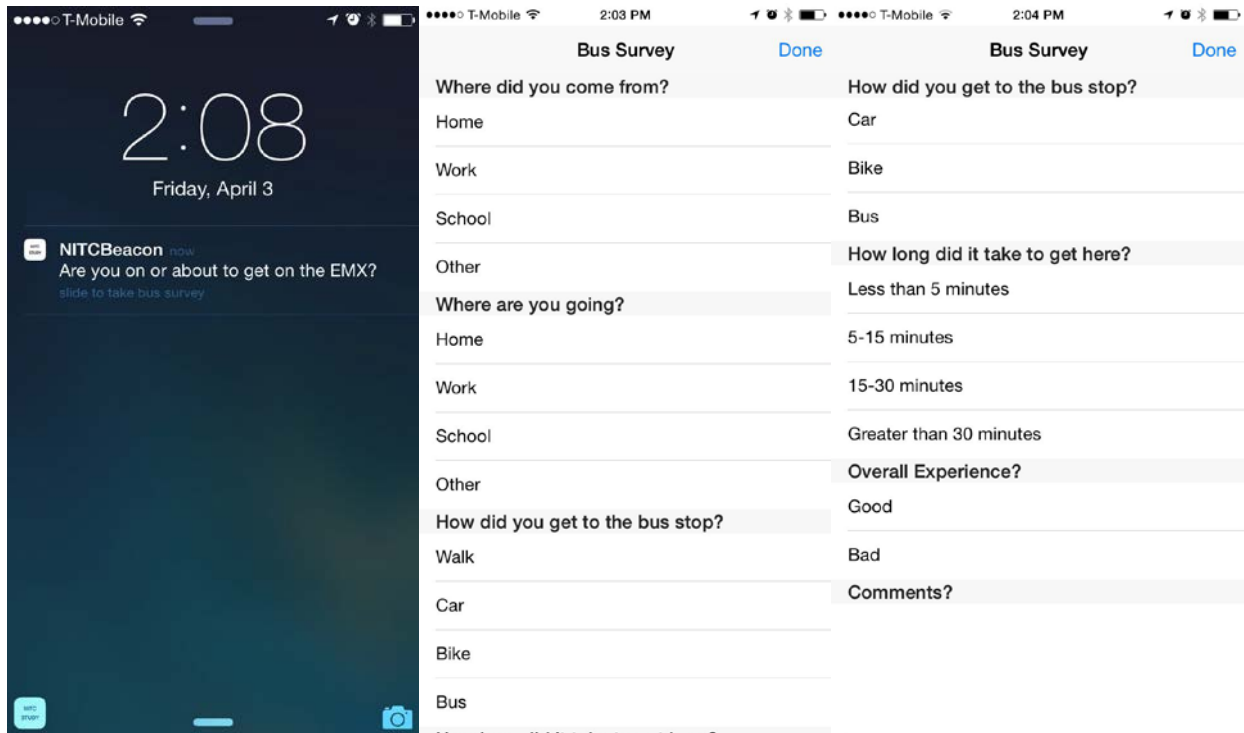


Figure 2.2. Screenshots showing the application interface.

The application was developed with minor differences when using the geofence versus the BLE, as shown in Figure 2.3. Geofences are regions that are designated in the program around set points in the landscape. In this case, the geofences were placed around the bus stops on the EmX line. When the user approaches the bus stop the application detects that it has entered the geofence based upon the phone's GPS location. Once the users are on the bus, they are passing through the geofences at each of the stops. The application counts down from five minutes every time the user leaves a geofence. If a user does not enter another geofence before the counter expires, the application asks the user if they have left the bus. If they have, the location is logged and the trip is recorded. If they reply that they are still on the bus, the counter recycles and begins counting down to five minutes again. If the counter recycles five times, the trip is logged as an error.

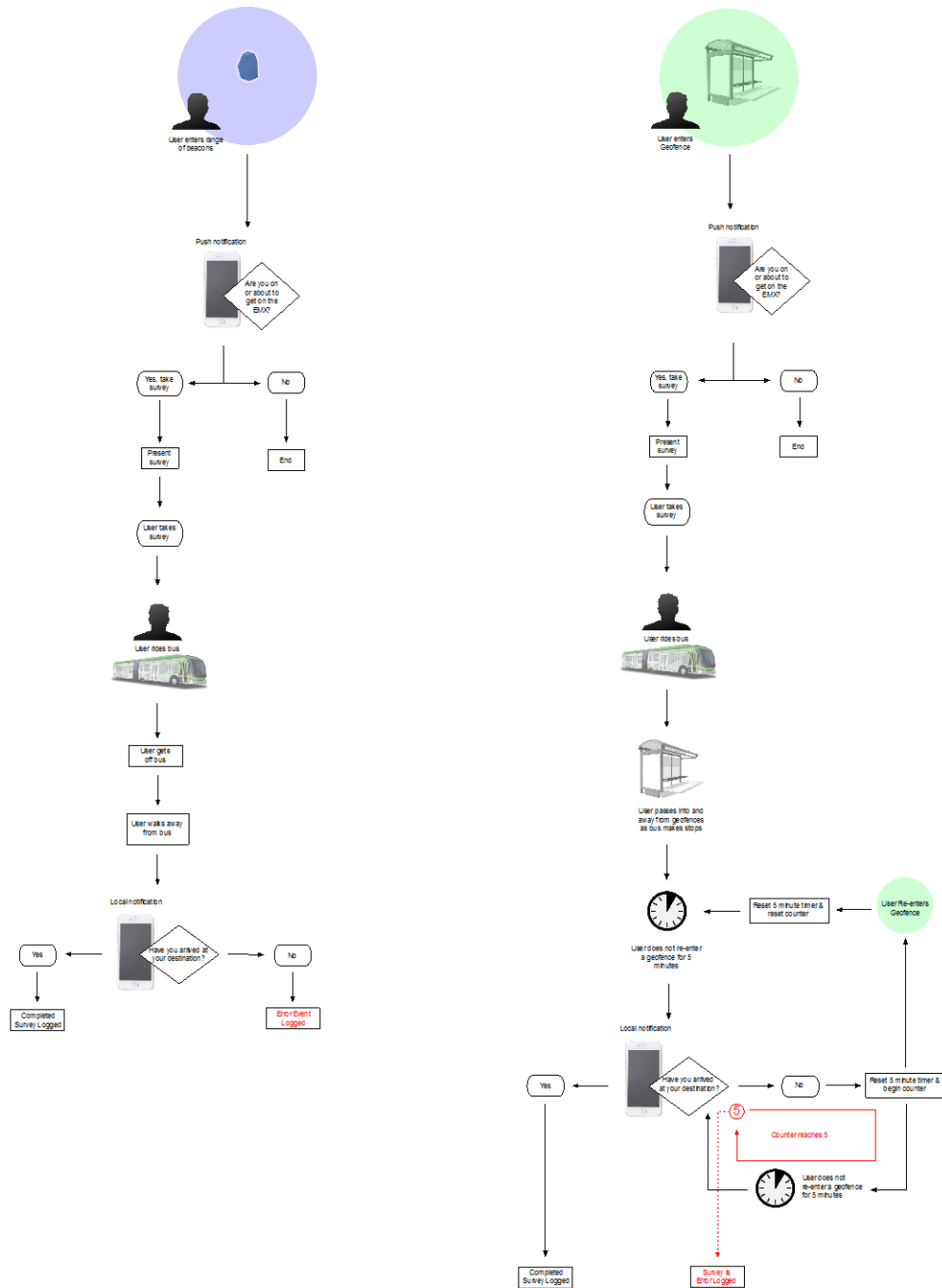


Figure 2.3. Workflow for both versions of the application.

The BLE beacons, shown in Figure 2.4, were purchased from Estimote, a company that specializes in producing Bluetooth beacons as well as developer tools. In cooperation with LTD, the beacons were placed on the buses in the electronics cabinet directly behind the driver. The beacons send out a constant signal. When running, the application on the mobile device constantly monitors, “listening” for the signal. Once the application detects the signal, the application knows to perform some action. In this case, once the application detected the signal from the beacon on the bus, the application sent the notification to the user asking them whether they were about to get onto the bus. Once the application stopped receiving the signal, the application assumed that the user had exited the bus and sent a notification to them.



Figure 2.4. Two of the Estimote Bluetooth beacons used in the study.

The application for both the geofence and BLE beacons was developed and tested for Apple iOS only in order to target a large segment of the University of Oregon student population, as our preliminary analysis revealed a widespread use of iPhones among students. The application operates on the newest version of iOS (8.1 at the time of the study), and only with iPhone 5 or newer phones because of the location services and Bluetooth requirements for the application.

### 2.3 STUDY IMPLEMENTATION

Our target population for the study included students and employees of the University of Oregon and LTD employees. Participants were recruited via email, which produced a participant group of 24 individuals.

The research team met with the participants at the beginning of the study period in order to install the application on their phones, and to explain the study requirements and how to utilize the application. At this time participants were randomly assigned a version of the application relying on either of the technologies. The research team met a second time with participants at the end of the study in order to download the data from the application, and to administer a post-study survey about the experience of using the application.

The study ran for a period of three weeks during February and March of 2015. During that time, participants used the application each time they traveled on the EmX line. The application recorded the survey and location data for each during that time period. At the end of the study, the research team met with the participants in order to download the data from their phones and to administer an anonymous post-study survey. The survey was used to gauge the participants' experience of using the application, as well as gather information on any problems with the application. The survey questions are listed in Appendix B.

### 3.0 FINDINGS

#### 3.1 UTILITY OF DATA COLLECTED BY THE APPLICATION

The data collected by the developed application demonstrates the utility of LBS technologies for transit data collection. The data provides insights about both the number of commuters who are entering and exiting the transit network at each stop as well as the time and mode of transport commuters are using. The results shown in Figure 3.1 demonstrate that most commuters walk short distance to arrive at stops, while most commuters utilizing other modes travel longer distances to arrive at stops. The results in Figure 3.2 show that most of the study participants were traveling to and from school, which is unsurprising given our study population. Though an intuitive finding, such as data about different categories of commuters, can provide useful information to transit agencies for determining how best to provide resources. Similarly, agencies can better understand the proportion of commuters who are using transit to commute to work, school or home.

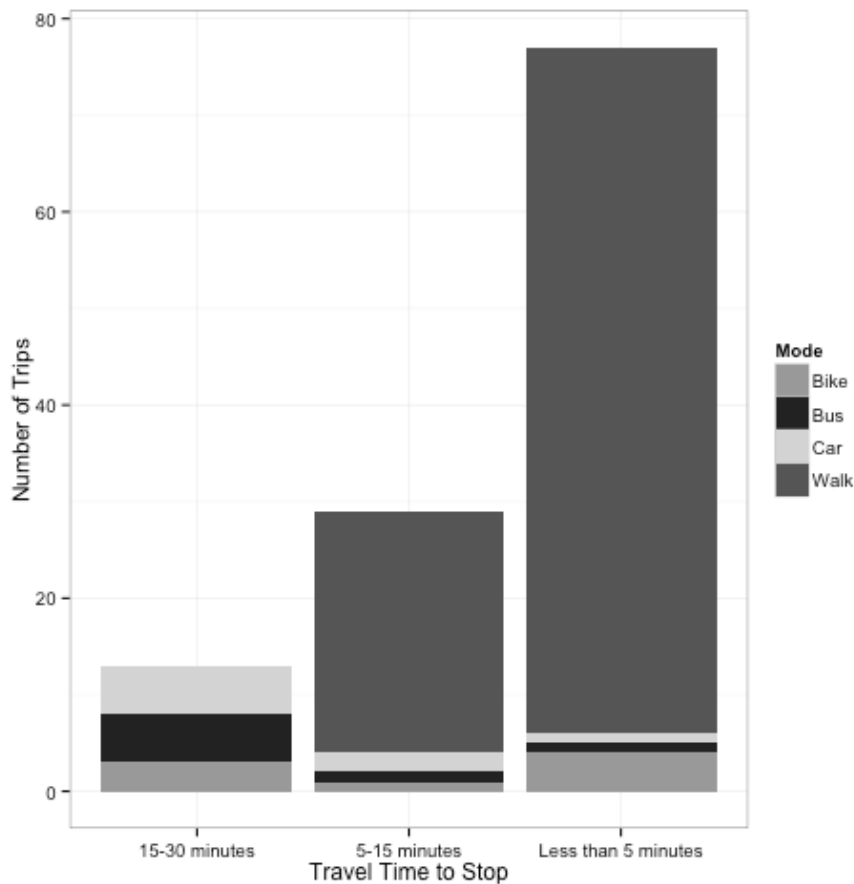


Figure 3.1. Travel times to stops organized by mode of travel to the stop.

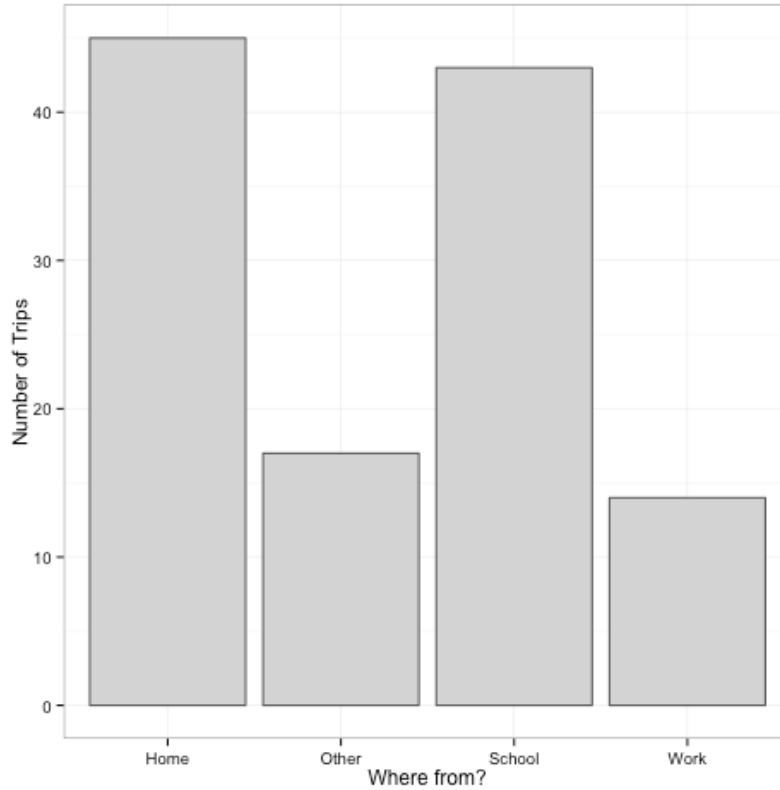


Figure 3.2. The place of transit rider departure before entering transit network.

LBS technologies can also provide rich data about the commuter population of each individual stop. For example, it can provide insights on transit modes and average commuting time for each stop, such as shown in Figure 3.3. Such data can guide the addition of infrastructure for safe access for pedestrians or the deployment of more bike racks onboard buses based upon the individual commuting patterns for each stop. Additionally, agencies can determine what areas would benefit most from the addition of new stops.

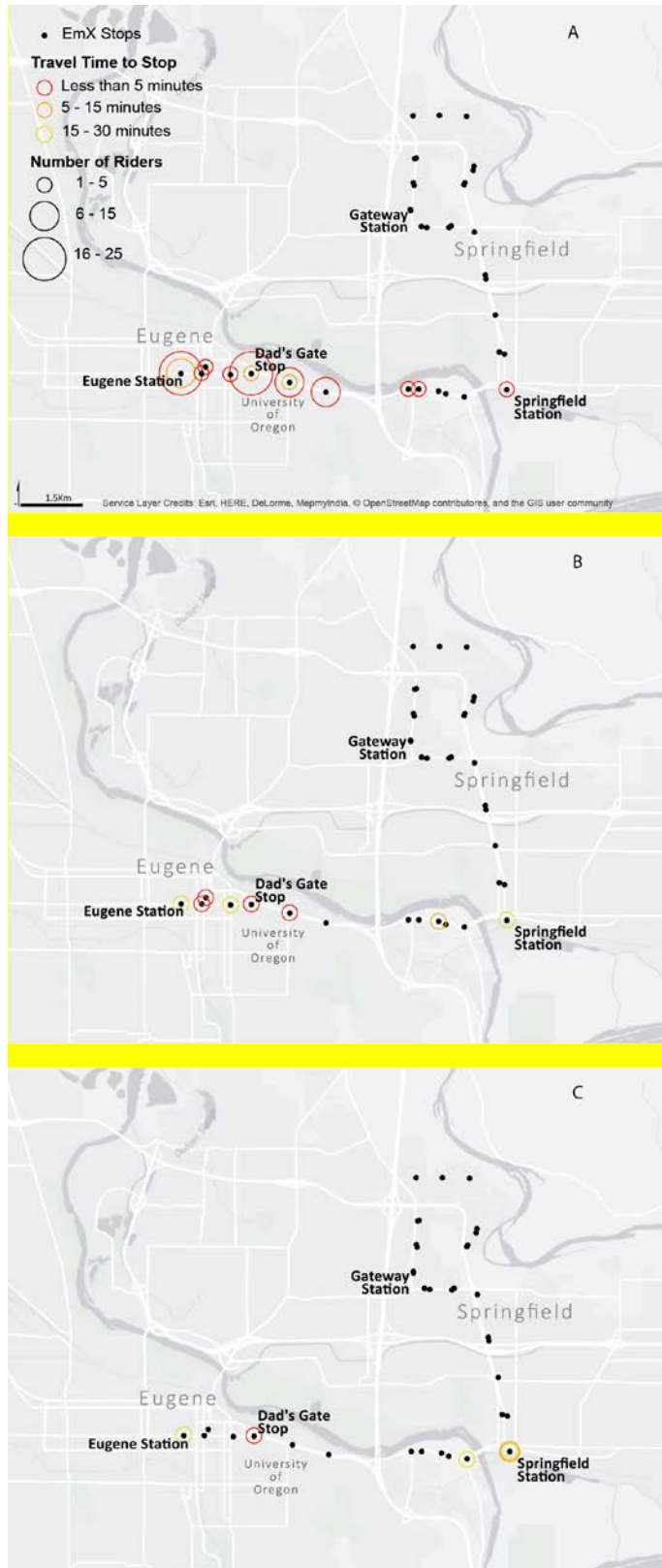


Figure 3.3: Average commuting time for participants walking to each bus stop.

## 3.2 ERROR COMPARISON BETWEEN THE TWO TECHNOLOGIES

During the three-week study period, 119 trips were recorded. The distribution of trips recorded by the two technologies is relatively equal, with 57 trips (47.9%) being recorded using the beacon application and 62 trips (52.1%) being recorded with the geofence application. The beacon application logged errors during 15 trips (26.3% of the beacon trips), which represents trips during which the application did not accurately capture when commuters exited a transit vehicle. However, none of the trips logged by the geofence application recorded errors. In order to understand possible reasons for why the beacon application produced errors while the geofence application did not, we examined the recorded trips and errors in the context of trip duration, trip time of day, and location in the bus network.

Figure 8 shows all trips organized by trip duration for trips from the geofence application and for the beacon application with and without error. The duration of the two longest beacon error trips exceeded the maximum trip time on the EmX line, which was likely caused by the application not properly recognizing when the commuter exited the vehicle. The remaining errors were recorded for trips that were less than 10 minutes. These errors were most likely the result of the beacon losing connection with the mobile application while the trip was still active. Therefore, it appears that signal interruptions between the application and the beacons were the cause of the errors recorded by the beacon application. While the geofence application recorded no errors among the trips collected during the study, two trips exceeded the maximum trip duration on the EmX. This suggests the possibility that commuters responded to the notification and confirmed their trip had terminated, but that they were not prompted to do so until long after they had exited the transit vehicle. This also helps to explain why geofence trips were recorded to be longer than the beacon trips, as the geofence application involves a more substantial time lag between when the commuter exits the vehicle and when they are prompted to confirm that they have indeed exited the vehicle.



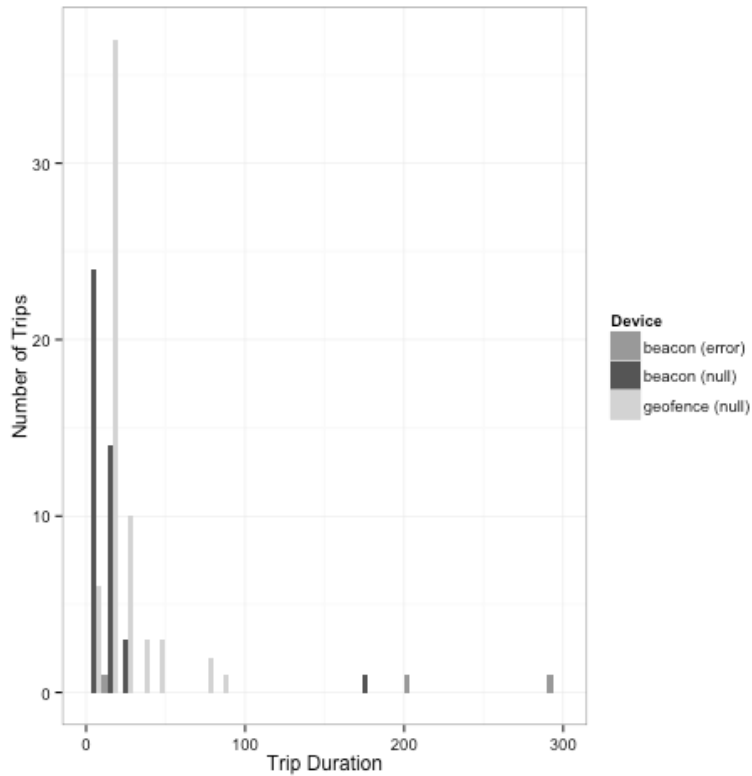


Figure 3.4. The duration of trips recorded during the study, organized by application.

The time of day does not appear to affect whether or not the beacon application would log an error, as errors were distributed throughout the day in a similar fashion to the beacon trips without errors as well as the trips recorded by the geofence application (Figure 3.5). This is an important finding, as it demonstrates that the connection problems are not sensitive to daily fluctuations in riders within the buses. One would expect to see clustering around peak commuting times if the errors were correlated to fuller buses, which is not what is seen in the data. Additionally, errors appear to be spatially random, not occurring in any clusters in the network (Figure 3.6).

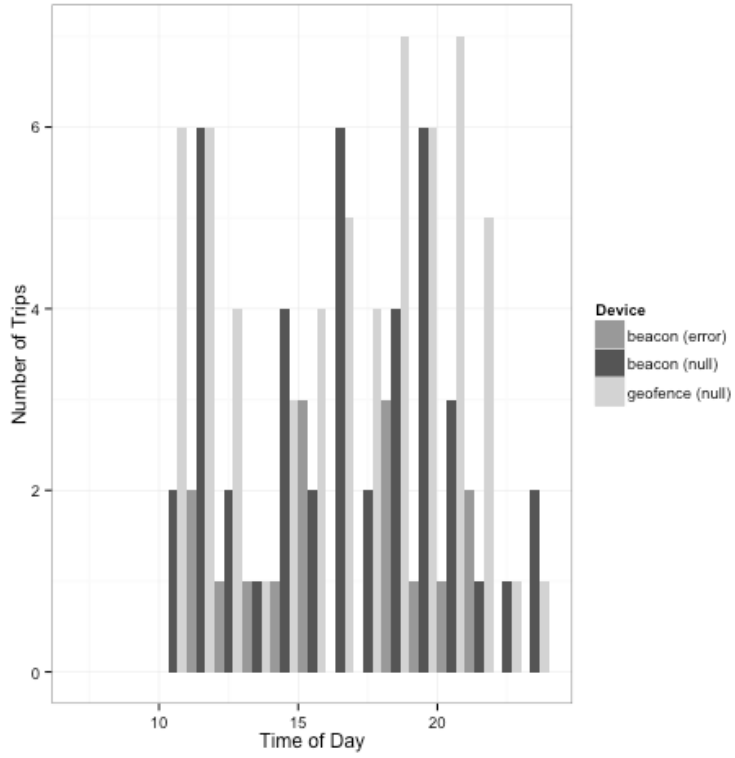


Figure 3.5. Distribution of errors and trips throughout the day.

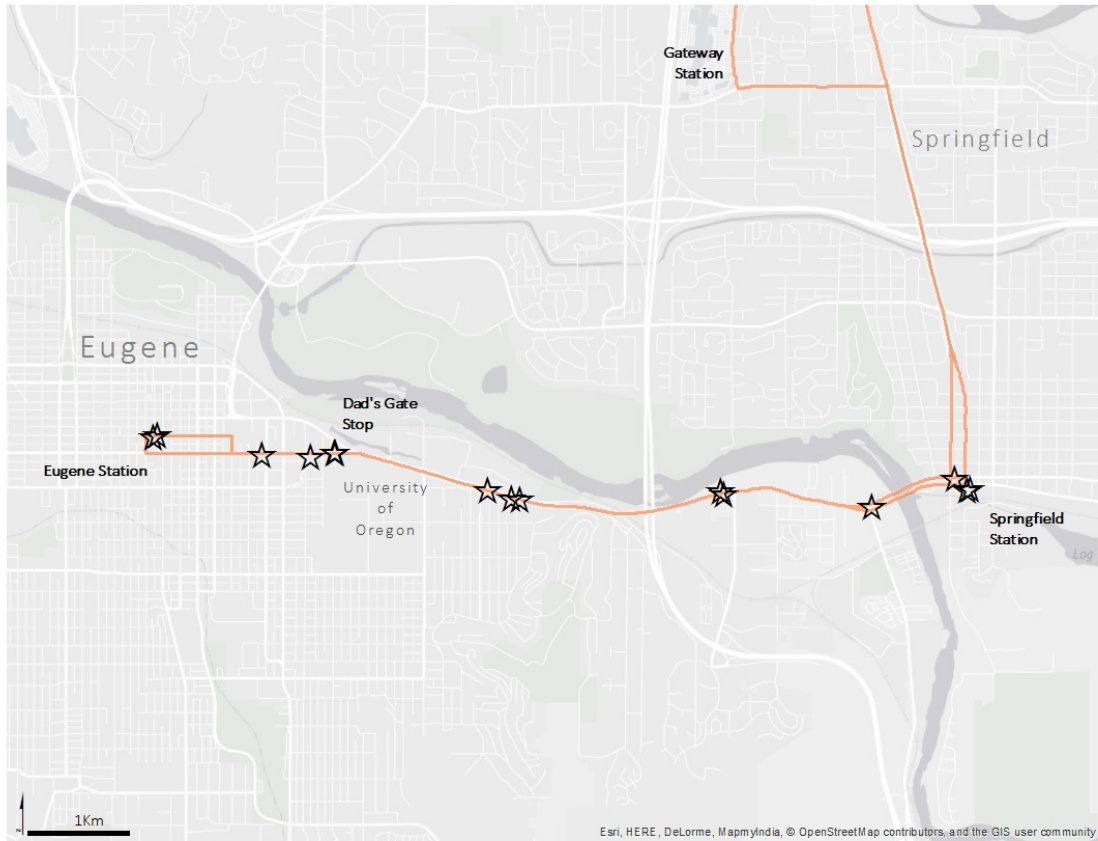


Figure 3.6. Location of errors generated by the BLE beacon application.

### 3.3 USER EXPERIENCE

The post-study survey asked participants to respond to nine questions related to their experience with using the application, including which version of the application they were using in order to assess how the participants' experiences varied between the two (see Appendix B for a full list of the survey questions).

The answers to the survey questions revealed that differences exist between the ease-of-use of the application between the two versions. Almost half of the beacon users rated the application as very easy to use as opposed to only two geofence users giving a similar rating. However, participants from neither group rated the applications as difficult to use.

Participants were asked about when the survey appeared on their phones when entering the bus. This allowed us to evaluate if one of the applications pushed the survey earlier than the other. For the most part, beacon application users stated that the survey appeared either immediately upon entering the bus (as would be expected with this application) or only after they had been on the bus for a significant amount of time. One beacon participant stated that the survey appeared as they approached the bus stop, a surprising occurrence as the user's mobile device must be in

proximity to the beacons, which are located on the buses. Most likely the application detected the signal from the beacon from outside the bus or located on a passing bus (one participant commented that he or she observed that the survey was triggered by a passing bus on one occasion). Most of the geofence participants stated that the survey prompt appeared as they approached the bus stop, which is what would be expected for the geofence application. However, several of the geofence participants stated that the survey only appeared after they had been on the bus for a significant amount of time. This is most likely because the participants did not dwell in the geofence region when they boarded the bus long enough to trigger the notification.

The survey inquired as to how often the survey prompt appeared when riding the bus. Most beacon participants answered that the survey either always appeared or appeared most of the time during their trip. A greater variability of responses is observed from the geofence participants' surveys; only three stated that the survey always appeared, and some stated that the survey appeared only some or a few of the times. When asked about how often the survey prompts appeared when not using transit, most participants reported that it rarely or never occurred. One participant from each group did state that the notifications did appear while not riding the bus. This is not surprising as the application could be triggered if a participant passed through a geofence or a bus passed close enough to the participant for the application to trigger the survey.

Finally, participants were polled about the effect of the applications on their mobile devices' battery usage. Most of the participants (95%) stated that there was no difference, or only slightly faster battery drain.

The post-study survey allowed participants to provide further comments about their experience. Among the beacon users, critiques were limited to the survey appearing when buses passed in the other direction or that position on the bus potentially affected signal strength. For example, one participant felt that signal strength was weaker towards the rear of the bus. The geofence participants provided more critiques, with most focusing on how inconsistently the survey notifications were appearing on their devices. These critiques allude to the possibility that the geofence application had difficulty with determining when the user entered the bus.



## 4.0 CONCLUSION

### 4.1 KEY FINDINGS

The objective of this study was to evaluate how different LBS technologies can be utilized to collect volunteered data from transit commuters. BLE beacons were selected as one of these technologies because they provide an example of how physical sensors can be placed in the environment and used to connect citizens to specific places based upon proximity. Geofencing was selected as the second technology, as it represents an approach where devices need not be placed in the environment; rather, geofences simply operate by alerting the mobile application when its coordinates overlap with the digital perimeter of the geofence. Both of these technologies are capable of capturing individuals entering and exiting public transit, useful for collecting location data. Both technologies are also useful for preserving the locational privacy of the users, as neither technology collects unnecessary location data before or after the user rides public transit. However, this useful feature represents a tradeoff: agencies sacrifice data precision in order to protect users' privacy, and they will have to decide what type of data they need to collect.

While both technologies can be used to collect similar variables, the accuracy of these technologies differs depending on what type of data is being collected. Though the beacon application produces errors when recording the exiting from transit vehicles, it provides a more accurate record as it detects when the user has moved outside the range of the beacon. However, the geofence application only knows that a user has left the vehicle if that user does not pass through another geofence on the bus route. Though post-processing of the data can ensure that the trips terminations are attributed to the correct stops, other challenges exist with the geofence application. A commuter could exit the bus and still pass through another geofence along the bus route, which would confuse the application and cause it to assume the commuter is still on the bus. Also, severe traffic delays could cause the application to assume that the commuter has left the bus, as the bus may not pass through a geofence for a longer period of time than expected. This will cause the application to repeatedly push notifications to the user asking them to confirm if they are still on the bus, and eventually the application will assume that the user has left the vehicle. Therefore, the geofence approach may be more effective in simple transit networks where stops are not densely located and traffic delays are less common. Bus rapid transit systems (such as the EmX used in this study) with allocated lanes are a good example.

BLE beacons may be more appropriate for busier networks, given that the application does not detect beacons from passing buses. For this study, we deployed a single beacon with a longer broadcasting range in order to cover the entire bus. This led to some participants' devices detecting beacons from passing buses. One way to address this would be to program a two-stage connection, where the device must pass close to the beacon in order to connect (e.g., one meter) signaling entry on the bus, but allow the connection to be maintained over longer broadcasting distance (e.g., 15 meters) and only recording an exit once the device has left that larger area.

Regardless, BLE beacons will still be challenged to operate effectively in areas with a high density of people or objects on a vehicle. Though our analysis did not reveal that errors were more likely during higher traffic times, we were not able to determine where a device was located on the bus when an error was logged, and the results from the post-study survey showed that at least one participant experienced connection problems when located in the rear of the vehicle – farthest from the beacon. One possible solution would be to increase the number of beacons in the vehicles or to place the beacon at a more central location in the vehicle. However, this would make our two-stage approach untenable. Regardless, BLE beacon-based applications will have to contend with interference with the signal, either from physical barriers and other devices, but these interferences could be reduced through further testing and experimentation.

## **4.2 FUTURE WORK**

Results from this study demonstrate the promise of BLE and geofence technologies for enabling the crowdsourcing of data from commuters, as well as the potential challenges for creating such a system. The approach taken in this study was to devise a relatively simple test, using a single route and two basic applications in order to test the effectiveness of these LBS technologies for collecting transit behavior data. Obviously, more work is required to refine the use of these technologies for use in transit systems. A worthwhile pursuit moving forward would be to survey transit riders from demographic groups and in different cities in order to determine how likely they are to use crowdsourced data collection applications. An additional need in this research field is identifying and developing data analytics that could be utilized for the types of data collected by our LBS approach, both for characterizing the overall commuting population as well as reducing errors and sources of uncertainty introduced by these technologies.

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## APPENDIX A

### APPLICATION SURVEY QUESTIONS

**1. Are you on or about ride the Bus?**

**2. Where did you come from? (*select one of the following*):**

- Home
- Work
- School
- Other

**3. Where are you going? (*select one of the following*):**

- Home
- Work
- School
- Other

**4. How did you get to the bus stop? (*select one of the following*):**

- Walk
- Drive
- Bike
- Bus Connection

**5. How long did it take you to get to the bus stop? (*select one of the following*):**

- Less than 5 minutes
- 5-15 minutes
- 15-30 minutes
- Greater than 30 minutes

**6. Overall Experience? (*select one of the following*):**

- Good
- Bad

**7. Comments?**

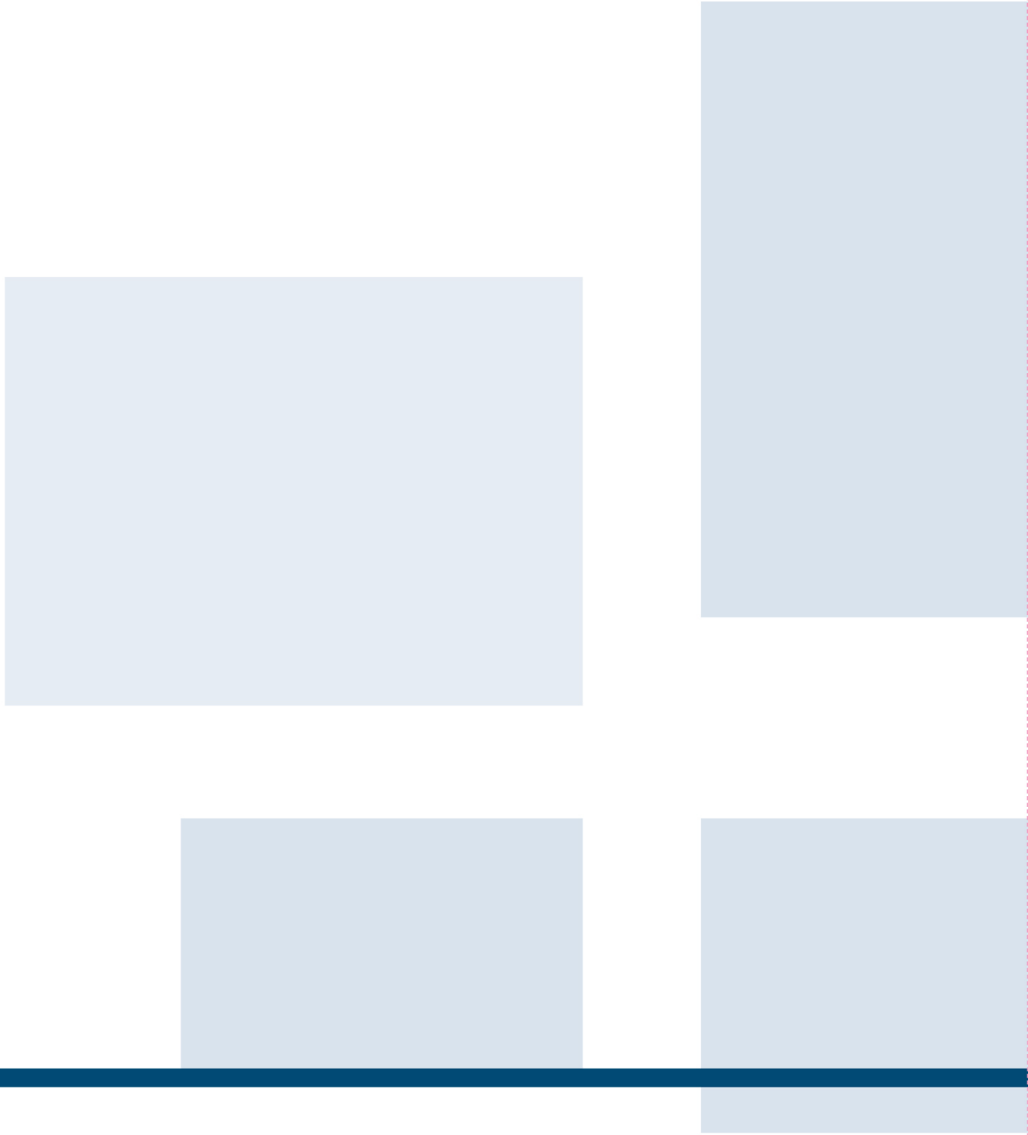


## APPENDIX B

### POST-STUDY SURVEY QUESTIONS

- 1. Which Version of the Application were you using?**
  - Beacons
  - Geofences
  
- 2. What type of phone do you have?**
  - iPhone 4S
  - iPhone 5
  - iPhone 5C
  - iPhone 5S
  - iPhone 6
  - iPhone 6 Plus
  
- 3. Overall, How did you find the use of the application?**
  - Very easy to use
  - Moderately easy to use
  - Slightly difficult to use
  - Moderately difficult to use
  - Very difficult to use
  
- 4. Overall, how clear were the survey questions?**
  - Very Clear
  - Somewhat Clear
  - Mixed
  - Somewhat Unclear
  - Very Unclear and Confusing
  
- 5. How did the application affect your phones' battery usage?**
  - The battery drained slower than normal
  - No noticeable impact on battery performance
  - Slightly faster battery drain compared to normal
  - Moderately faster battery drain compared to normal
  - Significantly faster battery drain compared to normal
  
- 6. How convenient was the application?**
  - Very convenient
  - Convenient
  - No Opinion
  - Inconvenient
  - Very Inconvenient

- 7. On Average, when did the survey appear on your phone?**
- Immediately while walking up to the bus stop
  - While I was waiting for the bus at the stop
  - Immediately upon the bus
  - Only after I had been on the bus for a significant amount of time
  - Only after I got off of the bus
  - It never popped up at all
- 8. How often did the survey prompt pop up when you were riding the EMX?**
- Always
  - Most of the times
  - Some of the times
  - Few of the times
  - Never
- 9. How frequently did the survey prompt pop up when you were NOT riding the EMX or about to ride the EMX?**
- Never
  - Rarely
  - Occasionally
  - Somewhat often
  - Very Often



Transportation Research and Education Center  
Portland State University  
1900 S.W. Fourth Ave., Suite 175  
Portland, OR 97201