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# A comparative health and safety analysis of electric-assist and regular bicycles in an on-campus bicycle sharing system.

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I am submitting herewith a dissertation written by Brian Casey Langford entitled "A comparative health and safety analysis of electric-assist and regular bicycles in an on-campus bicycle sharing system.." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Civil Engineering.

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# A COMPARATIVE HEALTH AND SAFETY ANALYSIS OF ELECTRIC-ASSIST AND REGULAR BICYCLES IN AN ON-CAMPUS BICYCLE SHARING SYSTEM.

A Dissertation Presented for the

Doctor of Philosophy

Degree

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# ABSTRACT

E-bikes have emerged in recent years as a valid mode of transportation. Comparable to regular bicycles in many ways, e-bikes offer some added advantages due to the additional electric motor on the bicycle. This dissertation combines three different research efforts centered on the study of e-bikes and their inclusion in e-bike sharing systems. First, it looks at a model for e-bike sharing at the University of Tennessee and examines system operations, performance, and demand from users. It investigates the characteristics of trips using the sharing system's fleet of regular and electric bicycles, and it describes the preferences among system users that influence their mode choice. Second, this dissertation presents a study on user safety, investigating user behaviors of those who use the regular bicycles and e-bikes that are a part of the e-bike sharing system. GIS analysis is incorporated to study user movements on roadways, shared-use facilities, and at intersections. Comparisons are made between bicycle types and facility types with regard to safety. Lastly, this dissertation presents a study on physical health implications for users of regular bicycles and e-bikes and compares those impacts to walking trips. It also presents a methodology for extending this study to naturalistic data collected through the on-campus e-bike sharing system.

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# CHAPTER 1: INTRODUCTION

Electric bicycles (e-bikes) have begun to emerge as a new transportation option in recent years and have some advantages over regular bicycles in that they reduce the effort required by the rider, thereby promoting greater travel distances. The e-bikes considered in this study offer this advantage through an electric motor, which provides some level of assistance to the user based on the amount of effort provided by the user. Both modes require some level of effort on the part of the user, providing some benefit in terms of physical activity, and both modes operate very similarly with differences in performance.

At the same time, another relatively new transportation option, bicycle sharing, has taken a foothold in many places. Bicycle sharing systems offer a healthy, sustainable, alternative transportation choice, particularly for short trips. Furthermore, the initiation of such systems has shown to promote a modal shift, particularly from passive transportation modes [1, 2].

The unique combination of bicycle sharing with e-bikes in North America's first electric bicycle sharing system provides the opportunity to analyze the effect of both electric and regular bicycles on user health in a holistic manner with emphasis on implications to user safety, physical health, and exposure to air pollution. Additionally, it gives an opportunity to understand the impact of the system as a whole on the surrounding community, in this case students, faculty, and staff at the University of Tennessee.

This dissertation focuses on three research efforts investigating e-bikes and e-bike sharing and their impacts to users. The focus of this dissertation is to address the following question: As compared with regular bicycles, do e-bikes promote greater physical health for users, and do they promote unsafe behaviors among those who use them? Understanding e-bikes and the role they play in the transportation network is an increasing priority. The works in this dissertation aim to clarify the impacts of e-bikes with regard to physical health and safety and to aide future work in this area by identifying areas of need in e-bike and e-bike sharing research.

# CHAPTER 2: CHARACTERIZING TRIPS AND USERS OF THE ON-CAMPUS ELECTRIC BICYCLE SHARING SYSTEM

This chapter presents a modified version of a research paper by Brian Casey Langford, Christopher Cherry, Taekwan Yoon, Stacey Worley, and David Smith titled 'North America's first e-bike share: A year of experience' [3]. The paper was accepted for publication by the Transportation Research Record: Journal of the Transportation Research Board in 2013. The paper was also presented in a presentation session at The 92nd Annual Meeting of the Transportation Research Board in Washington, D.C., in January 2013 [4].

## ABSTRACT

The integration of electric bicycles (e-bikes) with bikesharing can potentially increase the utility of bike sharing by reducing some barriers to bicycling and increasing the amount of prospective users. North America's first e-bike sharing system (cycleUshare) at the University of Tennessee, Knoxville, offers a new, sustainable transportation option for students, faculty, and staff. The cycleUshare system is a small pilot test with two stations to research the technology and user experiences. This paper presents an overview of the cycleUshare system and reports experiences from the first year of operation. With 93 enrolled users, cycleUshare provides a unique opportunity to study not only the system use, but also how individual users make trips with both regular and electric bicycles and the factors that influence those trips. The study finds that only 22% of users account for 81% of the trips. Factors of speed and convenience play major roles in participant's decisions to use the system, and speed and comfort are the most influential factors in selection of an e-bike over a regular bicycle. Most of the reported trips are class related, although e-bikes are found to be used for a wide variety of trip purposes. Walking is the mode most displaced by the system indicating that e-bike sharing expands user mobility. Additionally

user perceptions about bicycle types are explored. This model of electric bikeshare is found to be effective at attracting users to both regular and electric bicycles and is capable of expanding user mobility. This chapter is published in TRR as North America's first e-bike share: A year of experience.

## 2.1 INTRODUCTION

In recent years, bikesharing systems have emerged around the world to offer users an innovative new mode of transportation for short trips [2, 5, 6]. Bikesharing systems have started in cities in the United States as well [1, 7, 8]. These systems offer their users shared use of a bicycle fleet and access to that fleet at multiple locations, bringing the benefits of active transportation and increased accessibility for users in urban locations. Bikesharing and non-motorized transportation also has potential benefits in terms of improvements to traffic congestion, air quality, and injuries or fatalities due to traffic crashes due to increased modal share [9, 10]. Still, some may not be drawn to bikesharing for a number of reasons including trip distances, terrain, or weather conditions [11].

Another emerging technology that may present an alternative for those individuals not inclined to participate in typical bikesharing programs is the electric bicycle, or e-bike. E-bikes have risen in popularity, primarily in China, but are slowly gaining attention in the United States and in other locations as well [12-14]. Pedal-assist e-bikes operate similarly to regular bicycles but with the addition of a small electric motor that delivers additional power to supplement that provided by the user. This assistance increases range and reduces some barriers, making them more attractive to the casual rider. In some cases e-bikes can replace bus or car trips [14-16]. Also, because pedal-assist e-bikes still require the user to supply power, they can provide similar benefits as regular bicycles [17]. Rose [16] discusses the impacts e-bikes use with regard to mobility, the environment, and health and safety and identifies the need for future research in these areas.

This paper presents early experiences from cycleUshare, an e-bike sharing system on the campus of the University of Tennessee-Knoxville (UTK) that combines bikesharing with e-bike technology. It discusses the electric bikeshare system, its operation and components, and experiences in operating and managing the system within the campus setting. This paper also gives some insights on the users and their trip characteristics during the first year of operation. Lastly, the next steps for the e-bike sharing project, and e-bike sharing in general, are described.

### 2.2 E-BIKE SHARING AT UTK

In August 2011, North America's first electric bikeshare program, cycleUshare, launched on the campus of the UTK as a pilot project [18]. Currently, there are two stations with a capacity of 20 bikes (a mix of e-bikes and regular bicycles). The project merges bikesharing and e-bikes to provide users on campus with a sustainable, alternative mode of transportation suitable for many trips around and near campus. This combination of technologies can improve the depth of penetration of bikeshare systems to a new class of users by overcoming some barriers to traditional bicycling. In the case of UTK, e-bike sharing is particularly attractive because of the hilly terrain, a long distance between campus destinations, the large number of students using cars and buses to travel between campuses, and the relative shortage of parking. The project is open to all students, faculty, and staff of UTK, and registration is free, though enrollment is capped to not overload the system [19].

The project provides a unique opportunity to study how bicycles and e-bikes are used within the campus bikeshare system. Of the many research goals associated with the project, one is to study the technical and operational feasibility of the system and evaluate its role as a transportation alternative. Data for this research is drawn primarily from three sources. The first is the transaction log recorded by the system for each transaction that occurs including bicycle check-out, bicycle check-in, and errors. The transaction log provides a detailed description of each transaction type with the time, date, user identification, bicycle type and number, battery if vended, and error type if one occurred. The second data source is GPS data collected from bikes equipped with GPS equipment that collected data from all trips on equipped bikes. These data allow researchers to investigate specific trip routes, speeds, and terrain. The GPS data are supplemented with a third data source, a survey of current cycleUshare users. All existing users of the system were contacted between May 2012 and July 2012 to participate in a survey about their travel behavior and perceptions while using cycleUshare bicycles or e-bikes. Questions related to user travel behaviors were based on GPS data collected from the individual users' trips. Up to five trips were investigated in-detail for each user. 22 users participated in the surveys, representing 24% of the total population of current users. The survey participants were regular users, accounting for 57% of all trips made with the system's bicycles. Survey respondents are 59% male and 82% of them are current students.

## 2.3 UNIQUE CHALLENGES

The incorporation of e-bikes into a bikeshare system introduces some unique challenges not experienced with the sharing of regular bicycles only. E-bikes are hybrid vehicles, utilizing both user supplied power and power supplied from the onboard motor. The e-bike motor operates using energy from a rechargeable battery. This means not only securing and managing the bicycles in the system, as is done with typical bikeshare systems, but also providing a means for charging and distributing the e-bike batteries. Bikeshare stations that include or accommodate e-bikes must allow for the charging of batteries either onboard the e-bike or through a battery dispensing system that charges, secures, and maintains an entire bank of batteries.

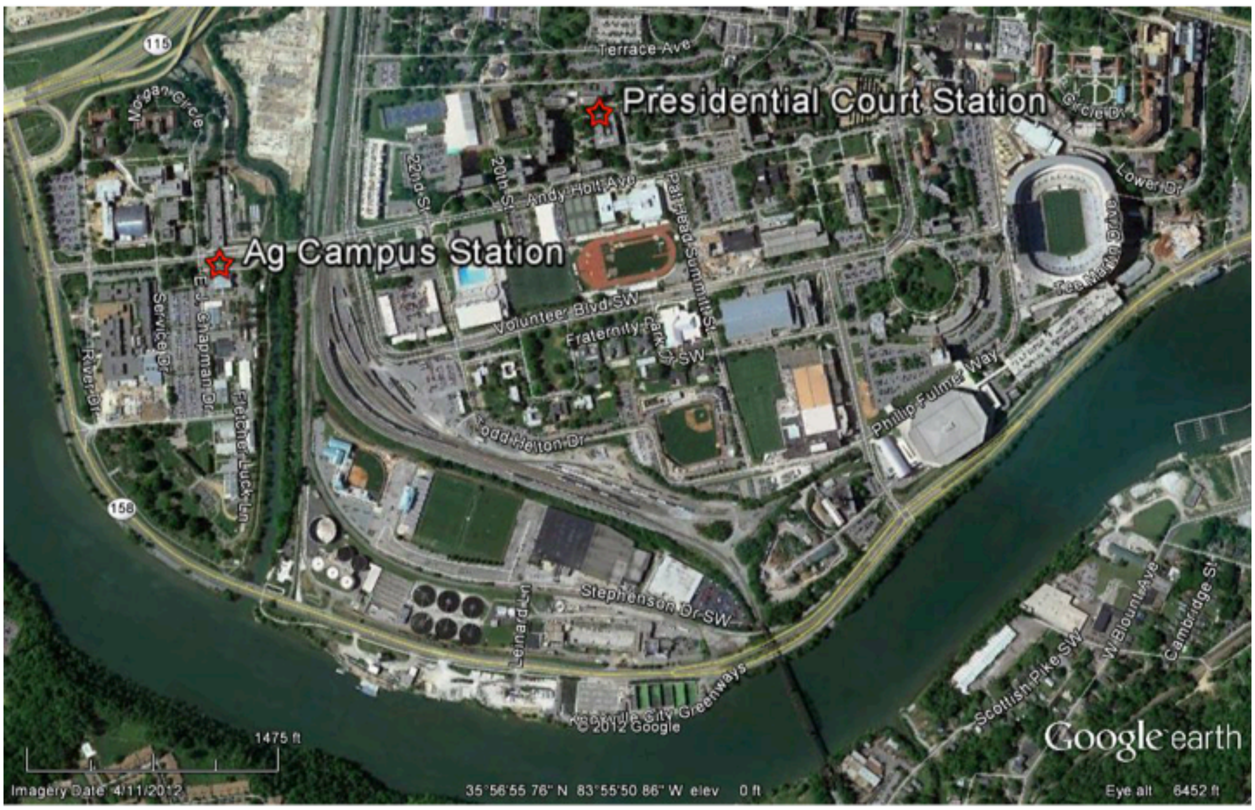
Another complicating factor at cycleUshare is that the system provides users access to both e-bikes and regular bicycles at the same station. Bicycle types are tracked by respective locations on the bicycle rack. These locations are updated automatically upon check-out and check-in. Failure to successfully track the bicycle type by location at the rack can result in the incorrect vending of bicycles to users and can create errors within the system software.

## 2.4 SYSTEM DESIGN

The typical components of the e-bike sharing system are the bicycles or e-bikes, a vending and charging station, and a back-office support system. Figure 1 (a) displays the configuration of these components at one of the e-bike sharing stations. The e-bike station, itself, serves multiple purposes. Similar to other non-electric bike sharing stations, the e-bike station provides security for the bikes not in use and access to the bikes at the station through a vending process. Unlike the non-electric bike sharing systems, the e-bike station is tasked with differentiating bicycle types, regular bicycle and e-bike, at both bike check-out and check-in. This difference is also important as the e-bike station also vends a battery for users selecting an e-bike. When users select an e-bike, they are also vended a charged battery through an automated process. The kiosk software tracks the transaction and logs the specific e-bike and battery vended to the user. This is also recorded upon check-in for the e-bike.


(a) Typical e-bike station components.

(b) Solar powered e-bike sharing station at UT's Ag Campus.




(c) E-bike sharing station locations at UTK.

**Figure 1: E-bike Sharing Station Components and Locations, parts (a), (b), and (c).**

The e-bike sharing system at UTK currently consists of two stations, each with a kiosk and user interface. The station is operated through a touch-screen and user-identification is achieved through scanning the University's magnetic student/staff identification card. Each station has the capacity for ten bicycles but can be expanded. The typical bicycle fleet at each station is seven e-bikes and three regular bicycles, although this ratio varies due to bicycle and station maintenance. The locations of the current e-bike sharing stations are depicted in Figure 1 (c).

The first station is located at Presidential Court, central to the University's main campus and provides access to student residence halls. This station was opened to users in August 2011 and has accounted for 91% of all trips to date. The Presidential Court station allows for the charging and dispensing of 12 batteries through grid-tied power. This station is available to users 24 hours each day.

The other e-bike sharing station is located on the University's Agricultural (Ag) Campus, depicted in Figure 1 (b). This station opened to users in April 2012 (near the end of the academic year). While still providing access to students, this station's location provides improved access to e-bike sharing for faculty members and other professionals on campus in addition to access from a large surface parking lot. This station is also placed adjacent to Knoxville's busiest greenway. The Ag Campus station has the capacity to charge and dispense 15 batteries. It operates completely on solar power, provided by photovoltaic panels (~1kW array) installed on the rooftop of the station itself. To manage power demand, this station is only available to users from 6:00AM to 10:00PM. All other aspects of the Ag Campus station are the same as those of the Presidential Court station.

The current station configuration does not allow for bicycles to be exchanged between the stations, while most bikeshare systems allow this. Only round trips returning to the station of origin are allowed, potentially limiting the number and type of trips. Future generations of the e-bike sharing stations and software are expected to allow for one-way trips. Users are instructed to adhere to a 4-hour time limit for checkouts (though there is no penalty for keeping it longer for this pilot test). To allow for safe parking of bikes away from the station, a lock is attached to each bike, and users are provided lock combinations when they enroll in the program.

The fleet technology mix allows for comparisons on user preferences and demand for each bicycle type. The e-bikes are pedal-assist e-bikes, meaning that they must be pedaled for motor assistance and function similarly to regular bicycles. The e-bikes also have controls for adjusting motor assist, allowing users to change between five different assist levels. The e-bikes use 24V, 10Ah batteries, which are charged by the station kiosk and dispensed to the user along with the e-bike. The battery connects to the rear of the e-bike to provide power to the e-bike motor (250W) when the user begins pedaling. For a 10-15 mile trip, which is approximately the range of a full battery, 0.024KWh of electricity is used. If a user loses battery power during a trip, the e-bike still functions as a regular bicycle, allowing the user to complete the trip or return to the station. Due to the additional weight of the e-bikes and the batteries, however, a loss in motor assistance increases the effort required by the user. The regular bicycles available in the e-bike sharing system are 24 speed bicycles.

## 2.5 OPERATIONAL CONCEPT

CycleUshare is an entirely automated e-bike sharing system. From the user's perspective, the system operates by a touch screen that presents the user with options during the bicycle check-in or check-out procedure. After the user indicates that he or she wants a bicycle, the system requests the user's identification be swiped. This allows for tracking of the bicycle and battery involved in the transaction. Only one bicycle, either an e-bike or a regular bicycle, is released for the user, and the user is directed to that bicycle by the kiosk screen and by an indicator on the bicycle rack. Similarly, if users select an e-bike, they are directed to a specific battery for their trip based on the battery having a minimum (80%) state of charge to guarantee a ten-mile range.

Check-in transactions proceed in reverse of the check-out transaction. Once users return a bicycle to the station, the kiosk requires the user to swipe his or her identification. This allows the system to correctly identify which bicycle (and bicycle type) was returned and allocate the bicycle to a specific place on the bicycle rack. If the user returns an e-bike, the system then asks that the battery be returned to the battery rack and is automatically docked for charging. In both check-in and check-out, the procedure is designed to be simple with built-in error handling if a user does not follow procedures correctly. Still, unanticipated user errors abounded and caused substantial maintenance requests.

Users of cycleUshare must be a student, faculty, or staff member at UTK. Registration in the project is free and can be done through the project's website [19]. The system currently has 93 users enrolled, with a several hundred potential users on a waitlist. Prior to becoming a registered user in the program, each potential user must watch mandatory videos about proper use of the e-bike sharing system and about safety while operating the bicycles. All users must be 18 years or older and agree to the terms and conditions of the program, including a waiver of liability, and consent to participate in a research project.

The rules of the program are intended to promote safe use of the bicycles in accordance with University rules. The bicycles in the program cannot be taken outside the city limits of Knoxville, TN, and must be returned to the e-bike sharing station within the specified time limit. Participants agree that they will be the sole users of the bicycles and that while operating the bicycles they will obey all traffic laws and safety rules. Participants also agree to inspect the bicycles before and after use to ensure proper working condition. Participants are encouraged, but not required to wear a helmet. In practice, almost no users wore helmets on either bicycle type.

**2.6 SYSTEM PERFORMANCE**

Data collected through the e-bike sharing systems transaction logs provide a resource to analyze how the system is utilized by the users. Tracking transactions by bicycle type reveal the demand for each bicycle type. Figure 2depicts the number of e-bike and regular bicycle check-outs over the initial months (academic year) of the program along with the increase in registered users during that time. The users were gradually added to the system to allow the research team to monitor technical performance and troubleshoot problems as they arose. Notably, use was high when the project started but diminished as the weather got colder in October and November 2011. There were no check-outs during Winter break, but usage increased again rapidly in the Spring as the weather got warmer, with the exception of few check-outs during spring break in

March. During this eight-month period, there were approximately 900 checkouts, nearly two thirds were e-bikes.

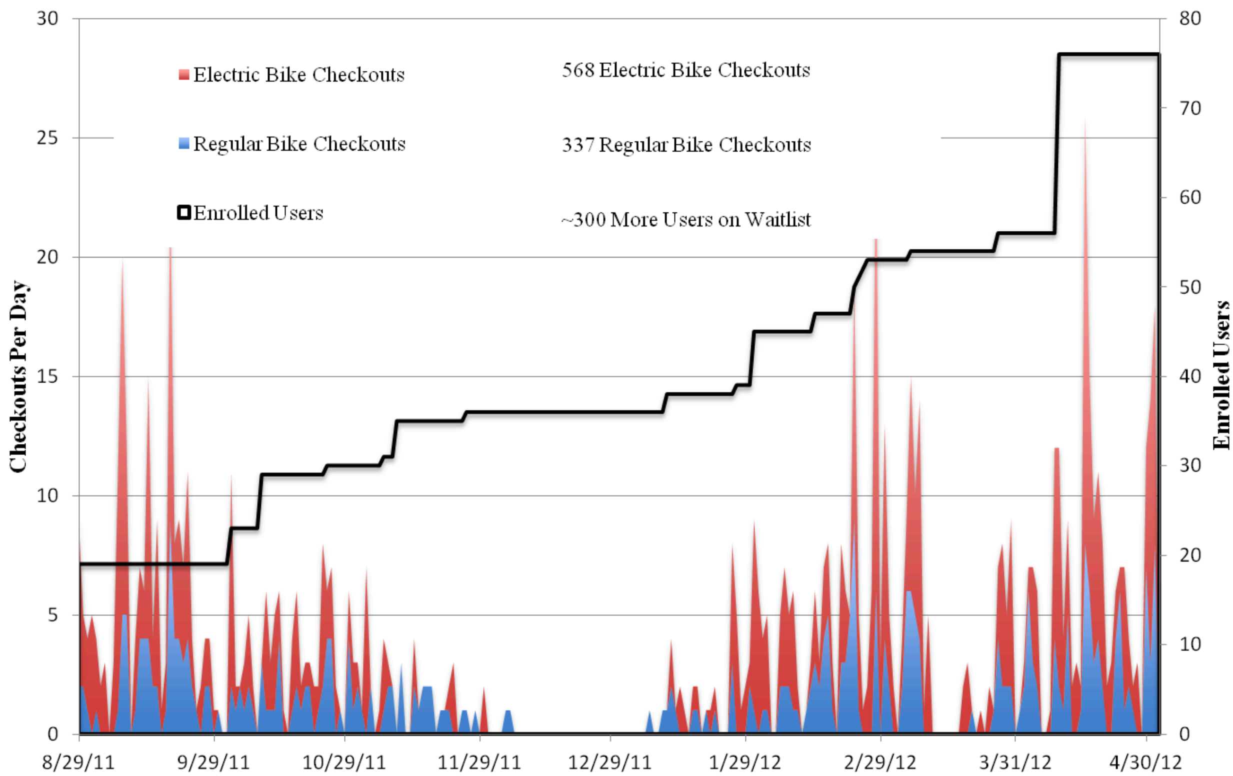



**Figure 2: User Enrollment and Transaction History.**

Of key interest is who actually uses the system. A small percentage of users are actually responsible for most of the system's usage, with most users contributing only a very small number of trips. Analysis of transactions reveals that 22% of users are responsible for 81% of all trips made using the e-bike sharing system. For only those trips on e-bikes, 21% of users make 80% of trips; and for only trips by regular bicycle, only 11% of users make 80% of the trips. Figure 3 shows the percentage of trips contributed by each user.

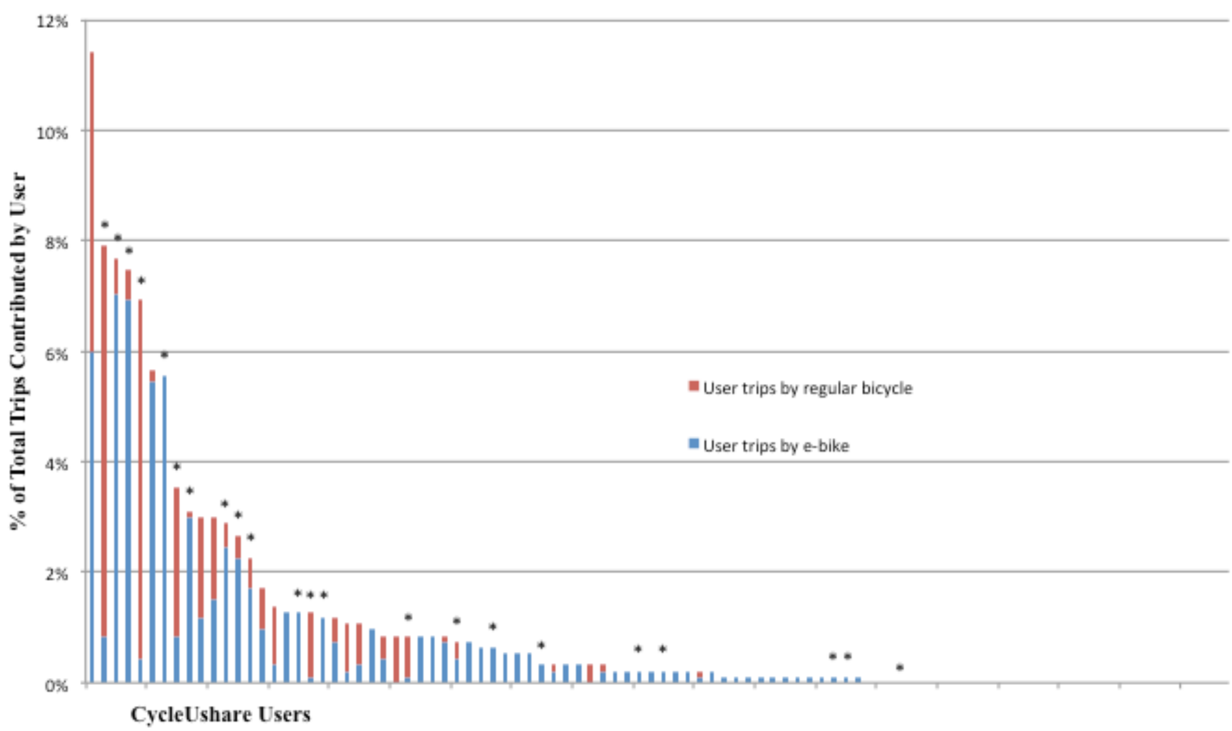



**Figure 3: Percentage of Trips by Each User.**
*Indicates user participated in survey.

The percentage of trips by bicycle type not only varies by individual but also by station of origin. At the Presidential Court station where most of the trips originate, 62% of check-outs are for e-bikes and 38% are for regular bicycles. At the Ag Campus station, 92% of check-outs are for e-bikes and only 8% are for regular bicycles. This large difference in preferences could be explained by the populations primarily using the stations. More students use the Presidential Court station, while more faculty and staff use the Ag Campus station. Another possible explanation is the length of time the stations have been operational. The Presidential Court station has been in operation longer allowing a larger variety of users to use the station. While there are currently 93 active users, approximately 1/3 of those users were enrolled since the opening of the Ag Campus station, and, unfortunately, less data is available about those users and their trips.

**2.7 USER SURVEYS**

From user surveys conducted from May through July 2012, user behaviors and perceptions are analyzed. The 22 users (57% of trips) participating in the survey were asked about perceptions of the system and were also asked to recall recent specific trips they took using the bicycles and e-bikes from the sharing system based on GPS and kiosk data from their trips. Table 1 outlines the user characteristics for those participating in the survey. E-bikes constituted 64% of trips in the survey and 36% of the trips studied were regular bicycle trips. 88% of those trips originated from the Presidential Court station because of the longer installation on campus. The trips occurred between March 2012 and June 2012.

**Table 1: Characteristics of CycleUshare User Sample Group.**

| Category | Members (%) |
|---|---|
| Age | N = 22 |
| *18-20* | 55% |
| *21-25* | 27% |
| *Older than 25* | 18% |
| Status | N=22 |
| *Student* | 82% |
| *Faculty/Staff* | 18% |
| Sex | N=22 |
| *Male* | 59% |
| *Female* | 41% |
| Ethnicity | N = 22 |
| *White/Caucasian* | 82% |
| *Black/African American* | 9% |
| *Hispanic* | 9% |
| *Native American* | 0% |
| *Asian* | 0% |
| *Pacific Islander* | 0% |
| BMI[a,b] | N=20 |
| *Underweight (BMI value less than 18.5)* | 5% |
| *Normal (BMI value 18.5 - 24.9)* | 55% |
| *Overweight (BMI value 25.0 - 29.9)* | 35% |
| *Obese (BMI value 30.0 or above)* | 5% |
| Bicycle access and ownership | N=22 |
| *Currently owns a bicycle* | 41% |
| *Currently owns an automobile* | 86% |
| *Access to a bicycle other than e-bike-share* | 68% |

[a]Values calculated using CDC formula for Body Mass Index (BMI) [20].
[b]BMI values of users from this study (Mean=23.49, Std. Dev=3.36) were statistically the same as a sample of 1100 entering freshman in 2006 (Mean=23.41, Std. Dev=4.48)

For each trip studied in the survey, users were asked to describe their trip purpose and their alternative mode for that trip. Table 2 presents the trip characteristics for the trips in the study. The most common trip purpose is class related trips, accounting for 40% of all trips. For trips by regular bicycle, class related trips account for 57% of all trips studied. Trips by e-bike are more varied in purpose, although the most common trip purpose is still class related. Although this study focuses on a campus environment, the large percentage of school or class related trips corresponds well to the large percentage of work or school trips observed in other bikeshare systems [7].

The second most common trip purpose is exercise or leisure with 15% of all trips. Of note is that 29% of female regular bicycle users reported making trips for exercise or leisure while only seven percent of male regular bicycle users reported this for a trip purpose. A number of e-bike trips, 16%, were reported as personal trips, while no regular bicycle users reported personal reasons as a trip purpose. Users making e-bike trips averaged slightly higher BMI values. Male users also average slightly higher BMI values among both e-bike and regular bike users.

**Table 2: Sample CycleUshare Trip Characteristics.**

| | E-bike trips | | | Regular-bicycle trips | | |
|---|---|---|---|---|---|---|
| | All | Male | Female | All | Male | Female |
| Trip attribute | *N=37* | *N=25* | *N=12* | *N=21* | *N=14* | *N=7* |
| Trip Origin (% of total trips) | | | | | | |
| *Presidential Court* | 52% | 36% | 16% | 36% | 24% | 12% |
| *Ag Campus* | 12% | 7% | 5% | 0% | 0% | 0% |
| Average trip length, (m)[a] | 2025 *(953)* | 2090 *(836)* | 1864 *(1236)* | 1796 *(703)* | 1913 *(587)* | 1563 *(899)* |
| Average active trip time, (minutes)[a] | 13.07 *(8.19)* | 13.45 *(7.16)* | 12.12 *(10.76)* | 10.61 *(5.42)* | 11.49 *(4.66)* | 8.85 *(6.74)* |
| Average check-out duration, (minutes)[a] | 73 *(86)* | 86 *(98)* | 40 *(33)* | 140 *(129)* | 118 *(64)* | 178 *(200)* |
| Average BMI value for users[a,b] | 24.33 *(3.17)* | 24.98 *(3.34)* | 22.69 *(2.03)* | 22.74 *(3.31)* | 23.97 *(3.31)* | 20.27 *(2.09)* |
| Trip purpose (% of total trips by category) | | | | | | |
| *Class* | 30% | 36% | 17% | 57% | 57% | 57% |
| *Exercise or leisure* | 16% | 16% | 17% | 14% | 7% | 29% |
| *Food* | 14% | 12% | 17% | 10% | 14% | 0% |
| *Library/Study* | 14% | 8% | 25% | 14% | 14% | 14% |
| *Personal* | 16% | 12% | 25% | 0% | 0% | 0% |
| *Home* | 8% | 12% | 0% | 5% | 7% | 0% |
| *Unknown* | 3% | 4% | 0% | 0% | 0% | 0% |
| Alternative mode for trip (% of total trips by category) | | | | | | |
| *Walk* | 57% | 52% | 67% | 62% | 50% | 86% |
| *Personal Bike* | 11% | 16% | 0% | 19% | 29% | 0% |
| *Bus* | 11% | 4% | 25% | 10% | 14% | 0% |
| *Car* | 11% | 12% | 8% | 0% | 0% | 0% |
| *Other* | 0% | 0% | 0% | 0% | 0% | 0% |
| *No Trip* | 11% | 16% | 0% | 10% | 7% | 14% |

[a]Standard Deviation in Parenthesis
[b]Values calculated using CDC formula for Body Mass Index (BMI) [20].

Of the trips analyzed in the surveys, e-bike trips averaged 13% longer than regular bicycle trips although a wide range of trip lengths were observed. On average, check-out durations are nearly twice as long for regular bicycles compared to e-bikes, 2hrs 20mins compared to 1hr 13min. E-bike trips also had longer active trip times than regular bicycle trips although, again, a wide range of trip times were observed. Longer trip lengths for e-bike trips seem to be the result of added stops during the trip. Users of regular bicycles tend to have singular destinations, where e-bike users often reported multiple destinations during the same trip. This is also evident in the GPS data for these trips. In addition, e-bike users are able to travel greater distances in shorter periods of time, although on a campus setting the check-out duration may be related to class length or other factors.

The most displaced mode, by far, is walking with 58% of all respondents saying that walking would be their alternative mode. That number increases to 64% when considering only students. Displaced walking trips were most commonly reported by female regular bicycle users (86%) with female users indicating that the remaining trips (14%) would not have been made without the e-bike sharing system in place. The factors of speed and convenience as major influences in using the e-bike sharing system make the displacement of many walking trips obvious. This corresponds to research on other bikeshare systems that found bikeshare users decrease the amount of walking trips [7].

Among trips by male users, 16% of e-bike trips and 29% of regular bicycle trips would be replaced with trips using their personal bicycle. No female users of either bicycle type reported their personal bicycle as an alternative mode. During the surveys, several users indicated that they do not have access to a bicycle other than through cycleUshare. Prior to cycleUshare, the average time since last using a bicycle was 2.5 years, with some users reporting up to 12 years since they last used a bicycle. The most common groups reporting bus as an alternative mode were female e-bike users (25%). Only 4% of male e-bike users reported bus as an alternative mode, although 14% of male regular bicycle users would use this mode.

Surprisingly, no regular bicycle trips displaced car trips where 11% of e-bike trips displaced car trips. This might be related to the number of e-bike users who reported multiple destinations for the same trip. Furthermore, users reported that 11% of e-bike trips and 10% of regular bicycle trips would not be made without the e-bike sharing system in place. All but one person replying that they would have not made the trip without the e-bike system are faculty or staff members. Users were also asked why they chose a particular bicycle type for each trip and why they used the e-bike sharing system for that trip. The factors influencing those decisions are presented in Table 3. The most common reasons for choosing an e-bike over a regular bicycle are that e-bikes are seen as more comfortable (35%), they are perceived as faster (24%), and they are considered to require less energy from the user (22%). Comfort is the most common factor for both men and women e-bike users; however, speed is second most common among men (28%) while requiring less energy is second among women users (25%). The value of comfort is obvious in one user's statement:

"I appreciate bike-sharing because I have herniated discs in my back and the bikes allow me more mobility so I don't have to walk everywhere." –Anonymous cycleUshare user.

**Table 3: Factors Influencing CycleUshare User Bike Choice.**

| | E-bike trips | | | Regular bicycle trips | | |
|---|---|---|---|---|---|---|
| | All | Male | Female | All | Male | Female |
| Trip attribute | *N=37* | *N=25* | *N=12* | *N=21* | *N=14* | *N=7* |
| Why user chose bicycle type? (% of total trips by category) | | | | | | |
| *It is faster* | 24% | 28% | 17% | 43% | 50% | 29% |
| *It provides exercise* | 0% | 0% | 0% | 0% | 0% | 0% |
| *I had extra time* | 3% | 0% | 8% | 10% | 0% | 29% |
| *I had a load to carry* | 3% | 4% | 0% | 0% | 0% | 0% |
| *It is comfortable* | 35% | 32% | 42% | 5% | 7% | 0% |
| *It requires less work/energy* | 22% | 20% | 25% | 10% | 14% | 0% |
| *I was making a long trip* | 5% | 8% | 0% | 0% | 0% | 0% |
| *I dislike the other bicycle type* | 0% | 0% | 0% | 29% | 21% | 43% |
| *My preferred bicycle type was not available* | 5% | 8% | 0% | 0% | 0% | 0% |
| *Other* | 3% | 0% | 8% | 5% | 7% | 0% |
| Why user chose to use e-bike share for trip? (% of total trips by category) | | | | | | |
| *It is faster than my alternate mode* | 51% | 64% | 25% | 48% | 36% | 71% |
| *It provides exercise* | 3% | 4% | 0% | 14% | 21% | 0% |
| *It requires less energy than my alt. mode* | 19% | 12% | 33% | 0% | 0% | 0% |
| *It is convenient* | 24% | 16% | 42% | 29% | 29% | 29% |
| *It is free* | 0% | 0% | 0% | 0% | 0% | 0% |
| *It is better for the environment than my alternative mode* | 0% | 0% | 0% | 0% | 0% | 0% |
| *I do not have a bicycle* | 0% | 0% | 0% | 0% | 0% | 0% |
| *I do not have a car* | 0% | 0% | 0% | 0% | 0% | 0% |
| *I do not have to worry about parking* | 3% | 4% | 0% | 0% | 0% | 0% |
| *Other* | 0% | 0% | 0% | 3% | 3% | 0% |

Of users making a trip by regular bicycle, 43% responded that they selected that bicycle type because they perceive those bicycles as faster than e-bikes. This alludes to the division of opinion between users of the two bicycle types. The second most common reason for choosing a regular bicycle is that the user dislikes the other bicycle type. 29% of users selecting a regular bicycle responded that they dislike using e-bikes.

When asked why the user chose to use the e-bike sharing system for a particular trip, 51% of e-bike users and 48% of regular bicycle users responded that it was faster than their alternative mode, which for most users is walking. Convenience of the system was also an important factor. Of those trips by e-bike, 24% stated convenience as the reason for using e-bike sharing while 29% of those taking regular bicycles stated convenience as their reason. Only 3% of e-bike users and 14% of regular bicycle users said they use the system for exercise, and no one said they use it purely because it is better for the environment than their alternative. Male users are more likely to use e-bike sharing because it provides exercise. No female users of either regular bicycles or e-bikes stated that they use the system, itself, because it provides exercise.

## 2.8 USER PERSPECTIVES

In addition to reviewing actual trips, users were asked a number of questions related to their perceptions of regular bicycles and e-bikes. Questions required a 1-5 Likert scale response (Strongly Disagree to Strongly Agree). The results are widespread for most questions, although some have clearer strength of preference. Table 4 summarizes user perceptions about the two bicycle types utilized at cycleUshare by gender.

**Table 4: CycleUshare User Perceptions About E-Bikes and Regular Bicycles.**

| **E-bikes are more attractive because…**[a] | Strongly agree (%) | Agree (%) | Neutral (%) | Disagree (%) | Strongly Disagree (%) |
|---|---|---|---|---|---|
| They remove terrain barriers | 59% | 18% | 9% | 0% | 14% |
| *Male* | 54% | 23% | 8% | 0% | 15% |
| *Female* | 67% | 11% | 11% | 0% | 11% |
| Are easier to ride in traffic | 9% | 23% | 45% | 23% | 0% |
| *Male* | 15% | 31% | 31% | 23% | 0% |
| *Female* | 0% | 11% | 67% | 22% | 0% |
| Are easier to start at signals or stop signs | 32% | 32% | 18% | 9% | 9% |
| *Male* | 46% | 31% | 8% | 15% | 0% |
| *Female* | 11% | 33% | 33% | 0% | 22% |
| I can travel farther | 64% | 9% | 9% | 18% | 0% |
| *Male* | 69% | 8% | 8% | 15% | 0% |
| *Female* | 56% | 11% | 11% | 22% | 0% |
| **Regular bicycles are more attractive because…**[a] | Strongly agree (%) | Agree (%) | Neutral (%) | Disagree (%) | Strongly Disagree (%) |
| They are lighter and more maneuverable | 41% | 23% | 9% | 18% | 9% |
| *Male* | 38% | 8% | 8% | 31% | 15% |
| *Female* | 44% | 44% | 11% | 0% | 0% |
| They provide more exercise opportunities | 27% | 5% | 27% | 32% | 9% |
| *Male* | 15% | 0% | 31% | 38% | 15% |
| *Female* | 44% | 11% | 22% | 22% | 0% |
| They are better for the environment | 18% | 5% | 41% | 27% | 9% |
| *Male* | 15% | 0% | 38% | 31% | 15% |
| *Female* | 22% | 11% | 44% | 22% | 0% |
| I don't have to worry about battery range | 18% | 9% | 9% | 50% | 14% |
| *Male* | 15% | 8% | 0% | 77% | 0% |
| *Female* | 22% | 11% | 22% | 11% | 33% |

[a]N=22 for all fields.

One of the motivations for creating the e-bike sharing system was to attract additional users who may not otherwise ride a bicycle due to terrain barriers. Most (77%) respondents either agree or strongly agree that e-bikes are more attractive than regular bicycles because they remove terrain barriers. Responses were similar between male and female users on this issue with 54% of males and 67% of females strongly agreeing. Only 14% of users strongly disagree that e-bikes are more attractive because the remove terrain barriers. Responses from users point out that the performance of the e-bike motor is a factor:

"If the motor on the e-bike is working, I don't notice the difference in weight." -Anonymous cycleUshare user.

"For exercising, I like to walk about two miles each day, but the e-bike is great because I can go farther and not worry about going up hills." -Anonymous cycleUshare user.

Male users have stronger impressions than female users that e-bikes are more attractive because of their ease of use in traffic situations. Nearly half (31% of male users agree and another 15% strongly agree) think that e-bikes are more attractive because they are easier to ride in traffic. Women are more neutral on this issue. Also, 31% of male users agree and another 46% strongly agree that e-bikes are more attractive because they are easier to start at stop signs or traffic signals. Among women, only 11% strongly agree with this statement, 33% agree, and another 22% strongly disagree.

One of the possible advantages of regular bicycles is that they are lighter and thus more maneuverable. 64% of those surveyed either agree or strongly agree with that statement. Among users who only ride e-bikes, only 10% agree with that statement. Female users largely agree with this as 88% of female users either agree or strongly agree. Male users, however, are split on this issue as 46% agree or strongly agree while 46% disagree or strongly disagree. Other advantages of regular bicycles are they provide increased exercise opportunities and are better for the environment. Users are largely neutral on these issues, although 44% of women do agree that regular bicycles are more attractive as they provide more opportunity for exercise. As one user stated:

"When going long distances it is better to have a battery, but normally I like the other bikes for exercise." -Anonymous cycleUshare user.

Lastly from these results, range anxiety does not appear to be an issue for most users. 73% of users agree or strongly agree that e-bikes are more attractive than regular bicycles because they can travel farther with an e-bike. Only 18% of users disagree with that statement. Those users who only ride e-bikes all strongly agree with that statement. On a related question, 64% of users disagree or strongly disagree that regular bicycles are more attractive because battery range is not an issue with those bicycles. This would indicated that one of the biggest factors in choosing either an e-bike or regular bicycle is the additional mobility gained from using an e-bike.

### 2.9 CHALLENGES

A number of challenges arose during the development of the e-bike sharing system. Some of these were discussed previously in the challenges when describing operational requirements of sharing of e-bikes. Many other issues presented themselves during operation of the system.

System software to accomplish the management of the bicycles and batteries in addition to operation of the kiosk and user interface proved to be the most problematic issue. Prior to system deployment, the developed software was tested under various expected conditions and for various foreseen user related problems; however, throughout the operation of the system a number of other errors have occurred. To account for these problems, software development for the system is an ongoing process and new software versions are continually installed.

Tied very closely to the software problems are user generated errors. User errors are a persistent problem, even after user education on system use and modifications to the software. The most common user related errors are related to the check-out or check-in of a bicycle or e-bike. Correct system operation relies on users to swipe their identification at both check-out and check-in for proper allocation of the bicycles and batteries in the system. Users often complete this step at bicycle check-out but fail to do so at bicycle check-in. This creates problems tracking bicycles since the they do not have identification hardware (the identification method employed relies on user check-ins) and there are two types of bicycles in the system that require tracking.

The station hardware also proved problematic at times. Hardware problems have generally centered on sensors used within the station to detect the presence bicycles in the station's bicycle rack or the presence of batteries in the kiosk battery rack. Maintenance to the bicycles and e-bikes in the system has often created challenges, particularly for e-bikes. Both bicycle types require regular maintenance to ensure proper performance. The e-bikes also rely on several additional mechanical and electrical components to function properly. Maintenance, repair, or sometimes replacement of these components is often necessary. Adding e-bikes to a bikeshare system increases complexity, maintenance requirements, and costs compared to standard bikeshare systems.

Compliance with the rules of the e-bike sharing system were minor challenges. Most trips are within the allowed time and distance; however, a few problems have occurred with users not obeying the time constraints in the conditions of use. Although these occurrences are few in number, they typically involve the same users. Vandalism, to this point, has not been a major problem, although a few rare instances have occurred. Most instances of vandalism have caused minor damage to the bicycles themselves. No vandalism or damage has occurred to either station.

## 2.10 CONCLUSIONS AND NEXT STEPS

The model of bikesharing deployed at UTK is effective at attracting users to both regular bicycles and e-bikes as the qualities of each attract different types of users to the program. In the campus setting, most regular bicycle trips are shown to be of shorter distances and with a singular purpose. E-bike users can travel greater distances under a shorter timeframe allowing for additional stops. While the destinations for most trips in this study are class-related, a number of them included a destination off-campus. The extended mobility provided by the e-bike sharing system allows users to make trips off-campus without moving their car or waiting for the bus. Trips by e-bike are shown to have a wider variety of trip purposes than regular bicycle trips.

Considering that most e-bike trips are displacing walking trips in the campus environment, e-bike sharing greatly expands user mobility, though perhaps it does not have a strong positive influence on reduced environmental impacts of the transportation system. Based on user responses, the extended mobility and removal of terrain barriers are major advantages to the e-bikes. Male and female user responses were comparable on many issues; however, with regard to regular bicycles, a larger number of female users agree that they are more attractive than e-bikes because they are more maneuverable and because they provide more exercise opportunities. Also, users are shown not to have range anxiety over e-bike batteries, possibly because most trips are short distance.

Despite operational challenges, cycleUshare has largely been a success at the UTK. It has attracted new users to cycling and given expanded mobility to the students, faculty, and staff at the University. Interest in the program has steadily risen over the first year of operation, and, with the rise in registered users and increased demand at e-bike sharing stations, new challenges have evolved. Moreover, it has provided an educational platform to introduce alternative modes of transportation and alternative vehicle technologies to thousands of students and staff.

The next phases of development include producing an open source version of the e-bike sharing system that will be available to communities, organizations, and other groups with an interest in operating a similar system. An open source model will allow expansion of the system to other locations using the model developed at UTK. With this open platform, others can improve upon the existing design, allowing for constant evolution from the user community. System software is currently being redeveloped to produce a more user friendly and error free interface. Hardware is also being redeveloped to allow easier installation and maintenance. Last, the research associated with this project continues and additional phases of research are planned including future pricing experiments. Some say that widespread e-bike share is inevitable. In parallel, several groups are developing e-bike sharing solutions, including City Carshare (San Francisco), Sanyo (Japan), Velopass (Switzerland), Intrago, and Bike-In. This research begins to evaluate this technology as these systems are deployed.

# APPENDIX: CHAPTER 2

## APPENDIX 2.A: INSTITUTIONAL REVIEW BOARD RESEARCH CONSENT FORM AND LIABILITY WAIVER

# *UNIVERSITY OF TENNESSEE ELECTRIC BIKE AND BICYCLE SHARING PILOT PROGRAM RELEASE OF LIABILITY*

*Participant Name:* ___________________________ *Age:*_____ *Student ID No.:*__________________

*Date of Birth:* _______________ *Phone #:* ____________________

*Address:* _________________________ *City/State/Zip:* ____________________________

*E Mail Address:* ____________________________ *Major:* ___________________________________

*Degree Pursued:* __________________ *Expected Graduation Date:* __________________

**RELEASE AND ASSUMPTION OF RISK**
The undersigned hereby acknowledges that he/she understands that participation in bike sharing at the University of Tennessee is purely voluntary and is not part of the academic curriculum of the university. Participant understands and acknowledges that neither the University of Tennessee, nor the E Bike and Bicycle Sharing Pilot Program ("Pilot Program") is not an insurer of the behavior and/or actions of the Participant, and that the University of Tennessee and the Pilot Program assumes no liability whatsoever for personal injuries or property damages to the Participant or other third parties injured by Participant.

In consideration of the university making E Bikes (motorized bicycles) or Bicycles ("Bicycles") available for the Pilot Program and/or undersigned while participating in any such activities, the undersigned hereby releases The University of Tennessee, their successors, assigns, Trustees, officers, agents, and employees from any and all claims, demands and causes of action whatsoever, in any way growing out of or resulting from the undersigned's participation in the activities of the Pilot Program.

The undersigned further agrees that he/she understands that cycling involves substantial risk of bodily injury, property damage and other dangers associated with participation. Possible injuries include but are not limited to bruises, cuts and abrasions, twisted ankles, separated shoulders, broken bones, head injuries, or other serious physical injury or death. Hazards include but are not limited to debris on streets, pavement in poor condition, utility poles and other obstructions, acts of nature such as rock fall, varying weather conditions such as severe heat or cold and wet pavement, and other risks associated with riding with motor vehicles, E Bikes or bicycles.

It is expressly understood by the undersigned that he or she is solely responsible for any costs arising out of any bodily injury or property damage sustained through participation in normal or unusual activities of the Pilot Program. The participant does not have any medical conditions that would prevent participation in above named program. The participant has adequate health insurance to cover the costs of treatment in the event of any injury.

The undersigned understands that (1) all of his or her movements on any bicycle and/or motor driven vehicle while he or she participates in this project will be monitored by global position system software via a central processing unit installed on the vehicle, and (2) movements when he or she checks out and checks in a bicycle at the bike stations will be monitored and/or recorded with webcams and hereby waives his or her right to the customarily expected right of privacy afforded his or her freedom of movement during the time that he or she participates in this project.

Participant understands and agrees that his or her participation in this project is completely voluntary and that the data obtained from participation, including routes and whereabouts, will be recorded and shared for the purposes of research and/or education and consents to such disclosure for those purposes and/or for disclosure pursuant to lawful requests for information from law enforcement agencies.

**TERMS AND CONDITIONS**

The participant is the sole user, and is voluntarily participating in and is familiar with the E Bike and Bicycle Sharing Pilot Program ("Pilot Program") sponsored by The University of Tennessee and agrees to take full responsibility for the Pilot Program's shared Bicycle while it is under his or her watch. This includes adhering to all safety rules while riding the Bicycle at all times – avoiding riding on sidewalks, obeying all traffic laws, not riding while impaired, using head and taillights (not supplied) while riding at night, properly locking up the Bicycle to bicycle racks with the supplied locks. Wearing helmets (not supplied) is strongly encouraged.

The participant is a competent bike user. Participants shall exercise extreme due care at all times while cycling, and shall constantly be on the lookout for, and yield to pedestrians at all times. The participant must complete the Knoxville Transportation Planning Organization's "Bicycling Training Course" before participating in the program. The participant agrees that he/she will not carry or transport any persons or passengers on the Bicycle under any circumstance. Participants shall be aware of their surroundings and be on guard when using their student ID while checking in and checking out Bicycles. Bicycles shall not be taken into any buildings on the UT campus,

The participant must inspect the Bicycle before use, riding and/or operation of the Bicycle, and agrees to ensure that the Bicycle is in proper working conditions before using it and within 20 feet of the Bicycle station. Accidents and/or incidents must be reported within 24 hours to the University of Tennessee of or the City of Knoxville Police Department.

The participant must not use, ride or operate the Bicycle in the event of mechanical failure

The participant will not make any modifications to the equipment.

Maximum use time shall be 8 hours. If not returned in timely manner, the user must report stolen Bicycles to authorities. Participant takes full responsibility for any fines, traffic tickets, court costs, attorney's fees, judgments, etc,

Bicycles may be used and or operated only in the City of Knoxville and shall not taken outside of the city limits.

<u>The Undersigned must be 18 years of age or older.</u> If the Undersigned is married, then the signature of the spouse, appearing in the space indicated below signifies acceptance by said spouse,
that the terms and conditions hereof shall be binding upon them and shall constitute a release by them of any and all claims, demands and causes of action whatsoever which they or any of them may have against The University of Tennessee, its successors, Trustees, officers, agents or employees as a result of the undersigned student's, staff and/or faculty's participation in the E Bike and Bicycle Sharing Pilot Program.

**I HAVE CAREFULLY READ AND UNDERSTAND COMPLETELY THE ABOVE PROVISIONS AND AGREE TO BE BOUND THEREBY.**

Participant Signature: ________________________________________ Date: ___________________
Spouse Signature: __________________________________________ Date: ___________________

## APPENDIX 2.B: CYCLEUSHARE USER SURVEY FORM

9 digit User ID#: __________ Age: __________ Height: __________

Home Zip code: __________ Sex: M / F Weight: __________

Ethnicity:

- ☐ White/Caucasian
- ☐ Black/African American
- ☐ Hispanic
- ☐ Native American
- ☐ Asian
- ☐ Pacific Islander

Do you currently own a bicycle in Knoxville? Y / N

Do you currently own an automobile in Knoxville? Y / N

Prior to cycleUshare, did you own or have access to a bicycle? Y / N

Prior to cycleUshare, when was the last time you regularly rode a bicycle? (year/age) _____

What percent of the time does the system have to be available for you to consider using it (e.g. 90%) ____

Please answer the following questions about your previous trips using cycleUshare:

| | **Trip 1** | **Trip 2** | **Trip 3** | **Trip 4** | **Trip 5** |
|---|---|---|---|---|---|
| Date | | | | | |
| Time | | | | | |
| Origin | | | | | |
| Destination | | | | | |
| Weather (temp, precipitation, wind) | | | | | |
| Trip Purpose | | | | | |
| E-bike or R-bike? | | | | | |
| Why did you choose E-bike vs. R-bike for this trip? | | | | | |
| What would be your alternate mode for this trip?<br>*(1) Walk, (2) Personal Bike, (3) Bus, (4) Car, (5) Other (please specify)* | | | | | |
| Why did you choose bike-share for this trip?<br>*(1) It is faster than my alt. mode,*<br>*(2) It provides exercise,*<br>*(3) It requires less effort than my alt. mode,*<br>*(4) It is convenient,*<br>*(5) It is free,*<br>*(6) It is better for the environment,*<br>*(7) Other (please specify)* | | | | | |
| During this trip, did you travel by sidewalks? Y / N | | | | | |
| During this trip, did you travel by greenway? Y / N | | | | | |
| Additional comments about this trip. | | | | | |

Do you feel that the trips identified here are a good representation of your use of the cycleUshare system?
Y / N

If not, please comment: ______________________________________________
______________________________________________________________________
______________________________

**Please answer the following questions on a scale of 1 to 5, with 1 being not important at all and 5 being very important:**

How important of a factor is physical health in your mode choice decision?

☐ 1 not important ☐ 2 ☐ 3 neutral ☐ 4 ☐ 5 very important

How important do you consider safety when choosing your mode of travel?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

When you ride a bicycle or electric bicycle to make trips how important is safety to your route choice?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

As a bicycle rider, how important is it for you to follow traffic laws during your trips?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

**Please respond to the following statement on a scale of 1 to 5, with 1 being strongly disagree and 5 being strongly agree and 3 being neutral:**

**E-bikes** are more attractive than regular bicycles because they **remove terrain barriers (hills) when cycling**.

☐ 1 strongly disagree ☐ 2 ☐ 3 neutral ☐ 4 ☐ 5 strongly agree

**Regular bicycles** are more attractive than E-bikes because they **are lighter and more maneuverable**.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

**E-bikes** are more attractive than regular bicycles because they **are easier to ride in traffic**.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

**Regular bicycles** are more attractive than E-bikes because they **provide more exercise opportunities**.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

**E-bikes** are more attractive than regular bicycles because they **are easier to start at signals or stop signs**

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

**Regular bicycles** are more attractive than E-bikes because they **are better for the environment.**

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

**E-bikes** are more attractive than regular bicycles because I **can travel farther.**

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

**Regular bicycles** are more attractive than E-bikes because I **don't have to worry about battery range**.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

When riding a regular bicycle, I typically ride on the sidewalk.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

When riding a regular bicycle, I always come to a complete stop at traffic signals or stop signs.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

When riding an e-bike, I typically ride on the sidewalk.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

When riding an e-bike, I always come to a complete stop at traffic signals or stop signs.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

As a cyclist, I observe safer riding behaviors since joining cycleUshare.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

If there were a price per rental, I would be willing to pay more for e-bikes compared to regular bikes always.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

If there were a price per rental, I would be willing to pay more for e-bikes compared to regular bikes for long trips.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

If there were a price per rental, I would be willing to pay more for e-bikes compared to regular bikes in hot weather.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

When making a trip in the rain, I am most likely to choose:

| | | | | |
|---|---|---|---|---|
| ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 |
| Walk | Bicycle | E-bike | Car | Bus |

When making a trip in cold weather, I am most likely to choose:

| | | | | |
|---|---|---|---|---|
| ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 |
| Walk | Bicycle | E-bike | Car | Bus |

Additional comments about bike-sharing: ________________________________________

________________________________________________________________

________________________________________________________________

________________________________________________________________

# CHAPTER 3: A STUDY OF USER SAFETY ON REGULAR AND ELECTRIC BICYCLES USING OBSERVED BEHAVIORS.

## ABSTRACT

As electric bicycles (e-bikes) have emerged as a new transportation mode, their role in transportation systems and their impact on users have become important issues. The performance of e-bikes provides some benefits to users, compared to regular bicycles, such as a reduction in user effort required for similar trips, increased range, and increased speed to name a few. The performance characteristics of e-bikes could influence the behavior of riders and could influence on user safety. This work uses GPS data collected during user trips on both e-bikes and regular bicycles, which are part of an on-campus e-bike sharing system, to study user safety behavior between bicycle and e-bike modes. The work in this chapter focuses on behaviors observed under four situations: 1) riding behaviors on directional roadway segments, 2) riding behaviors on shared use paths, 3) stopping behavior at stop-controlled intersections, and 4) stopping behaviors at signalized intersections. Behavior is studied in each situation and analyzed with regard to the desired, or safest, behavior. Results show some differences in behaviors between users of the two bicycle types but indicate that bicycle type has a small influence on safety behavior as compared to facility characteristics and other factors.


## 3.1 INTRODUCTION

In recent years, electric bicycles, or e-bikes, have emerged as a new, sustainable form of active transportation. While e-bikes are similar to regular bicycles in terms of function, they offer differences in terms of performance through the addition of an electric motor, which provides some level of assistance to the user during travel. Different e-bike models provide this assistance through different methods including pedal-based assistance, throttle-controlled assistance, or a combination of the two. The e-bikes considered in this study incorporate a pedal-based assist delivered when the user applies force through the pedals. Compared with regular bicycles, e-bikes could provide some benefits with regard to travel range and effort required by the user, promoting increased travel distance, easier acceleration from stops, and higher average speeds while overcoming challenging terrain and other obstacles. It is unclear how these benefits may affect user behavior, particularly related to safety.

The differences in performance between the two modes raise important questions about the safety of users on the two bicycle types. Following these concerns, much of the regulation on e-bikes, worldwide, is focused on safety concerns [21]. In the United States, while e-bikes are a relatively new mode of transportation, there are existing concerns for the safety of bicycle users. In New York, e-bikes are illegal because they are not considered bicycles due to the on-board motor and not motor vehicles as they are not registered and because the increased speed associated with e-bikes is considered riskier [22, 23]. The State of California requires helmets for users of e-bikes but not for users of regular bicycles; it also requires e-bike users to be 16 years old or older [24]. According to the Bureau of Transportation Statistics [25], 4,654 pedestrians and 698 cyclists were killed in traffic crashes in 2007. In the United States, cyclists are 12 times more likely to be killed in an accident than a driver of an automobile [26]. While an increase in modal share for non-motorized transportation generally results in fewer fatalities per user, an increase in the number of vulnerable road users could result in an overall increase in injuries and fatalities for users in that group.

### *3.1.1 BICYCLE SAFETY*

The impacts of bicycling on safety and health have been investigated by many studies, although comprehensive analysis of the combined impact of these parameters is not often considered. Leden et al. [27] developed a model to estimate safety risk for bicyclists based on speed data and expert evaluations of various components such as initial vehicle speed and risk of collision. The bicyclist intersection safety index developed by Carter et al. [28] also incorporated expert opinion of several situations through the form of safety ratings. That study also analyzed video footage of various intersections and modeled safety risk based on observed avoidance maneuvers, without which a crash would likely have occurred. A bicycle network analysis tool for comparing perceived safety for bicycles on various facilities was developed by Klobucar and Fricker [29]. One common thread amongst these models is the inclusion of user or expert perception about the safety of the facilities in question.

Other studies have investigated bicycle-related crashes at intersections. Wang et al. [30] modeled collision risk between bicycles and automobiles at signalized intersections, and Schepers et al. [31] modeled bicycle-automobile collisions at unsignalized intersections. These models highlight the role of intersection geometry and, at signalized intersections, the role of phasing on collision risk. Weinert et al. [32] studied e-bike use in Shijiazhuang, China, and found that, among other conclusions, e-bikes promote a perception of increased safety compared to regular bicycles at intersections.

The behavior of the cyclists themselves, for instance route choice, speed, and other behaviors, also has a large influence on safety. By relating route information of bicyclists to facility attributes in a geographic information system (GIS), Aultman-Hall et al. [33] studied the exposure of cyclists on roadways, on off-road paths, and on sidewalks, finding that the relative rates for falls or injuries was least on roadways, followed by off-road paths, and lastly by sidewalks. A study of bicycle users in Brazil found that, while most cyclists, over 95%, agree they should respect traffic rules, a significant number of them violate basic traffic safety laws such as running red lights or riding the wrong direction on the street [34]. That study found that violating traffic rules as well as riding seven days per week, as opposed to riding fewer days each week, increases the risk of an accident. An Australian study shows that most crashes involving adult cyclists occur in the roadway, primarily at intersections; however, for adolescents, most crashes involve a cyclist entering the roadway from a sidewalk and colliding with an automobile [35].

Educational efforts to curb dangerous or risky cycling behavior are not always successful. In one study, over 1,000 individuals in Brazil were invited to meetings, which included educational material covering bicycling safety in traffic, distribution of a safety kit, and bicycle maintenance as necessary. Many cyclists did not attend, and there was no observed effect from the meetings on either the number of accidents or near-accidents [36]. Furthermore, a study of adolescents, age 13 to 18, in the Netherlands shows that not only do they often violate traffic rules while cycling, many of them are aware that they are conducting risky cycling behavior [37].

The issue of safety is particularly important because of the vulnerability of users of active transportation. In China, for instance, although the total number of deaths resulting from traffic crashes and the number of regular bicycle related deaths have decreased, the number of casualties resulting from crashes involving e-bikes has risen. This is also true for non-fatal injury cases. As the number of injury cases involving regular bicycles has decreased, the number of injury cases for e-bikes has risen [38]. A possible explanation for this increase in e-bike injuries is the modal shift from regular bicycles to e-bikes.

### *3.1.2 INTRODUCING NEW TECHNOLOGIES THROUGH E-BIKE SHARING*

Along with the introduction of e-bikes as a new transportation mode, another recent innovation is bicycle sharing. Bikeshare systems have emerged around the world [2, 5, 6] with many systems installed in the United States in recent years as well [1, 7, 8]. As an evolution of bikesharing, the integration of e-bikes with bikesharing introduces e-bikes to a new audience of users who otherwise may not be familiar with the technology or have access to it. This was implemented at the University of Tennessee, Knoxville, through an on-campus e-bike sharing system pilot project, which offers users access to both regular bicycles and e-bikes [3].

The motivation for this study stems from this introduction of new technology. Introducing e-bikes and e-bike sharing technology could influence user behaviors, which raises concerns over the impact to user safety. For instance, behaviors on shared use facilities, greenways, or bicycle paths as well as user behaviors in mixed traffic conditions can have impacts to user safety [39-43]. This study seeks to investigate the differences in behavior between users of regular bikes and e-bikes and uses the on-campus e-bike sharing system as a platform for this investigation. We focus on four key behaviors that could reduce safety, comparing e-bike rider behavior with bicycle rider behavior: 1) wrong-way riding on one-way streets, sidewalks, or two-way streets, 2) speed on shared-use paths, 3) stopping behavior at stop-controlled intersections, and 4) stopping behavior at signalized intersections. The primary objective is to objectively quantify user behavior to inform policy on an e-bike's role in the transportation system. On one hand, we expect that e-bikes could influence more dangerous riding behavior because of increased speed. On the other hand, e-bikes could influence safer driving behavior because of improved acceleration and hill-climbing capability, prompting the rider to adhere to auto-oriented traffic control devices (e.g., stop signs on hills).

## 3.2 METHODS OF ANALYSIS

### *3.2.1 RECORDED TRIP DATA*

Data collected through a variety of measures provide details for each trip by each user in the pilot program. These include detailed transaction logs describing user transactions from each e-bike sharing station and global positioning system (GPS) data collected from the bikes during user trips. Figure 4 identifies the location of the GPS device installed on a typical bike and e-bike in the sharing system. The component configuration of the GPS device, including the GPS data logging system (Garmin GPS18xLVX), the data collection module, and connection to the bike's battery power, are depicted in Figure 5. GPS data consists of National Marine Electronics Association (NMEA) sentences containing date, time, position, altitude, speed, and measures of data precision and error.

GPS collection devices were installed on six regular bicycles and seven e-bikes with data collection beginning in October 2011 through December 2012. These sources provide a method for tracking system use and demand as well as providing a direct observation of user behavior and performance while operating the bikes. The GPS devices recorded data once per second after the device was initiated. For e-bikes, this process was connected to the bikes controller, turning on the GPS device when the e-bike received power. For regular bicycles, this was accomplished via a separate battery pack, which ran continuously. Data recorded for each bike type are filtered to represent only data for actual trips and to eliminate positions with poor fix quality.

**Figure 4: Location of GPS Receiver on E-bike.**

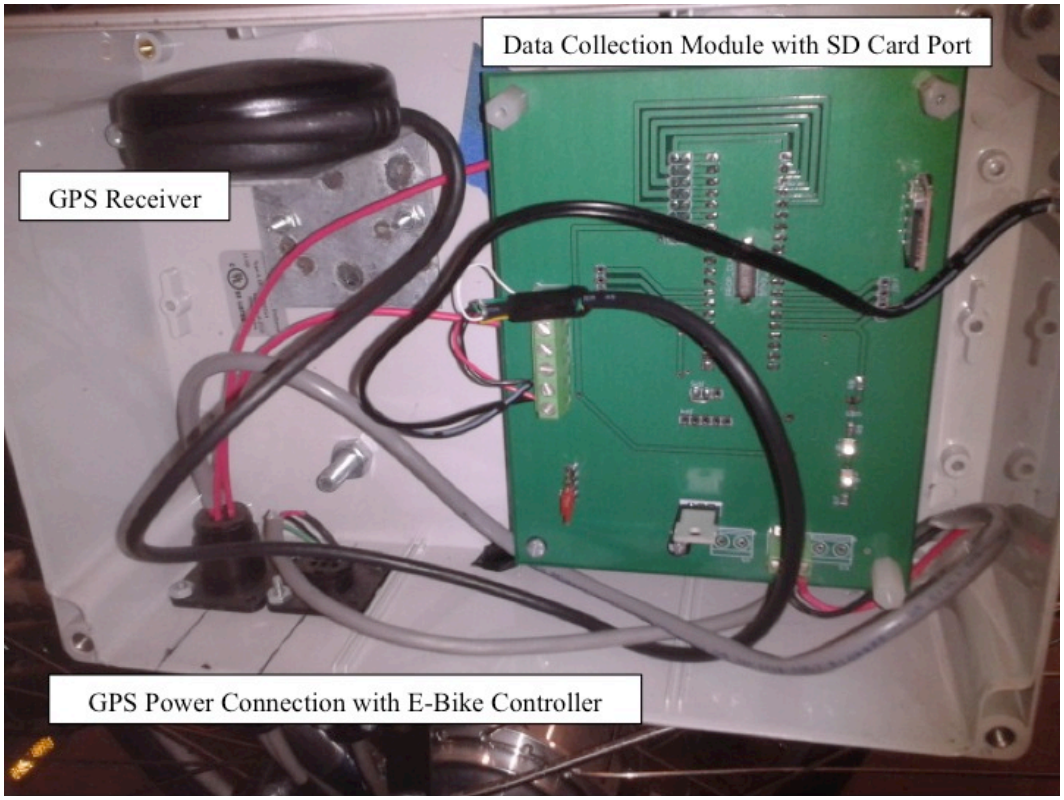


**Figure 5: GPS Data Collection Components.**

*3.2.2 GIS ANALYSIS*

Collected GPS data were processed and analyzed using geographic information system (GIS) software, ArcGIS. The data were overlaid with a detailed network representing area streets, sidewalk edges, greenway facilities, and traffic signal locations. Additional layers were created to establish zones for detecting behaviors at intersection approaches and along roadways and greenways. Furthermore, annual average daily traffic (AADT) counts [44] where available and posted speed limits for roadway segments were matched to the network. Data for each recorded trip were processed into point and line layers for analysis within the network. Processed data for each trip is depicted in Figure 6. With regard to user safety, data analysis occurred over four areas: 1) user behaviors on roadways under mixed traffic conditions, 2) user behaviors on shared use facilities or greenways, 3) user behaviors at stop-controlled intersections, and 4) user behavior at signalized intersections.

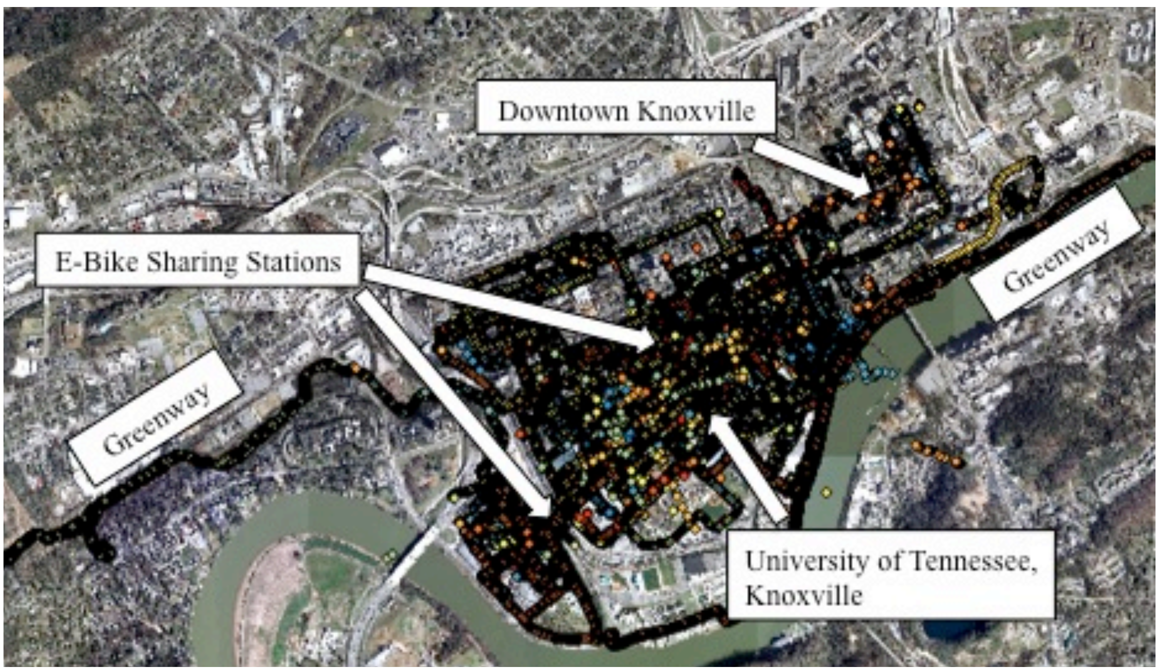



**Figure 6: GIS Data from Recorded Trips.**

#### 3.2.2.1 TRAVEL ON ROADWAYS

Analysis of user behaviors along roadway segments included 170 directional roadway segments, primarily in the area of the campus of the University of Tennessee, Knoxville. User movements along each roadway segment were identified and analyzed with regard to speed and direction of travel. One-way road segments were identified within the GIS network. On roadway segments allowing two-way travel, buffers were created corresponding to the lanes for travel in each direction. Directional layers were established, corresponding with the correct direction of travel on each segment. Due to GPS accuracy to accurately classify observations of bike users riding on the far right side of the road, these buffers included sidewalks or adjacent paths and extended to the centerline of the roadway. The created buffer layers were used to intersect with data points corresponding to trips along each of the roadway segments and to identify the direction of travel for each point.

#### 3.2.2.2 TRAVEL ON SHARED USE FACILITIES

Similar analysis methods were applied to shared use facilities or greenways as were used for analysis on roadway segments. Buffer zones were created as overlay layers based on greenway locations. Using these overlays to intersect trip data points, trips utilizing the greenway segments were identified. Observations were analyzed across 23 greenway segments in the Knoxville area with regard to travel speed.

#### 3.2.2.3 ANALYSIS AT STOP-CONTROL INTERSECTIONS

Intersection approaches were analyzed in two categories, those with stop-control and those with traffic signals. Analysis at stop-control approaches included 76 approaches. To capture observations at stop-control intersections, buffer layers were created for each approach extending from the edge of curb at the intersecting street, across the width of the street, including the width of the sidewalk on either side of the approach, and extending 20 feet beyond the stop bar. These buffer layers were then intersected with point data corresponding to user trips to determine trips entering the intersection via the given approach. A directional layer was incorporated to exclude any observations entering the buffer layer from one of the other intersection approaches. A typical stop-controlled intersection with observed trips is shown in Figure 7.

Observations were analyzed under varying speed-based thresholds to determine stop sign violation rates. The speed thresholds served as upper limits to identify observations of stopped bicycles at each approach and the severity of violation (e.g., running a stop sign at 5 kph versus 15 kph). Bike trips with observed speeds at or below the given threshold are considered stopped and, thus, obeying the stop sign. Those observations with speeds greater than the given threshold are considered in violation of the stop sign. Both violations and non-violations were recorded to determine a violation rate for the approach.

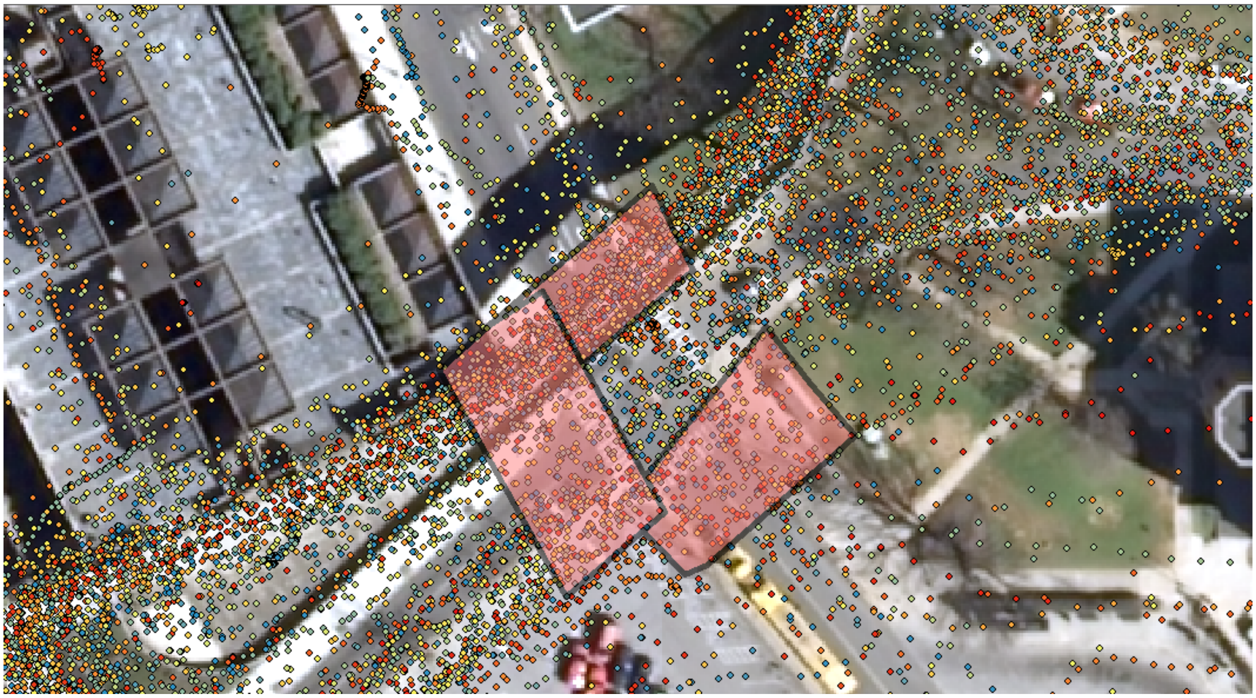


**Figure 7: User Trips at a Stop-Controlled Intersection.**

### 3.2.2.3 ANALYSIS AT SIGNALIZED INTERSECTIONS

Similar buffer layers and directional layers were created for approaches to signalized intersections to identify observations entering the intersection via the given approach. Observations were studied at 28 signalized approaches. At approaches to signalized intersections, additional data were incorporated to determine if movement was in violation of the traffic signal. Traffic signal timing data were obtained from the City of Knoxville Traffic Engineering Division for signalized intersections in Knoxville, TN, based on the coverage area from recorded trips. Signal timing data for intersections using fixed timing patterns were incorporated into the GIS analysis and matched to observations based on the time recorded by the observation's GPS data and the reference time for the signal approach as given in Equation 1.

$$TIME_{Reference} = TIME + Offset + Correction \qquad \textit{(Eq. 1)}$$

Offset values for each signal are given by the signal timing plans. The correction factors are based on manual observations of each phase corroborated by GPS devices at the signal location and applied to correct any discrepancies in the time used by the signal controller and the actual time as shown through GPS. This approach allows second-resolution accuracy of matching bike GPS location and speed with signal phase at intersection approaches. Separate plans were created for each signal phase corresponding to the matching approach indicating whether movements are permitted or not for a given time of day (and thus signal phase).

This was used to determine first, if the observed user stopped at the signal; and second, if the user violated a red phase by not stopping. As with stop-controlled intersections, the analysis considered a range of speed thresholds to determine adherence to the traffic signal at that location. Trips that included observations with speeds below the set speed threshold were considered stopped at the intersection and not in violation of the signal. Those trips without such observations were considered potential violators of the traffic signal. Comparison to the approach timing plan identified those trips with movements that violated a red phase and those with movements that were permitted. Violation rates were calculated for each signal location and compared across bike types.

## 3.3 STUDY RESULTS

Algorithms were established in ArcGIS for analyzing user behaviors under each of the four categories. This analysis yielded results comparing user behavior in several areas of importance: travel speed, conformance to directional travel matching the roadway facility, and adherence to stop signs and traffic signals. As a result of the methods used to identify observations, other behaviors were included in some of the results.

### *3.3.1 TRAVEL SPEEDS*

Travel speeds for users of both regular and electric bicycles were studied on both roadway segments, indicating travel in mixed traffic conditions, and on shared use facilities. After filtering GPS data to match user trip times, many observations contained low speed values. Observations with speeds below 2 kilometers per hour (kph) were considered stopped. This value is consistent with GPS based observations of e-bike and regular bicycle users by Cherry et al. [45]. The travel speeds for e-bike users are higher on average, 13.3 kph, than those for regular bicycle users, 10.5 kph. These values also correspond well to observations of e-bike and regular bicycle users in China by Cherry et al. [45] and are statistically significant at a 99% confidence level.

This result fits the assumption that e-bike users are able to maintain higher travel speeds than regular bicycle users due to the increased performance of the e-bike. This could promote users to ride e-bikes on roadways more often, as opposed to on sidewalks or on other facilities. However, our surveys show that e-bike sharing system users have neutral opinions about the advantages of riding e-bikes in traffic [3].

While speed observations for both bike types are largely clustered well below 20 kph, users of both bicycle types are able to achieve much higher travel speeds. Pedal assistance on the e-bikes in this study is limited to 20 miles per hour (mph), or approximately 32 kph, corresponding to the 99$^{th}$ percentile of observed e-bike speeds in this study. The 85$^{th}$ percentile speed for e-bikes is 20 kph. For regular bicycle users, the 85$^{th}$ percentile speed is 17 kph and the 99$^{th}$ percentile is 29 kph. Average trip distance for e-bike trips is 700.4 meters (standard deviation = 492.9 meters) and for regular bicycles is 612.3 meters (standard deviation = 506.0 meters).

Posted speed limits through the area covered by these observations range from 15 mph (24.1 kph), near school zones, to 45 mph (72.4 kph). Most roadways on campus and in the area have posted speed limits of 25 mph to 35 mph, corresponding to 40 kph to 56 kph. Average travel speeds for users of either bicycle type are lower than these speed limits; yet, many users are able to travel at speeds similar to the posted speed limits.

On shared use facilities, regular bicycle users have slightly higher average travel speeds than e-bike users, 12.6 kph versus 11.0 kph respectively. They also have slightly higher average top speeds across all segments, 26.0 kph for regular bicycle users versus 25.4 kph for e-bike users. These comparisons are significant at a 95% confidence level. This could be indicative of the nature of trips and the users making those trips on greenways. Among studied bike sharing system users, 14% of regular bicycle users chose to use the sharing system because it provided a level of exercise compared to only three percent of e-bike users [3]. Higher travel speeds on these facilities for regular bicycle users could reflect the exercise nature of the trip and the physical fitness levels of the user. The importance of high travel speed observations on these facilities is the difference of those speeds with typical travel speeds of other users, in this case walking speeds that are typically 3 mph to 4 mph, or 4.8 kph to 6.4 kph. High top speeds, observed over 25 kph on average, for both bicycle types are the most concern on these segments because of the differential with walking speeds of pedestrians who share the facility. This finding also supports the notion that e-bikes should be allowed on greenways, at least to the extent that speed is a factor in the decision. E-bike riders in this study had lower average and top speeds on greenways.

Across the various shared-use facility segments, regular bicycle speed observations are more varied than e-bike speeds with some segments showing consistently low speeds and others having observations with much higher speeds, while observed e-bike speeds are more consistent between segments. Again this variation is likely reflective of the performance characteristics of the two bicycle types, where e-bike users can more easily maintain their travel speed across rolling terrain due to the added benefit of the e-bike motor.

### *3.3.2 WRONG WAY RIDING AND OTHER BEHAVIORS ON ROADWAY SEGMENTS*

In addition to analyzing travel on the 170 roadway segments by speed, other behaviors were considered. Mainly, the focus of this analysis was to determine the rate of users of regular bicycles and e-bikes travelling in the wrong direction on roadways. This is particularly important around the e-bike sharing system stations where some of the primary roadways accessing the station site are one-way streets. This analysis, however, includes roadway segments throughout the coverage area. By the nature of the design, a portion of other violations are captured in this analysis. Observations of users traveling on sidewalk facilities, in the opposite direction of traffic flow on the roadway, are also included in the results as violations on the given roadway segment, whereas sidewalk riding in the correct direction is not a violation. Sidewalk riding in either direction in Tennessee, by bicycle and e-bike, are generally legal. Due to GPS data accuracy, it is not possible to distinguish, however, between users travelling the on the roadway and those on the sidewalk. Therefore, observations of users on the sidewalk are treated as those on the roadway are only identified as violations based on direction of travel. Wrong-way riding on sidewalks, though not illegal, is generally risky behavior.

The average violation rate by regular bicycles along these segments is not significantly different than that for e-bikes, 0.43 compared to 0.42. Violation rate comparisons with posted speed limits are also not statistically significant; however, AADT values do appear significant in some cases. Roadways with an AADT counts between 5,000 and 10,000 have higher violation rates than roadways with AADT counts between 1,000 and 5,000 as well as those with counts greater than 15,000. These comparisons are significant at an 85% confidence level. Figure 8 shows the distribution of violation rates across the range of AADT values for the roadway segments.

These violation rates may indicate that traffic volume and speed have little impact over wrong way travel by bicycle and e-bike users. More likely, these values indicate that most users are actually traveling on sidewalks, particularly when traffic volumes on the roadway make travel on sidewalks more convenient. In the previous survey of e-bike sharing system users, many users responded that they had either completed one of the studied trips using sidewalks or admitted to using sidewalks on other trips [3].

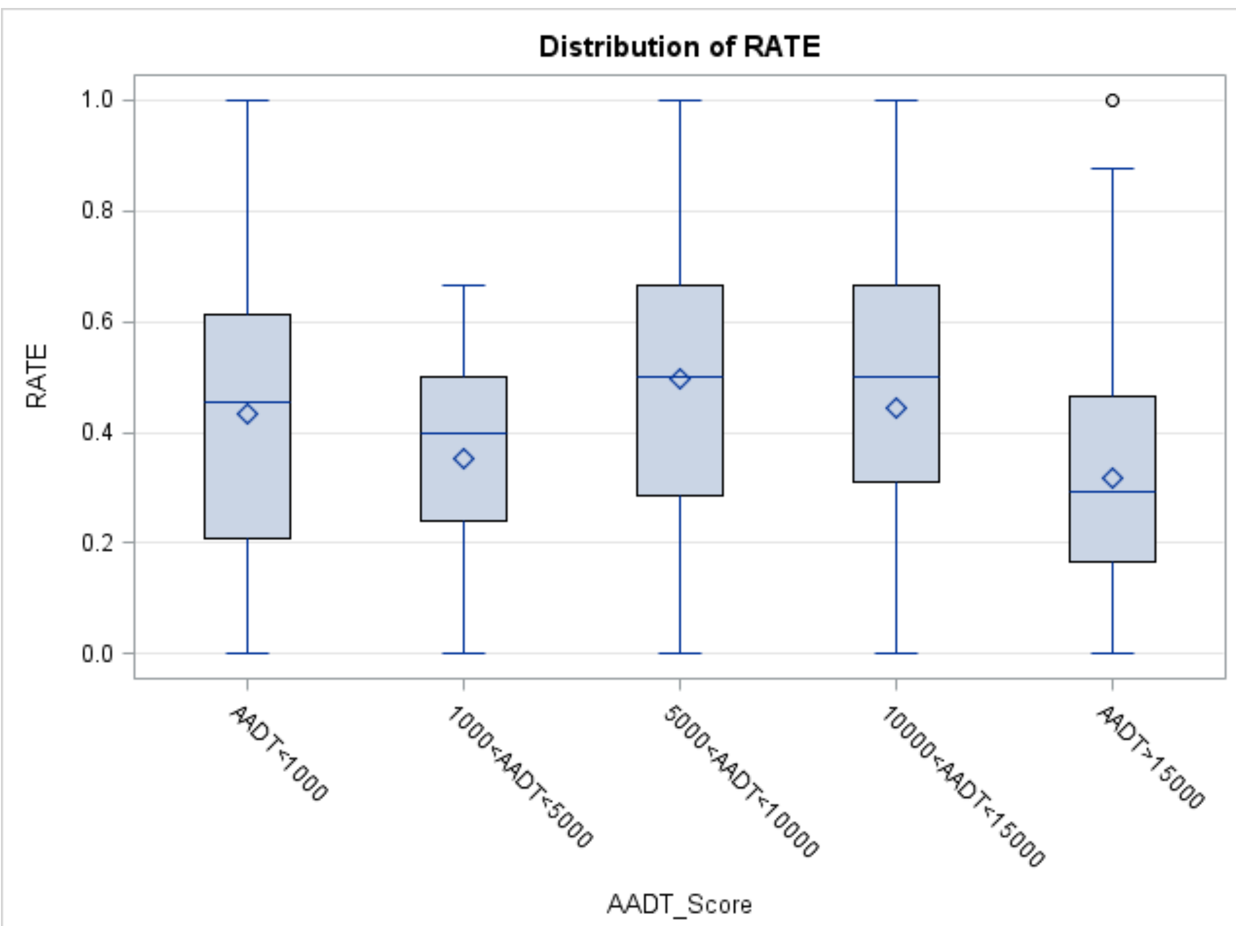



**Figure 8: Roadway Segment Violation Rates by AADT.**

### *3.3.3 USER BEHAVIORS AT STOP-CONTROL INTERSECTIONS*

Behaviors were observed at intersections with both stop-control and traffic signals with violations of intersection control analyzed by bicycle type and under varying speed detection thresholds. The average violation rates at intersection approaches with stop-control are depicted in Figure 9. At these intersection approaches, the average violation rate is lower for e-bike users for speed detection thresholds less that 11 kph but higher beyond this threshold. This indicates that e-bike users are more likely to obey stop signs; however, those who violate the stop sign are likely to do so at a higher speed than regular bicycle users. A threshold of 11 kph is also slightly higher than the average observed travel speed for regular bicycle trips, meaning few regular bicycle users are likely to enter an intersection above this threshold even when violating the stop sign.

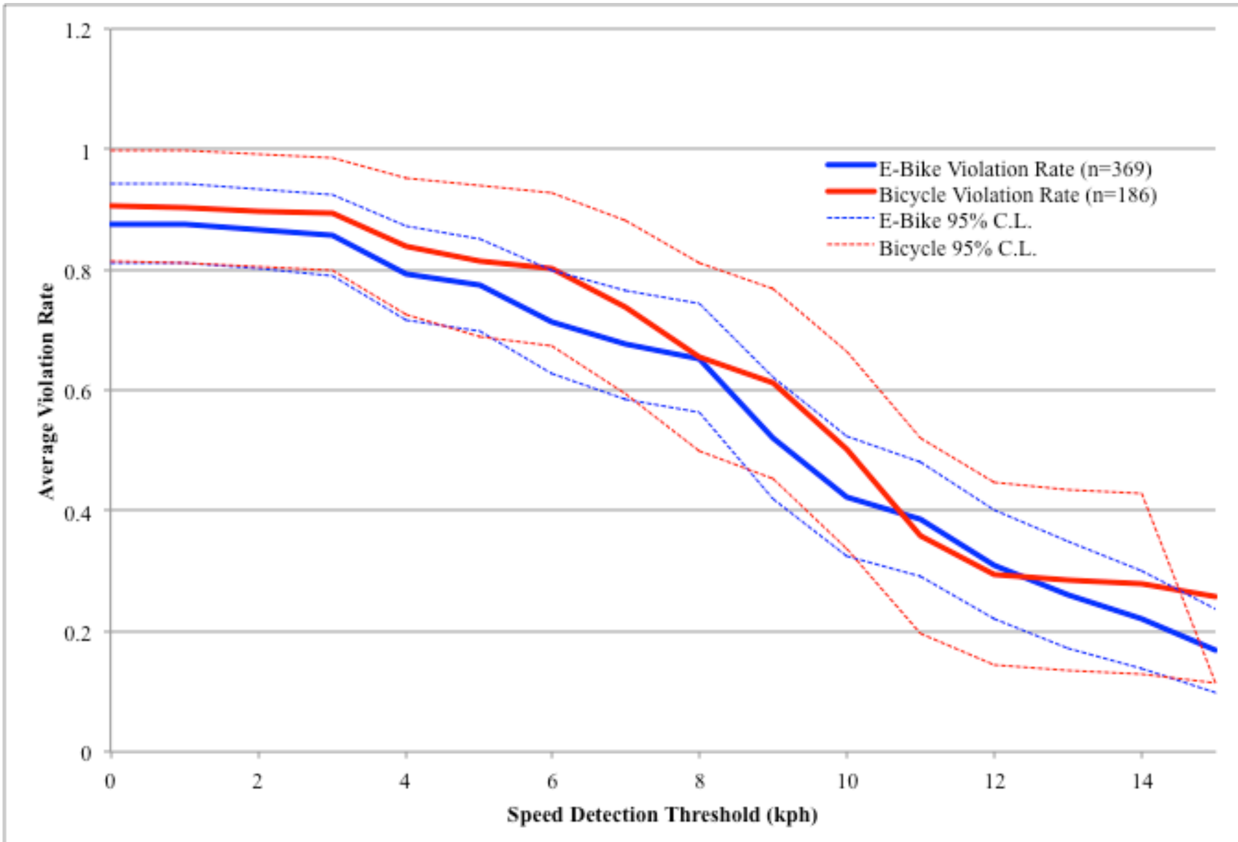



**Figure 9: Average Violation Rates at Stop-Control Intersection Approaches.**

*3.3.4 USER BEHAVIORS AT SIGNALIZED INTERSECTIONS*

For signalized intersections, violation rates are lower than those observed at stop-controlled approaches; however, violation rates by e-bike users are higher at these approaches under most speed thresholds. Furthermore, the number of observations of e-bikes at signalized approaches (n=240) is considerably higher than the number of observations of regular bicycles at those approaches (n=57). This observation could reflect that many regular bicycle users avoid signalized intersections or that, because of the performance of e-bikes, more of those users are likely to take routes that encounter signalized intersections. This could reflect an increased perception of safety on e-bikes than on regular bicycles while traveling through intersections.

Based on the average violation rates, detection thresholds of 3 kph or less consistently result in very high violation rates at both intersection approach types. Lower threshold values likely represent speeds too low for accurate detection of stopped vehicles with the given GPS data quality. Above this speed threshold, there is much variation among violation rates for regular bicycles and e-bikes at both types of intersections.

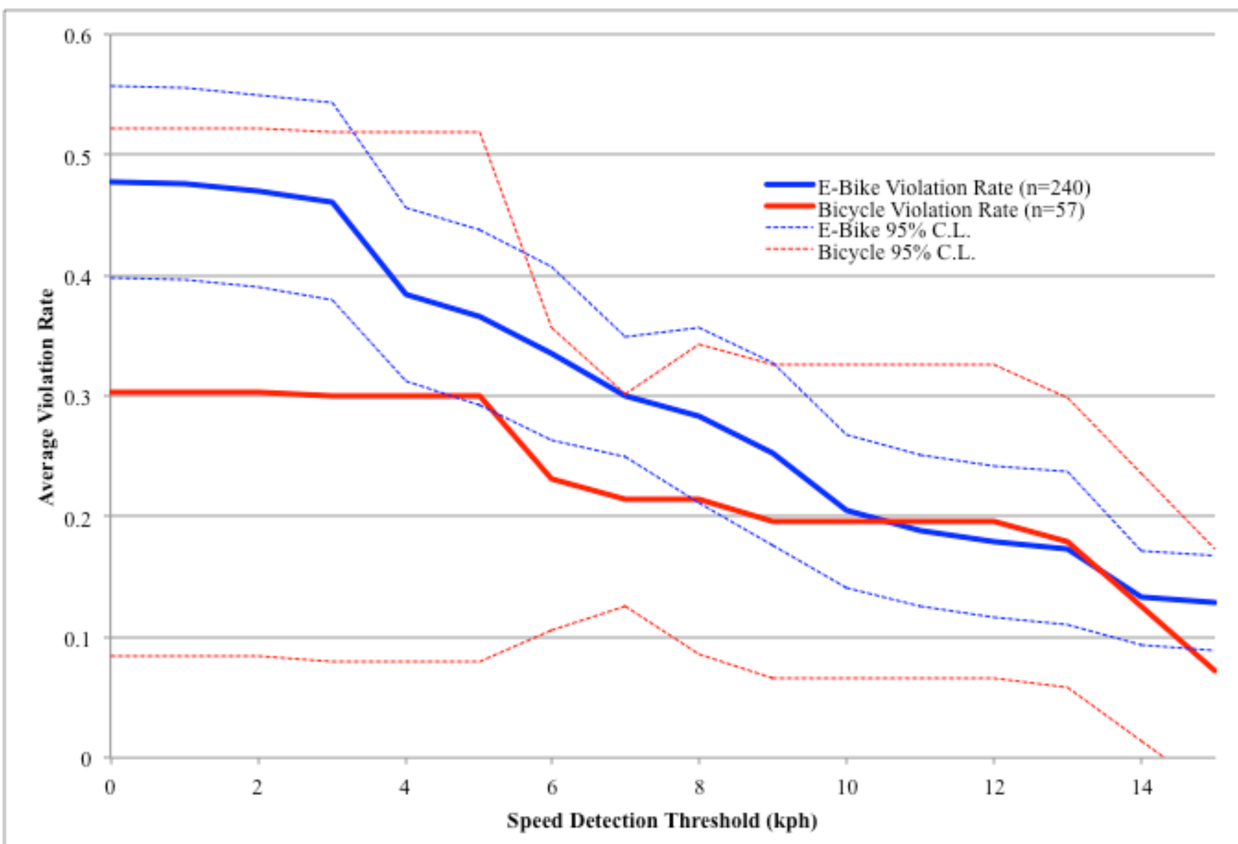


**Figure 10: Average Violation Rates at Signalized Intersection Approaches.**

Among the intersection approaches studied, there is much variation in violation rates, some with very high violation rates and others with relatively low rates. A number of variables were considered as potential factors influencing violation rates at each location: AADT for the approach and for the intersecting roadway; posted speed limits for both the approach and intersection roadway; whether the slope of the approach is uphill, downhill, or level; as well as bicycle type, either regular bicycle or e-bike. An ordinary least squares regression model, of the form presented by Equation 2, including these variables was fitted to investigate the impacts of each variable of on violation rates ($V_{Rate}$) at the intersections.  Model parameters are described in Table 5.

$$V_{Rate} = \beta_0 + \sum_{i=1}^{n} \beta_i x_i \qquad \textit{(Eq. 2)}$$

Considering all approaches, the approach type, posted speed limit and AADT of the approach and intersecting street, and interactions between AADT and posted speed are significant factors contributing to violation rates. For stop-control intersections, these factors are intersecting AADT, approach grade entering the intersection, and interaction between approach and intersecting street AADT counts. Signalized intersections are again different, with important factors of approach AADT, posted speed limits for the approach and intersecting street, as well as interactions for the approach and intersecting street AADT and posted speed limits.

**Table 5: Models for Violation Rates at Intersection Approaches.**

| | All Approaches* | | Stop-Control** | | Signalized*** | |
|---|---|---|---|---|---|---|
| | Parameter Estimate | Pr > \|t\| | Parameter Estimate | Pr > \|t\| | Parameter Estimate | Pr > \|t\| |
| Intercept | -12.19199 | 0.0039 | 0.88417 | <.0001 | -3.80652 | 0.0041 |
| Approach Type | -0.51805 | <.0001 | N/A | - | N/A | - |
| Approach AADT | 1.57811 | 0.0002 | - | - | 1.26678 | 0.0005 |
| Approach Speed | 0.53422 | 0.0018 | - | - | 0.2369 | <.0001 |
| Intersecting AADT | -0.11893 | 0.0178 | -0.14676 | 0.0210 | - | - |
| Intersecting Speed | 0.22057 | 0.044 | - | - | -0.08241 | 0.009 |
| Grade | - | - | -0.06177 | 0.1347 | - | - |
| Bike Type | - | - | - | - | - | - |
| Interaction(AADT) | 0.06691 | 0.006 | 0.13503 | 0.1194 | - | - |
| Interaction (Speed) | -0.00909 | 0.0341 | - | - | - | - |
| Approach AADT*Speed | -0.06738 | <.0001 | - | - | -0.05156 | 0.0002 |
| Intersecting AADT*Speed | - | - | - | - | 0.00688 | 0.0056 |

*R-Square = 0.4441.
**R-Square = 0.1120
***R-Square = 0.4145

These models suggest that approach slope and intersecting traffic volumes have more bearing on violation rates at stop-control intersections than signalized ones. A negative value for approach grade indicates that a downhill slope promotes more stop sign violations than an uphill slope. Significant factors of approach AADT and posted speed limit for signalized intersections indicates that the approach environment itself is highly important at those intersections.

One important factor that does not enter any model is bicycle type.  Approach type, on the other hand, is significant. This indicates that while behaviors are different between users of each bicycle type the performance differences between the two modes are not significant factors to safety at intersections. The characteristics of the intersection itself, however, are significant factors to user safety. While the factors included in these models were found to be significant, low R-Square values for each model indicate that additional factors are important, highlighting a need for additional research into facility characteristics and user safety.

### 3.4 DISCUSSION AND CONCLUSIONS

This research investigates user safety on two modes that share many similar characteristics but differ in terms of performance, regular bicycles and e-bikes. Concerns over user safety on e-bikes as compared to regular bicycles stems from the added benefit that users gain from the electric motor on e-bikes, which raise important policy questions about the differential role and place of e-bikes in the transportation system. In this study we considered several factors that have relevance to user safety: speed on roadways and shared use facilities, behaviors at intersections, and wrong way travel. While differences in behavior exist, and these differences have bearing on overall user safety while operating the two bicycle types, the differences are generally small and generally explained by other factors, unrelated to the bike itself. This infers that the advantages that users gain from e-bikes have little overall effect on user safety as compared users of regular bicycles. For instance, violation rates at intersections differ between the two modes, but the larger difference occurs between intersection types, not bicycle types.

These findings have relevance to bicycle and e-bike policy, mainly in removing a misconception that e-bikes are intrinsically more dangerous than regular bicycles. Violation rates were generally high for both modes. Further, this study identifies some areas for future research in understanding safety for users of the two modes. User performance on the two modes varies by facility type and facility characteristics. Additional characteristics such as the presence of bicycle lanes and other bicycle related facilities could curb dangerous user behavior, and reduce violations, by promoting safer practices among bicycle users.

# APPENDIX: CHAPTER 3

## APPENDIX 3.A: INSTITUTIONAL REVIEW BOARD RESEARCH CONSENT FORM AND LIABILITY WAIVER

# *UNIVERSITY OF TENNESSEE ELECTRIC BIKE AND BICYCLE SHARING PILOT PROGRAM RELEASE OF LIABILITY*

*Participant Name:* ___________________________ *Age:*_____ *Student ID No.:*__________________

*Date of Birth:* _______________ *Phone #:* ____________________

*Address:* _________________________ *City/State/Zip:* ____________________________

*E Mail Address:* ____________________________ *Major:* ___________________________________

*Degree Pursued:* __________________ *Expected Graduation Date:* __________________

**RELEASE AND ASSUMPTION OF RISK**
The undersigned hereby acknowledges that he/she understands that participation in bike sharing at the University of Tennessee is purely voluntary and is not part of the academic curriculum of the university. Participant understands and acknowledges that neither the University of Tennessee, nor the E Bike and Bicycle Sharing Pilot Program ("Pilot Program") is not an insurer of the behavior and/or actions of the Participant, and that the University of Tennessee and the Pilot Program assumes no liability whatsoever for personal injuries or property damages to the Participant or other third parties injured by Participant.

In consideration of the university making E Bikes (motorized bicycles) or Bicycles ("Bicycles") available for the Pilot Program and/or undersigned while participating in any such activities, the undersigned hereby releases The University of Tennessee, their successors, assigns, Trustees, officers, agents, and employees from any and all claims, demands and causes of action whatsoever, in any way growing out of or resulting from the undersigned's participation in the activities of the Pilot Program.

The undersigned further agrees that he/she understands that cycling involves substantial risk of bodily injury, property damage and other dangers associated with participation. Possible injuries include but are not limited to bruises, cuts and abrasions, twisted ankles, separated shoulders, broken bones, head injuries, or other serious physical injury or death. Hazards include but are not limited to debris on streets, pavement in poor condition, utility poles and other obstructions, acts of nature such as rock fall, varying weather conditions such as severe heat or cold and wet pavement, and other risks associated with riding with motor vehicles, E Bikes or bicycles.

It is expressly understood by the undersigned that he or she is solely responsible for any costs arising out of any bodily injury or property damage sustained through participation in normal or unusual activities of the Pilot Program. The participant does not have any medical conditions that would prevent participation in above named program. The participant has adequate health insurance to cover the costs of treatment in the event of any injury.

The undersigned understands that (1) all of his or her movements on any bicycle and/or motor driven vehicle while he or she participates in this project will be monitored by global position system software via a central processing unit installed on the vehicle, and (2) movements when he or she checks out and checks in a bicycle at the bike stations will be monitored and/or recorded with webcams and hereby waives his or her right to the customarily expected right of privacy afforded his or her freedom of movement during the time that he or she participates in this project.

Participant understands and agrees that his or her participation in this project is completely voluntary and that the data obtained from participation, including routes and whereabouts, will be recorded and shared for the purposes of research and/or education and consents to such disclosure for those purposes and/or for disclosure pursuant to lawful requests for information from law enforcement agencies.

**TERMS AND CONDITIONS**

The participant is the sole user, and is voluntarily participating in and is familiar with the E Bike and Bicycle Sharing Pilot Program ("Pilot Program") sponsored by The University of Tennessee and agrees to take full responsibility for the Pilot Program's shared Bicycle while it is under his or her watch. This includes adhering to all safety rules while riding the Bicycle at all times – avoiding riding on sidewalks, obeying all traffic laws, not riding while impaired, using head and taillights (not supplied) while riding at night, properly locking up the Bicycle to bicycle racks with the supplied locks. Wearing helmets (not supplied) is strongly encouraged.

The participant is a competent bike user. Participants shall exercise extreme due care at all times while cycling, and shall constantly be on the lookout for, and yield to pedestrians at all times. The participant must complete the Knoxville Transportation Planning Organization's "Bicycling Training Course" before participating in the program. The participant agrees that he/she will not carry or transport any persons or passengers on the Bicycle under any circumstance. Participants shall be aware of their surroundings and be on guard when using their student ID while checking in and checking out Bicycles. Bicycles shall not be taken into any buildings on the UT campus,

The participant must inspect the Bicycle before use, riding and/or operation of the Bicycle, and agrees to ensure that the Bicycle is in proper working conditions before using it and within 20 feet of the Bicycle station. Accidents and/or incidents must be reported within 24 hours to the University of Tennessee of or the City of Knoxville Police Department.

The participant must not use, ride or operate the Bicycle in the event of mechanical failure

The participant will not make any modifications to the equipment.

Maximum use time shall be 8 hours. If not returned in timely manner, the user must report stolen Bicycles to authorities. Participant takes full responsibility for any fines, traffic tickets, court costs, attorney's fees, judgments, etc,

Bicycles may be used and or operated only in the City of Knoxville and shall not taken outside of the city limits.

The Undersigned must be 18 years of age or older. If the Undersigned is married, then the signature of the spouse, appearing in the space indicated below signifies acceptance by said spouse,
that the terms and conditions hereof shall be binding upon them and shall constitute a release by them of any and all claims, demands and causes of action whatsoever which they or any of them may have against The University of Tennessee, its successors, Trustees, officers, agents or employees as a result of the undersigned student's, staff and/or faculty's participation in the E Bike and Bicycle Sharing Pilot Program.

**I HAVE CAREFULLY READ AND UNDERSTAND COMPLETELY THE ABOVE PROVISIONS AND AGREE TO BE BOUND THEREBY.**

Participant Signature: ________________________________________ Date: __________________
Spouse Signature: __________________________________________ Date: __________________

# CHAPTER 4: PHYSICAL ACTIVITY IMPLICATIONS OF REGULAR AND ELECTRIC BICYCLES FOR USERS OF AN ON-CAMPUS E-BIKE SHARING SYSTEM

**ABSTRACT**

This chapter presents a study on user physical health, focused around the users of an on-campus e-bike sharing system at the University of Tennessee [3]. The study involves 19 users of the sharing system and investigates physical activity metrics on identical trips made by those users with three modes: regular bicycle, electric assist bicycle, and walking. The users completed a 2.75 mile (4.4 kilometer) trip using each mode. Heart rate and user supplied power output were monitored along with GPS and power meter data for each trip. In addition, the study uses a laboratory test to relate $VO_2$ (ml/kg/min) and EE (kcal/min) to user heart rate during trips as a measure of energy expenditure. This study finds that energy demands for e-bikes are 24.5% less than that for regular bicycles for the same trip. Walking trips, while requiring less energy per unit time, take longer to complete and, in this case, require a greater amount of total energy from the user. These comparisons vary between male and female users and between users who do or do not own a personal bicycle. The study also reports on perceived exertion and level of enjoyment among the participants for each trip. Lastly, a method is introduced for extending this study to naturalistic data collected directly through the on-campus e-bike sharing system data.

## 4.1 INTRODUCTION

Electric assisted bicycles (e-bikes) have emerged in recent years as a new mode of sustainable transportation as well as a mode that serves as an active transportation option for users. Active transportation has many benefits to the user as an increased number of cycling or walking trips promotes improved public health and helps to reduce the risk of chronic diseases such as obesity and hypertension. Additionally, these modes can also reduce costs such as congestion, parking costs, energy consumption, and greenhouse gas emissions [9].

E-bikes, as well as regular bicycles, are types of active transportation, as they require an energy contribution from the user. Many authors have explored the impacts of active transportation modes on physical health. Use of active transportation modes results in a number of benefits such as reduced likelihood of obesity, reduced risk of cardiovascular disease, and reduced likelihood of diabetes [46, 47]. Those who use active transportation modes for at least some part of their commute are also shown to engage in other physical activities for exercise and recreation [48]. Furthermore, involvement in moderate or high levels of physical activity has been shown to increase life expectancy and have other positive benefits such as increasing the number of years lived without cardiovascular disease [49-51]. Even in populations of smokers, higher levels of physical activity result in more years of life expectancy as well as more years of life without disability [50].

Hankey et al. [10] indicates that the benefits of increased physical activity received through increased active transportation could be offset by the harmful impacts of exposure to poor air quality. This is contradictory, however, to findings from de Hartog et al. [52]. His study indicates that the benefits from increased physical activity through active transportation outweigh the impacts of air pollution and safety. A study by Rojas-Rueda et al. [53] on Bicing bikeshare system in Barcelona, Spain, used similar methods and concluded similar results for that system.

Some recent studies into the benefits associated with riding e-bikes as a mode of active transport have emerged. In a study with 18 otherwise sedentary participants, Gojanovic et al. [54] studied a typical commute by the modes of walking, bicycle, e-bike on a moderate assist level, and e-bike on a high assist level. All trips by all participants yielded a MET value (a standard metabolic equivalent equal to 1 kcal/kg/hr) of at least 3.0 MET, corresponding to a moderate intensity activity level. 72% of walking trips, 47.1% of trips by e-bike on high assist, 88.2% or trips by e-bike on moderate assist, and 100% of biking trips resulted in greater than 6.0 MET, corresponding to vigorous activity; however there was no significant difference in average MET for trips made by walking and by e-bike with high assist. Sperlicht et al. [55] investigated the impacts of e-bike use on women users in terms of biomedical, cardiorespiratory, and metabolic responses and determined that while the effects on the user are lower than from regular bicycles, e-bikes can serve as an approach to engaging sedentary women to exercise.

There is currently little knowledge on the comparative health benefits of e-bikes to regular bicycles. This study aims to build on these previous findings by considering the effects of e-bikes on the physical health of users of an on-campus e-bike sharing system. In contrast to previous studies which focus on the effects on currently sedentary individuals, this study considers individuals who already have access to and use bikes through the e-bike sharing system, although to varying degrees of use. Characteristics of this system cycleUshare are explained in Langford et al. [3]. Users of this system have access to both regular bicycles and e-bikes at sharing stations on the campus of the University of Tennessee, providing an opportunity to study the users of these modes and the effect of their mode choice on their physical health. In addition, this work builds a platform for future physical activity studies focused on naturalistic use of the e-bike sharing system.

## 4.2 METHODS

### *4.2.1 USER PARTICIPATION*

This study incorporates users of the on-campus e-bike sharing system as participants, with a sample of e-bike sharing system users volunteering to participate. A summary of those volunteers is presented in Table 6. Criteria for participation included: first, that the volunteer be a registered user of cycleUshare, and second, that the volunteer pass a physical activity readiness questionnaire (PAR-Q) [56] ensuring that the participant is healthy enough to complete the study. Prior to beginning the study, participant height and weight were measured. Other user information was verified through collection of updated consent forms for the e-bike sharing program. The study began with 19 volunteers, three of which did not finish all parts of the study. The participants represent a broad range of user characteristics as described by Table 6, though are representative of the typical e-bike sharing system user in terms of abilities.

**Table 6: Summary of Study Participants.**

| Sex | N |
|---|---|
| Male | 11 |
| Female | 8 |
| Age | |
| <20 | 3 |
| 20-25 | 8 |
| 26-30 | 4 |
| 31-40 | 2 |
| 41-50 | 0 |
| >50 | 2 |
| Ethnicity | |
| White | 14 |
| Minority | 5 |
| Other: | |
| Own/have access to a bike | 9 |
| Own a car | 17 |
| BMI[a,b] | |
| Male | 26.10 |
| Female | 22.44 |

[a]Values calculated using CDC formula for Body Mass Index (BMI) [20].
[b]BMI values of users from this study (Mean=24.56, Std. Dev=4.09) were statistically the same as a sample of 1100 entering freshman at the University of Tennessee in 2006 (Mean=23.41, Std. Dev=4.48).

### *4.2.2 TECHNOLOGIES USED*

The study uses two regular bicycles and two e-bikes, which are the same as those used by the e-bikes sharing system. The regular bicycle model used in the sharing system is a Marin Larkspur weighing approximately 30 pounds (lbs), or approximately 13.6 kilograms (kg). The e-bikes used in this study are Currie Technology I-Zip Trekking Enlightened models, which are modified in the sharing system and weigh approximately 60lbs, or 27.2kg, including the battery. The e-bikes use 24V, 10Ah batteries, which connect to the rear of the e-bike to provide power to the e-bike motor (250W) when the user begins pedaling. They use Currie Technology's torque measurement method (TMM) to provide power to the motor proportional to the power supplied by the user through the pedals.

For this study both bicycle types were modified to include Quarq SRAM S2275 MTB power meters, which replaced the existing crank set on each bicycle used, resulting in 16 gears (range 1:0.8 to 1:3.6) on the regular bicycles and eight gears (range 1:1.2 to 1:3.3) on the e-bikes. This model of power meter was selected since the gear ratio is similar to that used by the bicycles in the sharing system; however, with the power meter installed, regular bicycles are limited to two sets of front gears, which reduces the total number of gears available to the user to 16, rather than 24 available gears for the bikesharing bikes. For the e-bikes used in this study, there is no change in the number of available gears as the front derailleur is disabled, which only allows the user to access eight gears. The power meters were calibrated prior to beginning each trip.

Study participants wore Garmin heart rate monitors during all trips. The heart rate monitors and Quarq power meters synchronize with a Garmin Edge 500 GPS receiver to provide a data point each second during the study. Data from each source, as well as the GPS data for the trip, were downloaded following each exercise. Data were filtered to eliminate any recorded points prior to the trip beginning as well as to eliminate points collected after the trip ended.

### *4.2.3 LAB TESTING*

Each participant began the study with a laboratory test, where the user rode a stationary bicycle under varying levels of resistance. Participants began the test with a two-minute rest on the stationary bicycle. They then began riding at the lowest resistance setting (100 watts) and resistance increased by increments of 50 watts after each two-minute phase until the participant reached their age predicted maximum heart rate [57], as described in Equation 2. Participant heart rate, in beats per minute (bpm), oxygen ventilation rate ($VO_2$), measured in milliliters per kilogram per minute (ml/kg/min), and energy expenditure (EE), measured in kilocalories per minute (kcal/min) were measured at the end of each phase.

$$85\%\ Age\ Predicted\ Heart\ Rate = (220 - Age)\times 0.85 \qquad \textit{(Eq. 2)}$$

Values obtained in the lab test were used to correlate both $VO_2$ and EE to user heart rates, important for field tests. Curves were fitted for each user, individually, and applied to heart rate values measured during field tests. Based on the laboratory data, separate curves were fitted above and below the heart rate inflection point as observed for each user. Figure 11 and Figure 12 depict typical curves for VO2 and EE for a typical participant. Participants were advised not to consume caffeine prior to laboratory testing as their heart rates could be affected.

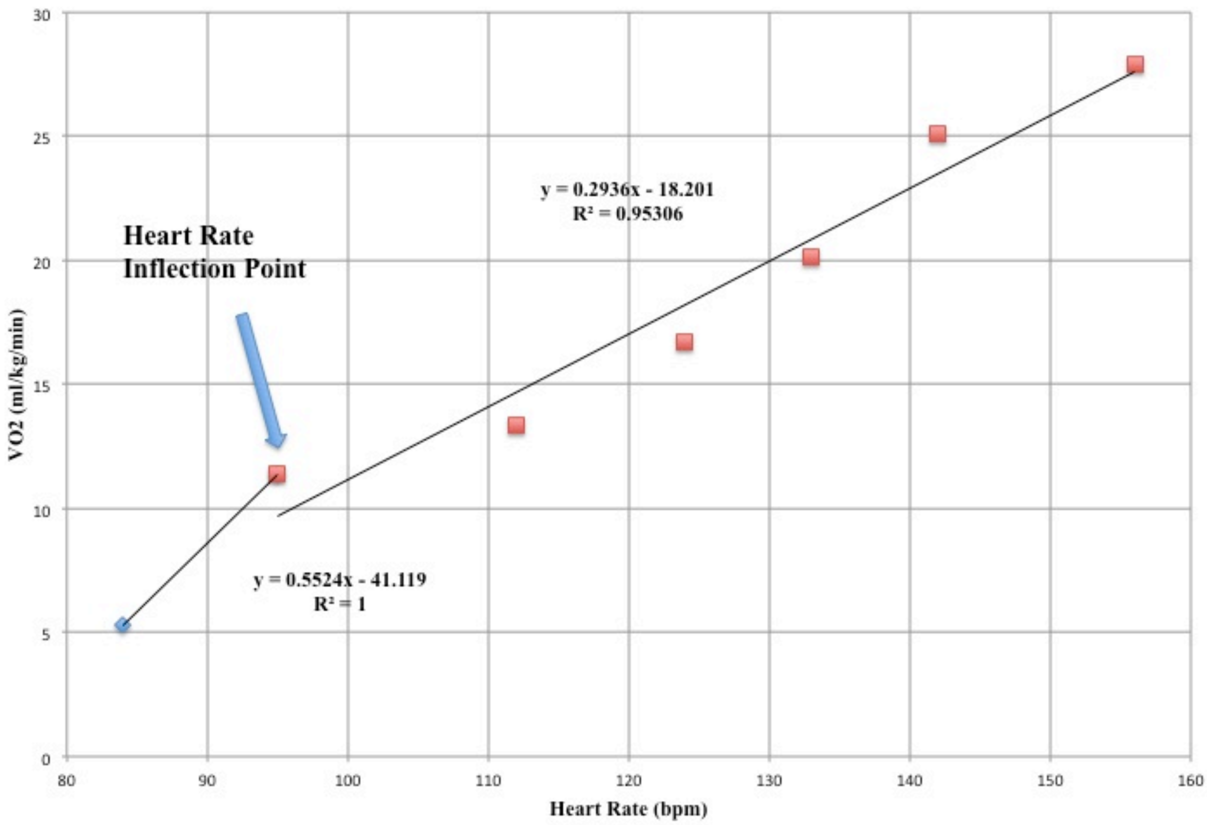



**Figure 11: Heart Rate Versus $VO_2$ for a Typical Participant.**

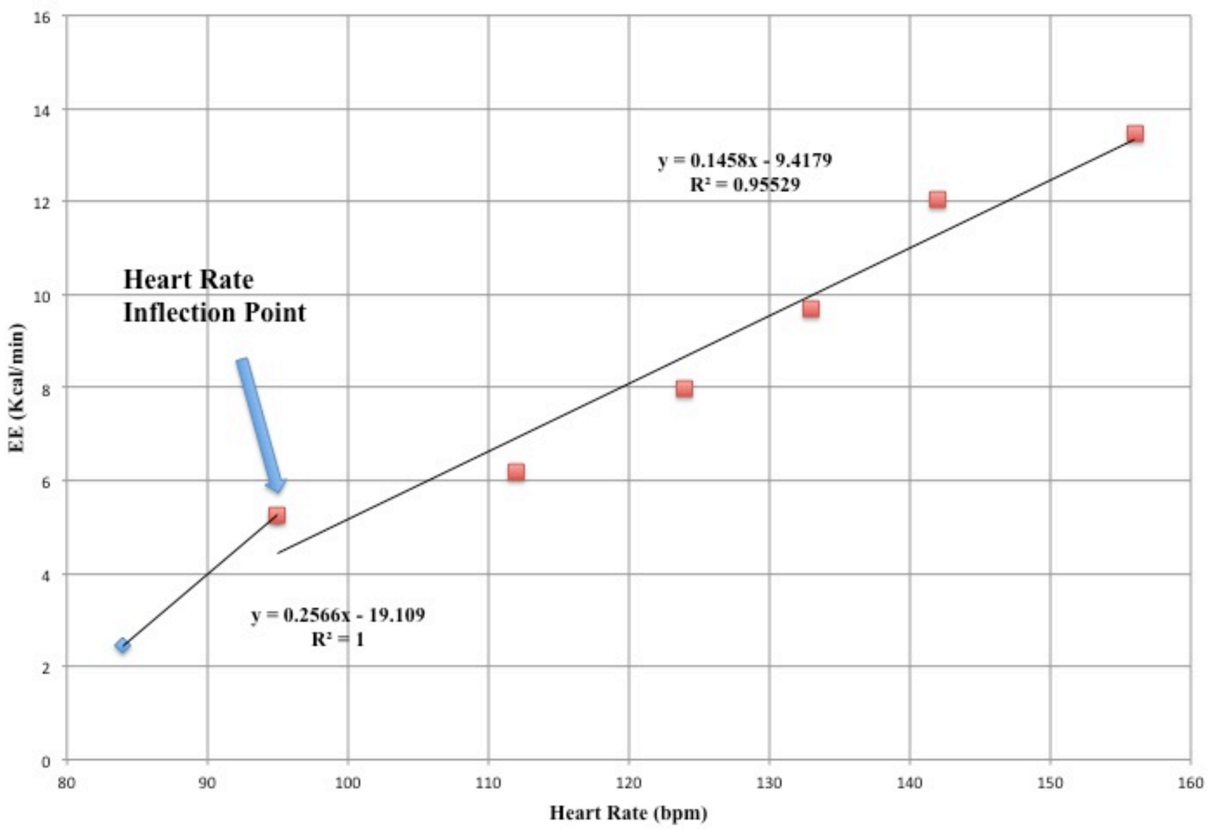
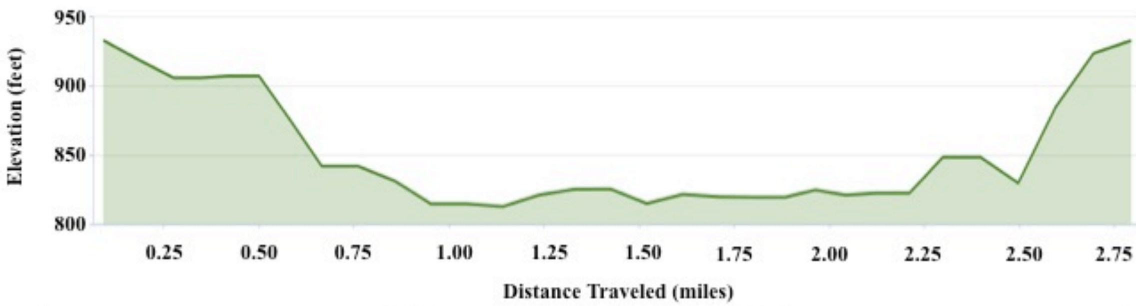



**Figure 12: Heart Rate Versus EE for a Typical Participant.**

### *4.2.4 FIELD TESTING*

Following completion of laboratory testing, participants then completed a series of trips on varying modes: regular bicycle, e-bike, and walking. These three modes represent the dominant modal alternatives for users of the bikesharing system [3]. These trips were conducted on separate days, with a minimum of 24 hours rest between tests, to ensure the participant was not affected by a previous test. Each test followed a predefined 2.75 mile (4.4 km) route consisting of varying grade changes. The trips included segments along roadways, in which the participant was exposed to traffic and encountered stop signs and traffic signals. Other trip segments were along a local greenway. The route was a loop, but represents a typical route that might be taken in urban Knoxville. A description of these segments is included in Figure 13.



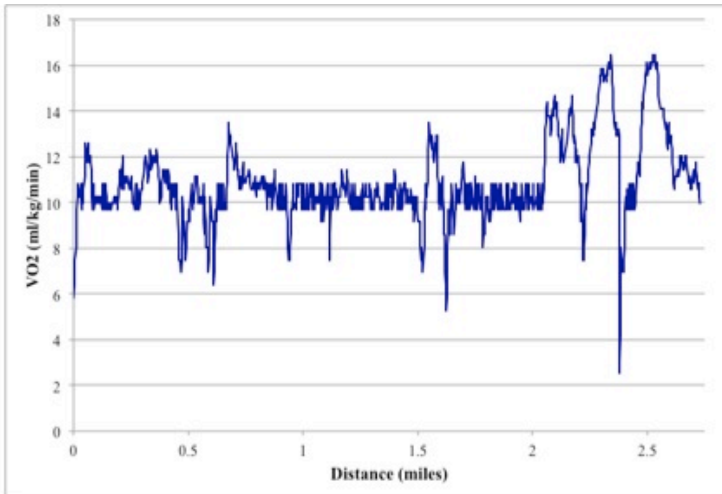

| Segment ID | Facility Type | Distance Traveled (miles) | Begin Elevation (feet) | End Elevation (feet) | Average Slope (%) |
|---|---|---|---|---|---|
| 1 | Roadway | 0.06 | 932 | 936 | 1.26 |
| 2 | Roadway | 0.27 | 936 | 905 | -2.80 |
| 3 | Roadway | 0.41 | 905 | 907 | 0.27 |
| 4 | Roadway | 0.64 | 910 | 848 | -5.11 |
| 5 | Greenway | 0.92 | 848 | 820 | -1.89 |
| 6 | Greenway | 1.58 | 820 | 821 | 0.03 |
| 7 | Greenway | 2.11 | 821 | 822 | 0.04 |
| 8 | Greenway | 2.27 | 822 | 850 | 3.31 |
| 9 | Roadway | 2.42 | 850 | 866 | 2.02 |
| 10 | Roadway | 2.75 | 866 | 932 | 3.91 |

**Figure 13: Summary of Course for Field Tests.**

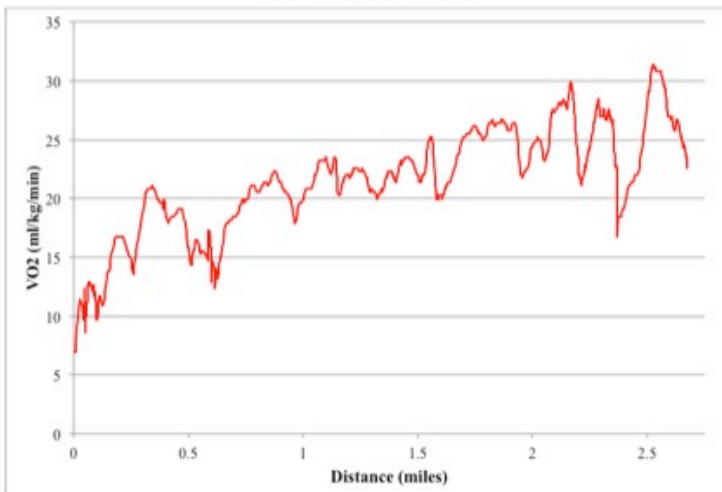
Each participant began the field test portion of the study by walking the course. This allowed the participant to learn the route while minimizing the risk of unnecessary stops or other errors during the trip. Following completion of the walking activity, regular bicycle and e-bike trips were completed in random order on following testing days.

During each trip, participant heart rate, power output, and speed were recorded at a one-second resolution. Figure 14, Figure 15, and Figure 16 display examples of the $VO_2$, EE, and power output data for one participant during each trip type. Participants were instructed to ride, or walk, as they normally would when completing a utilitarian trip on campus. It was assumed that during typical travel on e-bikes those users select the highest level of assistance on the e-bike, out of five levels. Thus, for e-bike trips, participants were instructed to use the highest level of assistance on the e-bike for the entire trip.

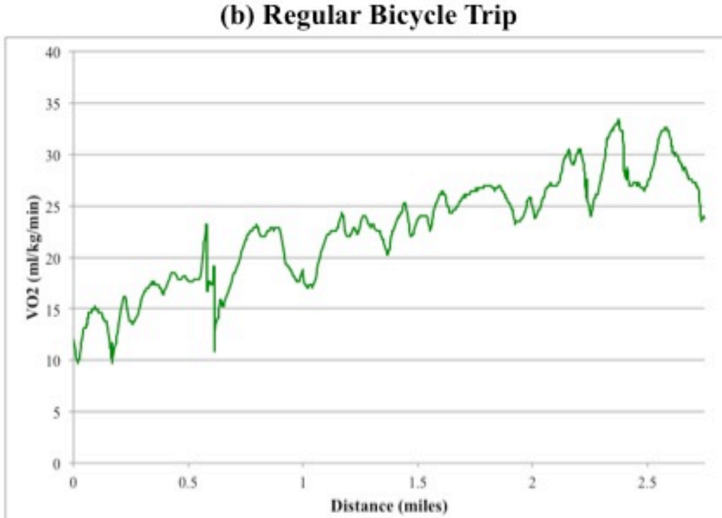
The field tests took place between March 19, 2013, and May 9, 2013. During this time period, weather conditions ranged greatly with temperatures ranging from 32° Fahrenheit to 83° Fahrenheit at the time of testing. No tests were conducted when temperatures were below freezing, and participants were provided the option to reschedule testing if they felt the weather conditions were unsuitable for the activity that day. Also, no tests were conducted on days with rain or a strong chance of rain or storms.




(a) Walking Trip

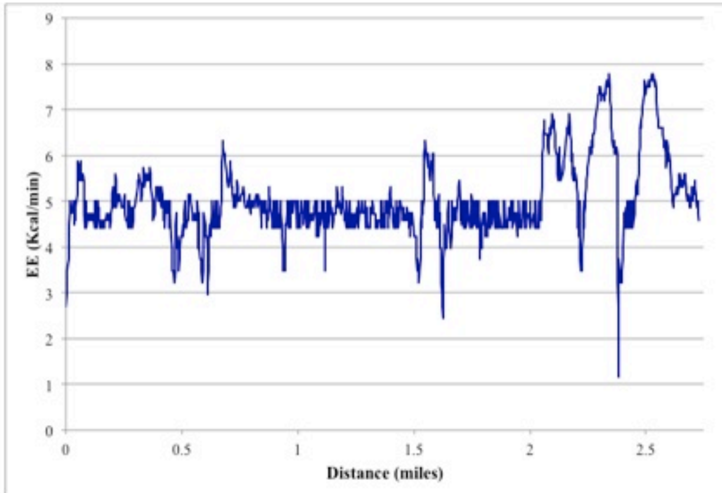



(b) Regular Bicycle Trip

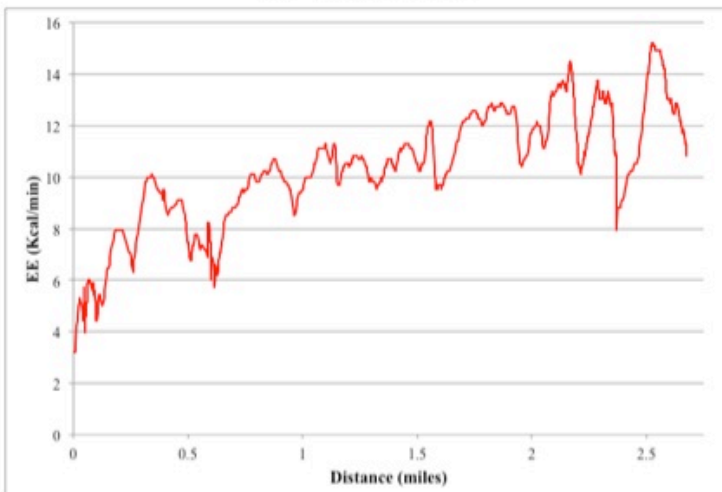



(c) E-Bike Trip

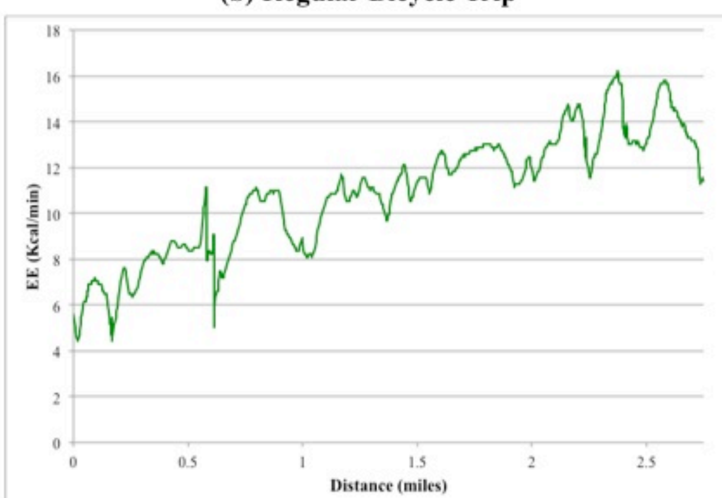
**Figure 14: Example $VO_2$ Measurements for a Study Participant, parts (a), (b), and (c).**




**(a) Walking Trip**

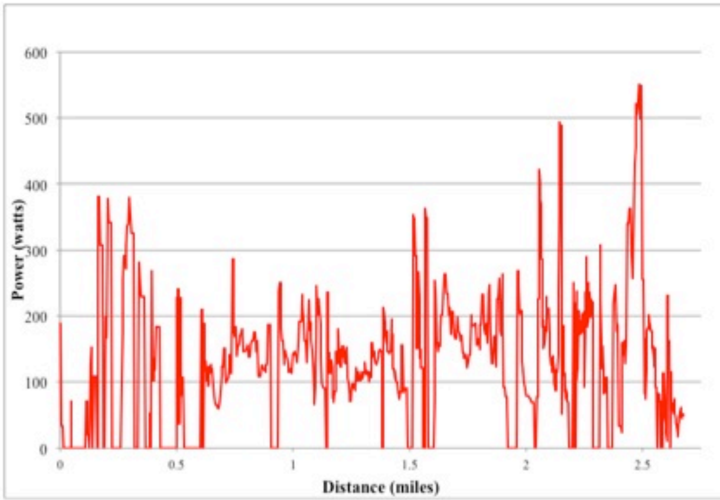



**(b) Regular Bicycle Trip**

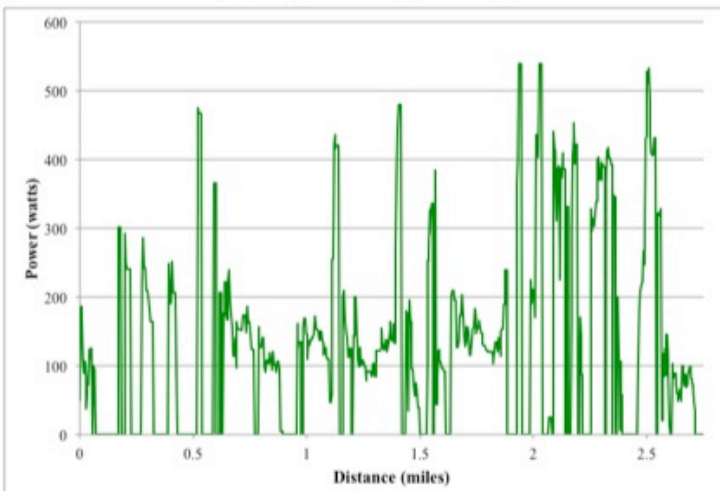



**(c) E-Bike Trip**

**Figure 15: Example EE Measurements for a Study Participant, parts (a), (b), and (c).**




**(a) Regular Bicycle Trip**




**(b) E-Bike Trip**

**Figure 16: Example User-Supplied Power Measurements for a Typical Participant, parts (a) and (b).**

Immediately following each trip, the participants were presented with post-activity surveys. These surveys asked users about the trip they just completed with regard to a number of metrics. Alternative modes were gauged in these surveys, as were the participants' perceived need for a shower following the trip, the participants' perceived level of exertion -- measured using the Borg scale of exertion, and the participants' level of enjoyment during the trip. These surveys were also used to identify and document any problems that arose during the trip that could affect the overall outcome. For instance as the selected route encounters several intersections with either stop signs or traffic signals, some users reported delays that they considered unusually long.

**4.3 RESULTS**

Of the 19 participants that began the study, all of them completed a walking trip, but only 17 completed an e-bike trip and 16 completed a regular bicycle trip. Performance on the course was studied for each participant, and laboratory measurements for $VO_2$ and EE were correlated to heart rate measurements collected during each trip either walking or on a regular bicycle or e-bike. These rates were applied over the course of the trip and summed to provide a measure of total energy expenditure and total amount of oxygen ventilated during the trip. Table 7 summarizes and compares metrics for trips on each mode.

**Table 7: Summary Statistics from Field Tests by Mode.**

| | Travel Mode[a] | | | | |
|---|---|---|---|---|---|
| | Walking n=19 | | Regular Bicycle n=16 | | E-Bike n=17 |
| Average Trip Time (min) | 50.70 | * | 20.29 | | 17.87 |
| | (4.70) | | (3.44) | | (2.00) |
| Average Power (watts)[b] | - | | 82.30 | * | 62.09 |
| | - | | (20.55) | | (23.52) |
| Heart Rate (bpm) | 114.76 | | 123.10 | | 120.36 |
| | (14.48) | | (17.43) | | (16.54) |
| Average EE (Kcal/min) | 5.64 | | 6.85 | | 6.09 |
| | (2.19) | | (2.64) | | (2.41) |
| Trip Total EE (Kcal) | 281.65 | * | 136.18 | | 107.96 |
| | (103.17) | | (51.61) | | (41.45) |
| Average VO2 (ml/kg/min) | 15.09 | | 18.12 | | 16.37 |
| | (5.01) | | (5.67) | | (4.93) |
| Trip Total VO2 (ml) | 57325.90 | * | 27242.35 | | 21914.89 |
| | (20877) | | (10269) | | (8323) |
| Average Speed (kph) | 3.02 | * | 8.01 | * | 9.20 |
| | (0.31) | | (1.01) | | (0.96) |
| Average Moving Speed (kph) | 5.14 | * | 14.35 | * | 16.36 |
| | (0.58) | | (1.43) | | (1.50) |

[a]Standard deviation shown in parenthesis.

[b]Average power calculated using moving observations only.

*Means comparison with e-bike is significant at a 99% confidence level.

While average EE (Kcal/min) and $VO_2$ (ml/kg/min) values on walking trips are slightly lower than for the other modes, longer trip times for walking trips produce greater total EE (Kcal) and $VO_2$ (ml) rates for the trip compared to regular bicycle and e-bike trips. E-bike trips have the lowest total EE (Kcal) and $VO_2$ (ml) rates, reflecting the higher average travel speeds for that mode compared to the other modes and lower average EE (Kcal/min) and $VO_2$ (ml/kg/min) rates compared to regular bicycle trips. This also reflects lower requirements on e-bike trips for user-supplied power than regular bicycle trips. The average power requirements while moving are presented, indicating that e-bike trips require 24.5% less power on average from the user than the regular bicycle trips.

Comparing user trips by gender shows that male users require more power on average for the same trip than female users, 87.49 watts for regular bicycle trips and 67.88 watts for e-bike trips compared to 72.97 watts and 52.44 watts for the females making the same trips, as shown in Table 8. This could reflect the heavier average weight for male participants compared with the female participants. Previous findings [3] show that female users of the on-campus e-bike sharing system are more attracted to the system by the physical activity benefits of the regular bicycles and e-bikes than male users. In this study, the female users who participated have a lower BMI compared to the male users, 22.44 versus 26.10, indicating that the female participants are more physically fit and are possible more active than the male participants. This is also reflected in EE (Kcal/min) and $VO_2$ (ml/kg/min) rates as male participants have higher rates for each mode compared with female participants. Interestingly, female users have higher heart rates, and thus higher EE (Kcal/min) and $VO_2$ (ml/kg/min) rates, for e-bike trips compared to regular bicycle trips, although total EE (Kcal) and $VO_2$ (ml) are lower due to higher average travel speed and lower duration of trips on e-bikes. This could be a result of the additional weight of the e-bike over the regular bicycle relative to the weight of the user.

**Table 8: Comparison of Trips by Gender.**

| | Gender[a] | | | | | |
|---|---|---|---|---|---|---|
| | Male | | | Female | | |
| Mode | Walking | Regular Bicycle | E-Bike | Walking | Regular Bicycle | E-Bike |
| n | 11 | 10 | 10 | 8 | 6 | 7 |
| Average Trip Time (min) | 50.89 * | 20.18 | 18.32 | 50.37 * | 20.50 | 17.11 |
| | (5.37) | (2.47) | (2.26) | (3.75) | (5.12) | (1.30) |
| Average Power (watts)[b] | - | 87.49 ** | 67.88 | - | 72.97 ** | 52.44 |
| | - | (17.90) | (26.88) | - | (23.71) | (13.41) |
| Heart Rate (bpm) | 113.40 | 129.93 | 117.04 | 117.03 | 110.81 | 125.89 |
| | (16.62) | (10.80) | (16.94) | (11.07) | (21.45) | (15.66) |
| Average EE (Kcal/min) | 6.17 | 8.02 | 6.72 | 4.76 | 4.72 | 5.06 |
| | (2.36) | (1.77) | (2.70) | (1.70) | (2.76) | (1.52) |
| Trip Total EE (Kcal) | 308.54 * | 160.91 | 120.97 | 236.82 * | 91.67 | 86.28 |
| | (110.23) | (34.88) | (44.60) | (78.75) | (48.70) | (25.93) |
| Average VO2 (ml/kg/min) | 15.29 | 20.09 | 16.44 | 14.77 | 14.58 | 16.26 |
| | (5.48) | (4.03) | (5.48) | (4.59) | (6.91) | (4.32) |
| Trip Total VO2 (ml) | 62865.99 * | 32070.12 | 24484.46 | 48092.41 * | 18552.37 | 17632.28 |
| | (21966) | (6966) | (8977) | (16592) | (9943) | (5249) |
| Average Speed (kph) | 3.01 * | 8.14 *** | 8.97 | 3.05 * | 7.79 * | 9.59 |
| | (0.35) | (0.96) | (1.04) | (0.26875) | (1.19) | (0.72) |
| Average Moving Speed (kph) | 5.21 * | 14.32 ** | 15.93 | 5.03 * | 14.42 * | 17.07 |
| | (0.66) | (1.34) | (1.49) | (0.44) | (1.75) | (1.35) |

[a]Standard deviation shown in parenthesis.

[b]Average power calculated using moving observations only.

*Comparison with e-bike is significant at a 99% confidence level.

**Comparison with e-bike is significant at a 95% confidence level.

***Comparison with e-bike is significant at a 90% confidence level.

The overall impacts of e-bikes and e-bike sharing on users with regard to physical activity benefits depends partially on the users activity level. Users who are active outside of using the e-bike sharing system benefit differently than those who are otherwise sedentary. Using bicycle ownership as a measure for user participation in active transportation, Table 9 compares trips by each mode for participants who own bicycles and those who do not. In this case, average trip travel times on either regular bicycle or e-bike are higher than those for users who do own a bicycle than for those who do. In terms of energy requirements, regular bicycles require approximately 30% more power from those users to complete the trip than e-bikes. This is also reflected in higher average EE (Kcal/min) and $VO_2$ (ml/kg/min) rates for these users on regular bicycles than on e-bikes.

**Table 9: Trip Comparison by Bicycle Ownership.**

| | Bicycle Ownership (outside of e-bike sharing system)[a] | | | | | |
|---|---|---|---|---|---|---|
| | Owns a Bicycles | | | Does Not Own a Bicycle | | |
| **Mode** | Walking | Regular Bicycle | E-Bike | Walking | Regular Bicycle | E-Bike |
| **n** | 9 | 7 | 7 | 10 | 9 | 10 |
| **Average Trip Time (min)** | 50.66 * | 17.83 | 17.55 | 50.74 * | 21.66 *** | 18.11 |
| | (5.30) | (2.08) | (1.73685) | (4.39) | (3.35) | (2.25) |
| **Average Power (watts)[b]** | - | 72.17 | 62.89 | - | 87.94 ** | 61.48 |
| | - | (19.74) | (20.77) | - | (19.79) | (26.70) |
| **Heart Rate (bpm)** | 111.17 | 121.74 | 123.43 | 118.36 | 123.86 | 117.97 |
| | (13.50) | (9.07) | (17.70) | (15.41) | (21.23) | (16.23) |
| **Average EE (Kcal/min)** | 5.11 | 5.64 | 6.19 | 6.16 | 7.52 | 6.02 |
| | (2.51) | (2.54) | (2.09) | (1.84) | (2.58) | (2.76) |
| **Trip Total EE (Kcal)** | 251.32 * | 99.66 | 107.36 | 311.97 * | 156.48 | 108.42 |
| | (107.28) | (47.71) | (31.85) | (95.90) | (43.52) | (49.60) |
| **Average VO2 (ml/kg/min)** | 13.48 | 14.97 | 16.91 | 16.70 | 19.87 | 15.95 |
| | (5.36) | (5.01) | (4.21) | (4.37) | (5.49) | (5.63) |
| **Trip Total VO2 (ml)** | 51739.28 * | 19836.22 | 21915.71 | 62912.52 * | 31356.87 | 21914.26 |
| | (22944) | (9476) | (6809) | (18334) | (8553) | (9753) |
| **Average Speed (kph)** | 3.03 * | 8.62 | 9.34 | 3.02 * | 7.67 * | 9.10 |
| | (0.35) | (0.58) | (0.96) | (0.29) | (1.07) | (1.01) |
| **Average Moving Speed (kph)** | 5.33 * | 14.61 *** | 16.24 | 4.95 * | 14.21 * | 16.45 |
| | (0.64) | (0.99) | (1.56) | (0.48) | (1.66) | (1.55) |

[a]Standard deviation shown in parenthesis.

[b]Average power calculated using moving observations only.

*Comparison with e-bike is significant at a 99% confidence level.

**Comparison with e-bike is significant at a 95% confidence level.

***Comparison with e-bike is significant at a 90% confidence level.

Comments received in post-activity surveys for each completed trip revealed that some users, on both regular bicycles and e-bikes, experienced difficulty completing portions of the trip, particularly segments involving uphill grades. However, when asked about level of enjoyment using a five-point Likert scale, participants responded favorably after trips on both bicycle types. Figure 17 shows the level of enjoyment reported following each trip. Participants completing walking trips responded most favorably with 52% indicating that the trip was very enjoyable, compared to only 31% of the regular bicycle trips and 26% of walking trips. None of participants responded that the trip was not at all enjoyable after completing an e-bike trip.

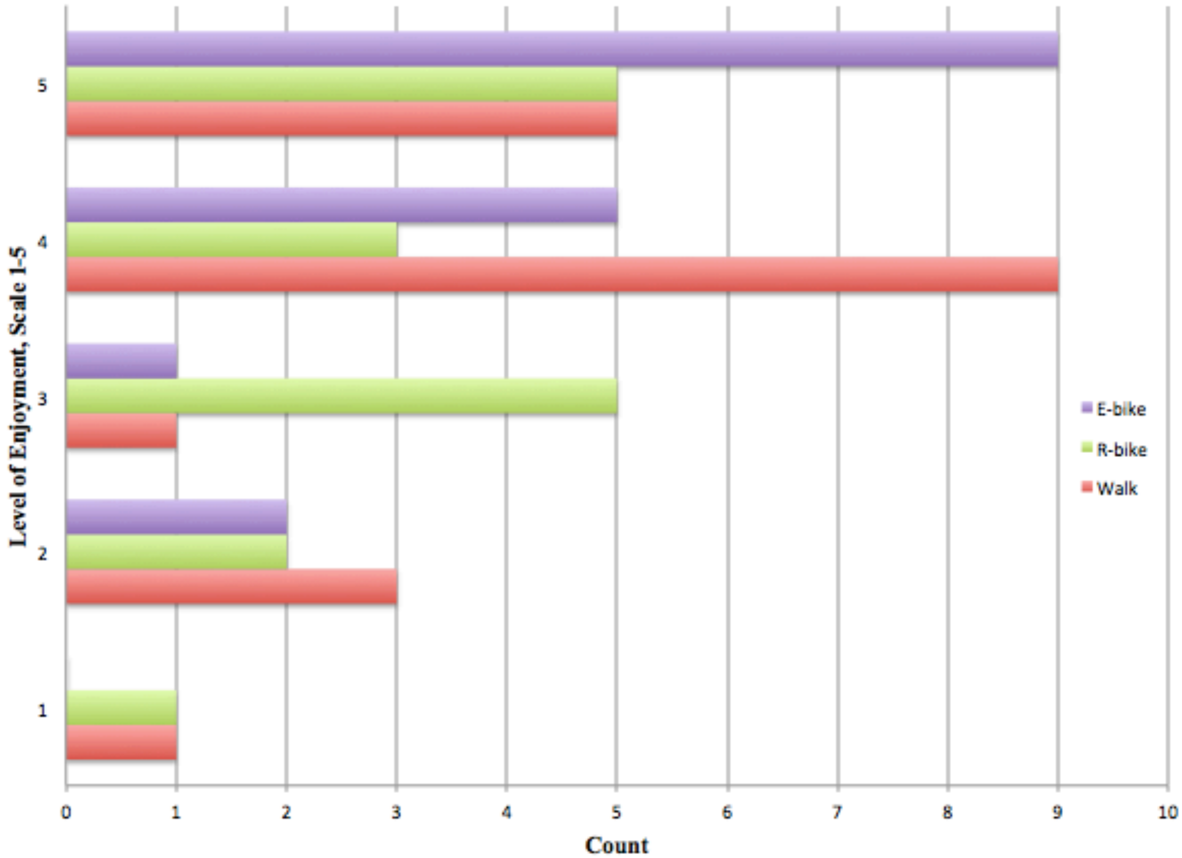



**Figure 17: Level Of Enjoyment During Trip**[a]

[a]Responses based on a five-point Likert scale with 5 being very enjoyable and 1 being not at all enjoyable.

Participants were also asked about their perceived level of exertion, using the Borg scale of exertion, their perceived need for a shower, and their choice of alternative mode after completing each trip. Results from post-activity surveys are summarized in Table 10. Perceived exertion levels for participants after e-bike trips is not significantly different than that those after walking trips. Participants completing trips on either regular bicycle or e-bike were less likely to identify car or bus as an alternative mode for the trip. This could, again, indicate a high level of enjoyment with using active transportation modes. Also, fewer participants responded that a shower was needed after completing the e-bike trip than after the other trips, demonstrating the perception among users that e-bike trips are less physically demanding compared to the other trip types. This is less, even, than the number of responses after walking trips that indicated a shower was needed, although the level of perceived exertion is slightly higher than that for walking trips.

**Table 10: Post-Activity Survey Results.**

| | Experimental Trip Mode | | |
|---|---|---|---|
| | Walk | Regular Bike | E-bike |
| Alternative Mode | | | |
| Walk | 1 | 5 | 3 |
| Regular Bicycle | 3 | 2 | 3 |
| E-bike | 0 | 0 | 0 |
| Car | 14 | 9 | 11 |
| Bus | 1 | 0 | 0 |
| Other | 0 | 0 | 0 |
| Shower Needed | 7 | 9 | 4 |
| Perceived Exertion | | | |
| Male | 9.09 | 13.30 | 9.57 |
| Female | 9.88 | 13.67 | 9.57 |

## 4.4 DISCUSSION AND CONCLUSIONS

The work presented in this study focuses on trips made along a predefined hilly course and uses technology installed on the bicycles and results from laboratory testing to reach conclusions about user performance along that course. The results show that e-bike trips require on average 24.5% less power from the user than the same trip on regular bicycles. Although walking requires the least amount of energy per unit time of the modes considered, on the course used in this study, the total EE (Kcal) for e-bike trips was 20.7% less than that of regular bicycle trips and 61.7% less than that of walking trips due to the length of time required to complete the trip for each mode. Similarly, walking trips produced the lowest $VO_2$ rate (ml/kg/min) among the three modes; however, due to travel times for the course, total $VO_2$ (ml) on e-bike trips is 19.6% less than for regular bicycle trips and 61.8% less than the total for walking trips.

The energy requirement comparison between modes has a different impact for different groups of users, and potential users. In this study average power requirements on an e-bike for individuals who do not own a bicycle are 30.1% less than the average requirement on a regular bicycle. The difference is only 12% among users who own a bicycle. Total EE (Kcal) for trips made by those users who do not own a bicycle are higher for all modes compared to the same trip by users who do own a bicycle; however, EE (Kcal) requirements for e-bikes between the two groups are not significantly different. Literature [55] suggests that e-bikes can serve as a gateway to active transportation for sedentary individuals. Users replacing a walking or regular bicycle trips with an e-bike trip receive less physical activity benefits since that mode requires less energy than the alternative modes. Users replacing a car, bus, or other less active transportation trips with an e-bike trip are receiving a greater physical activity benefit by choosing a more active transportation mode.

Trips of equal time, as opposed to equal distance, would generate different results, for example using a bike for a 30 minute exercise bout. Users of the e-bike sharing system selecting an e-bike for a trip would benefit more in terms of physical health than a user making a trip of the same duration by walking, but less than someone selecting a regular bicycle. This is relevant to exercise related trips or leisure trips where the user may wish to use the regular bicycle or e-bike for a given amount of time as opposed to traveling a certain distance in a transportation related trip purpose. In this study, users were required to choose the highest power setting; however, exercise oriented trips allow users to reduce the motor power, increasing physical activity. Also, since e-bikes promote longer trips, or trips involving multiple destinations [3], the added time of use with the e-bike could equalize the physical health benefits across the modes, not to mention increasing the utility of the mode of transportation relative to other modes.

This chapter focuses on investigating comparisons between trips made on e-bikes, regular bicycles, and walking. As expected, e-bike power demands from the user are lower than those of regular bicycles; however, e-bikes are shown as a tool to introduce active transportation to potential users. The added enjoyment of using an e-bike combined with the physical health benefits gained from using this mode of active transportation indicate that e-bikes can be a tool to promote active travel among normally sedentary roadway users.

*4.4.1 A METHODOLOGY FOR NATURALISTIC STUDIES*

This work does not consider that under natural conditions users of e-bikes could make longer trips than users of regular bicycles as indicated by previous work [3], or employ different riding characteristics (e.g. route choice). Future research is needed to investigate how the effects of actual e-bike and regular bicycle use vary and affect the user from a physical activity standpoint. The extension of this study to naturalistic data, collected from the e-bike sharing station, is proposed as a next phase to this research and builds upon the findings from the work presented here.

Wilson et al. [58] present a method for calculating user supplied power, $P_R$, as a function of mechanical efficiency, aerodynamic drag, velocity relative to the ground, headwind speed, terrain slope, the coefficient of rolling resistance, acceleration, and mass. Furthermore, the coefficient of rolling resistance is a function of tire pressure, and velocity. Many of these variables are available through the existing data collection framework. GPS data provides velocity, slope, and acceleration. Bicycle type and corresponding bicycle mass is known through kiosk transaction logs recorded at the sharing station. User identification is also known from the kiosk transaction logs, and user mass can be matched to this identification. Applying field data collected during this study with measured values for user-supplied power, Equation 3 was generated using a linear regression model. Parameter estimates and significance are presented in Table 11.

$$P_R = 306.84 - 116.29(Mode) + 1.186\left(V_{kph}\right) + 0.428g(m_T) - 3.17gm_B\left(\frac{s}{100} + C_R\right) + 48.41s \qquad \textit{(Eq. 3)}$$

Where, Mode is either 0 for regular bicycle or 1 for an e-bike, $V_{kph}$ is the measured speed relative to ground from the GPS device, $m_T$ is total mass including the user, the bicycle, and 4.5kg additional mass, $m_B$ is the mass of the bicycle, s is the slope as a percent. Given tire pressure, ρ, assumed at 70 pounds per square inch or 4.83 bars, the coefficient of rolling resistance, $C_R$ is given by Equation 4.

$$C_R = 0.005\left\{1 + \frac{2.1}{\rho}\left[1 + (\frac{V}{29})^2\right]\right\} \qquad \textit{(Eq. 4)}$$

**Table 11: Parameter Estimates for User-Supplied Power Equation.**

| | Parameter Estimate | Pr > \|t\| |
|---|---|---|
| Intercept | 306.84 | <.0001 |
| Mode | -116.29 | <.0001 |
| $V_{kph}$ | 1.186 | <.0001 |
| $gm_{Total}$ | 0.428 | <.0001 |
| $gm_{bike}(s/100+C_r)$ | -3.17 | <.0001 |
| s | 48.40908 | <.0001 |

R-Square = 0.3994

Applying Equation 3 to naturalistic data collected through the e-bike sharing system provides a platform for studying the effects of varying trip lengths and other characteristics that vary by user and trip type on physical health of the user. Furthermore, ventilation rates can be correlated to estimated user-supplied power and used to study user exposure to air pollution while on either a regular bicycle or e-bike. This method does not, however, provide a direct comparison to walking as an alternative mode.

# APPENDIX: CHAPTER 4

## APPENDIX 4.A: INSTITUTIONAL REVIEW BOARD RESEARCH CONSENT FORM AND LIABILITY WAIVER

## Physical Activity Survey of CycleUshare Users:

9 digit User ID#: ___________ Age: ___________ Height: ___________

Home Zip code: ___________ Sex: M / F Weight: ___________

Ethnicity: ☐ White/Caucasian ☐ Black/African American ☐ Hispanic ☐ Native American ☐ Asian ☐ Pacific Islander

Do you currently own or have access to a bicycle in Knoxville? Y / N

Do you currently own an automobile in Knoxville? Y / N

Prior to cycleUshare, did you own or have access to a bicycle? Y / N

Prior to cycleUshare, when was the last time you regularly rode a bicycle? (year/age) ______

---

## *UNIVERSITY OF TENNESSEE ELECTRIC BIKE AND BICYCLE SHARING PILOT PROGRAM RELEASE OF LIABILITY*

*Participant Name:* _________________________ *Age:*_____ *Student ID No.:*_______________

*Date of Birth:* _______________ *Phone #:* ____________________

*Address:* _________________________ *City/State/Zip:* ______________________

*E Mail Address:* ____________________________ *Major:* ______________________________

*Degree Pursued:* __________________ *Expected Graduation Date:* ____________

**RELEASE AND ASSUMPTION OF RISK**

The undersigned hereby acknowledges that he/she understands that participation in bike sharing at the University of Tennessee is purely voluntary and is not part of the academic curriculum of the university. Participant understands and acknowledges that neither the University of Tennessee, nor the E Bike and Bicycle Sharing Pilot Program (“Pilot Program”) is not an insurer of the behavior and/or actions of the

Participant, and that the University of Tennessee and the Pilot Program assumes no liability whatsoever for personal injuries or property damages to the Participant or other third parties injured by Participant.

In consideration of the university making E Bikes (motorized bicycles) or Bicycles (“Bicycles”) available for the Pilot Program and/or undersigned while participating in any such activities, the undersigned hereby releases The University of Tennessee, their successors, assigns, Trustees, officers, agents, and employees from any and all claims, demands and causes of action whatsoever, in any way growing out of or resulting from the undersigned’s participation in the activities of the Pilot Program.

The undersigned further agrees that he/she understands that cycling involves substantial risk of bodily injury, property damage and other dangers associated with participation. Possible injuries include but are not limited to bruises, cuts and abrasions, twisted ankles, separated shoulders, broken bones, head injuries, or other serious physical injury or death. Hazards include but are not limited to debris on streets, pavement in poor condition, utility poles and other obstructions, acts of nature such as rock fall, varying weather conditions such as severe heat or cold and wet pavement, and other risks associated with riding with motor vehicles, E Bikes or bicycles.

It is expressly understood by the undersigned that he or she is solely responsible for any costs arising out of any bodily injury or property damage sustained through participation in normal or unusual activities of the Pilot Program. The participant does not have any medical conditions that would prevent participation in above named program. The participant has adequate health insurance to cover the costs of treatment in the event of any injury.

The undersigned understands that (1) all of his or her movements on any bicycle and/or motor driven vehicle while he or she participates in this project will be monitored by global position system software via a central processing unit installed on the vehicle, (2) movements when he or she checks out and checks in a bicycle at the bike stations will be monitored and/or recorded with webcams and hereby waives his or her right to the customarily expected right of privacy afforded his or her freedom of movement during the time that he or she participates in this project, and (3) physical activity data in terms of power and energy expenditure will be monitored on certain e-bikes and bicycles as part of this project.

The undersigned understands that participation in any laboratory study associated with the project will require passing mandatory screening (PAR-Q). In laboratory tests, the undersigned will be asked to complete a survey about themselves and their history of bicycle use, and during the test, measures of physical activity will be collected including heart rate, ventilation rate, and caloric expenditure.

The undersigned also understands that by participating in trial course evaluations (1) all of his or her movements on any bicycle and/or motor driven vehicle while he or she participates in the study will be monitored by global position system software via a central processing unit installed on the vehicle, and (2) measures of physical activity in terms of power output, energy expenditure, heart rate, and oxygen consumption will be collected during the trial periods.

Participant understands and agrees that his or her participation in this project is completely voluntary and that the data obtained from participation, including routes and whereabouts, will be recorded and shared for the purposes of research and/or education and consents to such disclosure for those purposes and/or for disclosure pursuant to lawful requests for information from law enforcement agencies.

**TERMS AND CONDITIONS**

The participant is the sole user, and is voluntarily participating in and is familiar with the E Bike and Bicycle Sharing Pilot Program (“Pilot Program”) sponsored by The University of Tennessee and agrees to take full responsibility for the Pilot Program’s shared Bicycle while it is under his or her watch. This includes adhering to all safety rules while riding the Bicycle at all times – avoiding riding on sidewalks, obeying all traffic laws, not riding while impaired, using head and taillights (not supplied) while riding at night, properly locking up the Bicycle to bicycle racks with the supplied locks. Wearing helmets (not supplied) is strongly encouraged.

The participant is a competent bike user.  Participants shall exercise extreme due care at all times while cycling, and shall constantly be on the lookout for, and yield to pedestrians at all times.  The participant must complete the Knoxville Transportation Planning Organization's "Bicycling Training Course" before participating in the program.  The participant agrees that he/she will not carry or transport any persons or passengers on the Bicycle under any circumstance.  Participants shall be aware of their surroundings and be on guard when using their student ID while checking in and checking out Bicycles.  Bicycles shall not be taken into any buildings on the UT campus,

The participant must inspect the Bicycle before use, riding and/or operation of the Bicycle, and agrees to ensure that the Bicycle is in proper working conditions before using it and within 20 feet of the Bicycle station.  Accidents and/or incidents must be reported within 24 hours to the University of Tennessee of or the City of Knoxville Police Department.

The participant must not use, ride or operate the Bicycle in the event of mechanical failure.

The participant will not make any modifications to the equipment.

Maximum use time shall be 8 hours.  If not returned in timely manner, the user must report stolen Bicycles to authorities.  Participant takes full responsibility for any fines, traffic tickets, court costs, attorney's fees, judgments, etc,

Bicycles may be used and or operated only in the City of Knoxville and shall not taken outside of the city limits.

The Undersigned must be 18 years of age or older.  If the Undersigned is married, then the signature of the spouse, appearing in the space indicated below signifies acceptance by said spouse, that the terms and conditions hereof shall be binding upon them and shall constitute a release by them of any and all claims, demands and causes of action whatsoever which they or any of them may have against The University of Tennessee, its successors, Trustees, officers, agents or employees as a result of the undersigned student's, staff and/or faculty's participation in the E Bike and Bicycle Sharing Pilot Program.

**I HAVE CAREFULLY READ AND UNDERSTAND COMPLETELY THE ABOVE PROVISIONS AND AGREE TO BE BOUND THEREBY.**

Participant Signature: ______________________________________        Date: _____________

Spouse Signature: ________________________________________        Date: _____________

## APPENDIX 4.B: PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q)

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

# PAR-Q & YOU

**(A Questionnaire for People Aged 15 to 69)**

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

| YES | NO | | |
|---|---|---|---|
| ☐ | ☐ | 1. | **Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?** |
| ☐ | ☐ | 2. | **Do you feel pain in your chest when you do physical activity?** |
| ☐ | ☐ | 3. | **In the past month, have you had chest pain when you were not doing physical activity?** |
| ☐ | ☐ | 4. | **Do you lose your balance because of dizziness or do you ever lose consciousness?** |
| ☐ | ☐ | 5. | **Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?** |
| ☐ | ☐ | 6. | **Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?** |
| ☐ | ☐ | 7. | **Do you know of any other reason why you should not do physical activity?** |

**If you answered**

### YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

### NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

**DELAY BECOMING MUCH MORE ACTIVE:**

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

**PLEASE NOTE:** If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

**No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.**

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ____________________

SIGNATURE ____________________ DATE ____________________

SIGNATURE OF PARENT ____________________ WITNESS ____________________
or GUARDIAN (for participants under the age of majority)

**Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.**

CSEP SCPE  Supported by: Health Canada Sante Canada

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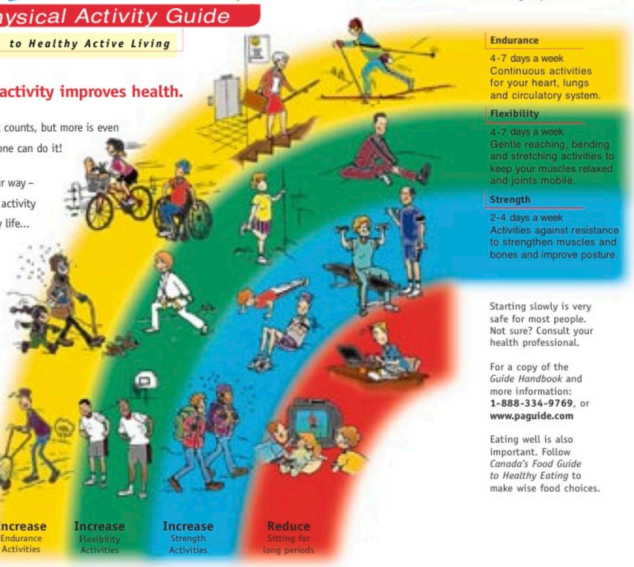
# PAR-Q & YOU

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)



CANADA'S **Physical Activity Guide** *to Healthy Active Living*

## Physical activity improves health.

Every little bit counts, but more is even better – everyone can do it!

Get active your way – build physical activity into your daily life…

- at home
- at school
- at work
- at play
- on the way

…that's active living!

Choose a variety of activities from these three groups:

**Endurance**
4-7 days a week
Continuous activities for your heart, lungs and circulatory system.

**Flexibility**
4-7 days a week
Gentle reaching, bending and stretching activities to keep your muscles relaxed and joints mobile.

**Strength**
2-4 days a week
Activities against resistance to strengthen muscles and bones and improve posture.

**Increase** Endurance Activities | **Increase** Flexibility Activities | **Increase** Strength Activities | **Reduce** Sitting for long periods

Starting slowly is very safe for most people. Not sure? Consult your health professional.

For a copy of the *Guide Handbook* and more information: **1-888-334-9769**, or **www.paguide.com**

Eating well is also important. Follow *Canada's Food Guide to Healthy Eating* to make wise food choices.

## Get Active Your Way, Every Day–For Life!

Scientists say accumulate 60 minutes of physical activity every day to stay healthy or improve your health. As you progress to moderate activities you can cut down to 30 minutes, 4 days a week. Add-up your activities in periods of at least 10 minutes each. Start slowly… and build up.

**Time needed depends on effort**

| Very Light Effort | Light Effort *60 minutes* | Moderate Effort *30-60 minutes* | Vigorous Effort *20-30 minutes* | Maximum Effort |
|---|---|---|---|---|
| • Strolling<br>• Dusting | • Light walking<br>• Volleyball<br>• Easy gardening<br>• Stretching | • Brisk walking<br>• Biking<br>• Raking leaves<br>• Swimming<br>• Dancing<br>• Water aerobics | • Aerobics<br>• Jogging<br>• Hockey<br>• Basketball<br>• Fast swimming<br>• Fast dancing | • Sprinting<br>• Racing |

Range needed to stay healthy

**You Can Do It – Getting started is easier than you think**

Physical activity doesn t have to be very hard. Build physical activities into your daily routine.

- Walk whenever you can – get off the bus early, use the stairs instead of the elevator.
- Reduce inactivity for long periods, like watching TV.
- Get up from the couch and stretch and bend for a few minutes every hour.
- Play actively with your kids.
- Choose to walk, wheel or cycle for short trips.
- Start with a 10 minute walk – gradually increase the time.
- Find out about walking and cycling paths nearby and use them.
- Observe a physical activity class to see if you want to try it.
- Try one class to start – you don t have to make a long-term commitment.
- Do the activities you are doing now, more often.

| Benefits of regular activity: | Health risks of inactivity: |
|---|---|
| • better health<br>• improved fitness<br>• better posture and balance<br>• better self-esteem<br>• weight control<br>• stronger muscles and bones<br>• feeling more energetic<br>• relaxation and reduced stress<br>• continued independent living in later life | • premature death<br>• heart disease<br>• obesity<br>• high blood pressure<br>• adult-onset diabetes<br>• osteoporosis<br>• stroke<br>• depression<br>• colon cancer |

Health Canada Sante Canada

Canadian Society for Exercise Physiology

ACTIVE LIVING


Cat. No. H39-429/1998-1E ISBN 0-662-86627-7

Source: Canada's Physical Activity Guide to Healthy Active Living, Health Canada, 1998 http://www.hc-sc.gc.ca/hppb/paguide/pdf/guideEng.pdf


**FITNESS AND HEALTH PROFESSIONALS MAY BE INTERESTED IN THE INFORMATION BELOW:**

The following companion forms are available for doctors' use by contacting the Canadian Society for Exercise Physiology (address below):

The **Physical Activity Readiness Medical Examination (PARmed-X)** – to be used by doctors with people who answer YES to one or more questions on the PAR-Q.

The **Physical Activity Readiness Medical Examination for Pregnancy (PARmed-X for Pregnancy)** – to be used by doctors with pregnant patients who wish to become more active.

References:
Arraix, G.A., Wigle, D.T., Mao, Y. (1992). Risk Assessment of Physical Activity and Physical Fitness in the Canada Health Survey Follow-Up Study. **J. Clin. Epidemiol.** 45:4 419-428.
Mottola, M., Wolfe, L.A. (1994). Active Living and Pregnancy, In: A. Quinney, L. Gauvin, T. Wall (eds.), **Toward Active Living: Proceedings of the International Conference on Physical Activity, Fitness and Health**. Champaign, IL: Human Kinetics.
PAR-Q Validation Report, British Columbia Ministry of Health, 1978.
Thomas, S., Reading, J., Shephard, R.J. (1992). Revision of the Physical Activity Readiness Questionnaire (PAR-Q). **Can. J. Spt. Sci.** 17:4 338-345.

For more information, please contact the:

Canadian Society for Exercise Physiology
202-185 Somerset Street West
Ottawa, ON K2P 0J2
Tel. 1-877-651-3755 • FAX (613) 234-3565
Online: www.csep.ca

The original PAR-Q was developed by the British Columbia Ministry of Health. It has been revised by an Expert Advisory Committee of the Canadian Society for Exercise Physiology chaired by Dr. N. Gledhill (2002).

Disponible en français sous le titre «Questionnaire sur l'aptitude à l'activité physique - Q-AAP (revisé 2002)».



Supported by: Health Canada Sante Canada

## APPENDIX 4.C: POST-ACTIVITY SURVEY FORM

### Physical Activity Survey of CycleUshare Users:
Post Activity Survey

9 digit User ID#: ____________________

Please indicate which mode you used today:

☐ Walk ☐ Regular Bicycle ☐ Electric Bicycle (E-bike)

What mode would you typically use to make a trip of similar length to the one you just completed?

☐ Walk ☐ Regular Bicycle ☐ Electric Bicycle (E-bike)
☐ Car ☐ Bus ☐ Other:______________________

On a scale of 1-5, with 1 being not enjoyable and 5 being very enjoyable, how would you rate your level of enjoyment in making the trip as you did today?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Not Enjoyable No Opinion Very Enjoyable

Did you encounter any problems in completing this trip? ☐ Yes ☐ No
If so, please specify: ________________________________________________
____________________________________________________________________

Assume you have a meeting or class to attend after completing this trip, would you feel the need to shower before that meeting or class? ☐ Yes ☐ No

Please rate your level of exertion using the following scale:

☐ 6 No exertion at all
☐ 7 Extremely light
☐ 8
☐ 9 Very light
☐ 10
☐ 11 Light
☐ 12
☐ 13 Somewhat hard
☐ 14
☐ 15 Hard (heavy)
☐ 16
☐ 17 Very hard
☐ 18
☐ 19 Extremely hard
☐ 20 Maximal exertion

Do you have any other comments: ____________________________________
____________________________________________________________

# CHAPTER 5:  CONCLUSIONS

In this dissertation, a few separate but interrelated studies are combined. They discuss safety and physical health impacts of e-bikes as well as the role of e-bikes in e-bike sharing systems. This mode of transportation has become available around the world with an increasing number of adopters. It has become vital that we understand the role of e-bikes within the transportation system as well as that we understand how e-bikes, as a new mode choice, influence our physical health and safety. The research included in this dissertation points out key differences in behaviors and performance of users on e-bikes and regular bicycles in an effort to distinguish between the role bicycle type plays on user physical health and safety.

The work in this dissertation includes, first, a study on early experiences with e-bike sharing. It investigates the system, user characteristics, trip characteristics, and overall experiences in operation. The model of bikesharing deployed at UTK is effective at attracting users to both regular bicycles and e-bikes as the qualities of each attract different types of users to the program. The research presented here shows that while most regular bicycle trips are of shorter distances and with a singular purpose, e-bike trips are typically for greater distances under a shorter timeframe and allow for additional stops. While the destinations for most trips in this study are class-related, a number of them included a destination off-campus. Trips by e-bike are shown to have a wider variety of trip purposes than regular bicycle trips. Most trips with either bicycle type in the e-bike sharing system displace a walking trip.

This research identifies that the extended mobility and removal of terrain barriers are major advantages to the e-bikes. Male and female user responses to survey questionnaires were comparable on many issues; however, with regard to regular bicycles, a larger number of female users agree that they are more attractive than e-bikes because they are more maneuverable and because they provide more exercise opportunities. Also, users are shown not to have range anxiety over e-bike batteries, possibly because most trips are short distance.

Second, a study on user behavior as related to user safety on e-bikes and regular bicycles as part of the e-bike sharing system is presented. Concerns over user safety on e-bikes as compared to regular bicycles stems from the added benefit that users gain from the electric motor on e-bikes, which raise important policy questions about the differential role and place of e-bikes in the transportation system. In this study several factors are cthat have relevance to user safety: speed on roadways and shared use facilities, behaviors at intersections, and wrong way travel. While differences in behavior exist, and these differences have bearing on overall user safety while operating the two bicycle types, the differences are generally small and generally explained by other factors, unrelated to the bike itself. This infers that the advantages that users gain from e-bikes have little overall effect on user safety as compared users of regular bicycles. For instance, violation rates at intersections differ between the two modes, but the larger difference occurs between intersection types, not bicycle types. These findings have relevance to bicycle and e-bike policy, mainly in removing a misconception that e-bikes are intrinsically more dangerous than regular bicycles. Violation rates were generally high for both modes. Further, this study identifies some areas for future research in understanding safety for users of the two modes. User performance on the two modes varies by facility type and facility characteristics. Additional characteristics such as the presence of bicycle lanes and other bicycle related facilities could curb dangerous user behavior, and reduce violations, by promoting safer practices among bicycle users.

Third, a study on user physical health is presented. This study investigates the effect on users making the same trip on e-bikes, regular bicycles, and by walking. The study shows that user physical health is affected by mode choice. Considering power requirements from the user, e-bikes require on average 24.5% less power to operate on the same course as regular bicycles. Comparisons made across the three modes of e-bikes, regular bicycles, and walking show that due to additional travel time required walking trips require the greatest total energy expenditure. While walking requires the least amount of energy from the user per unit time, total energy expenditure is least for e-bike trips, 20.7% less than that of regular bicycle trips and 61.7% less than that of walking trips. The study shows that e-bikes can serve as a tool to promote active transportation and serve as an alternative to otherwise sedative transportation options as it is considered enjoyable among users while it also produces physical health benefits in terms of energy expenditure.

# REFERENCES

1. *Nice Ride Subscriber Survey -Summary Report - Nov/1/2010*. 2010 November 1, 2010 December 3, 2010]; Available from: http://appv3.sgizmo.com/reportsview/?key=102593-416326-6d13ea0276ea0822c9f59f4411b6c779.
2. Tang, Y., H. Pan, and Q. Shen, Bike-Sharing Systems in Beijing, Shanghai, and Hangzhou and Their Impact on Travel Behavior, in Transportation Research Board 90th Annual Meeting2011: Washington DC.
3. Langford, B.C., et al., *North America's first e-bike share: A year of experience.* Transportation Research Record: Journal of the Transportation Research Board, 2013. **Accepted**.
4. Langford, B.C., et al. North America's first e-bike share: A year of experience. in The 92nd Annual Meeting of the Transportation Research Board. 2013. Washington, D.C.
5. DeMaio, P., *Bike-Sharing: History, Impacts, Models of Provision, and Future.* Journal of Public Transportation, 2009. **12**(4): p. 41-56.
6. Kanthor, R. *Cycle city: Shanghai ramps up its bike-share schemes*. 2010 [cited 2010 14 October, 2010]; Available from: http://www.cnngo.com/shanghai/play/shanghai-gets-its-ride-shanghai-rideshare-307485.
7. Shaheen, S.A., et al., Public Bikesharing in North America: Early Operator and User Understanding, 2012, Mineta Transportation Institute.
8. Toole Design Group, Bike Sharing in the United States: State of the Practice and Guide to Implementation, 2012.

9. Litman, T., Quantifying the Benefits of Nonmotorized Transportation For Achieving Mobility Management Objectives, 2009, Victoria Transport Policy Institute.

10. Hankey, S., J.D. Marshall, and M. Brauer, Health Impacts of the Built Environment: Within-urban Variability in Physical Inactivity, Air Pollution, and Ischemic Heart Disease Mortality. Environ Health Perspect, 2011.

11. Broach, J., J. Gliebe, and J. Dill, Bicycle Route Choice Model Developed Using Revealed Preference GPS Data., in 90th Annual Meeting of the Transportation Research Board2011: Washington, D.C.

12. Jamerson, F.E. and E. Benjamin, Electric Bikes Worldwide Reports -100,000,000 Light Electric Vehicles in 2009, 2009.

13. Shaheen, S., S. Guzman, and H. Zhang, *Bikesharing in Europe, the Americas, and Asia: Past, Present, and Future.* Transportation Research Record: Journal of the Transportation Research Board, 2010. **In Press**(related:m3gT2e26mD8J).

14. Dill, J. and G. Rose, E-bikes and Transportation Policy: Insights from Early Adopters, in Transportation Research Board 91st Annual Meeting2012: Washington, DC. p. 12.

15. Cherry, C. and R. Cervero, *Use characteristics and mode choice behavior of electric bike users in China.* Transport Policy, 2007. **14**(2007): p. 247-257.

16. Shaheen, S., et al., *China's Hangzhou Public Bicycle: Understanding Early Adoption and Behavioral Response to Bikesharing.* Transportation Research Record: Journal of the Transportation Research Board, 2011. **2247**: p. 33-41.

17. Boris, G., et al., Electric Bikes as a New Active Transportation Modality to Promote Health. Medicine & Science in Sports & Exercise, 2011.

18. Cherry, C., S. Worley, and D. Jordan, Electric bike sharing: System requirements and operational concepts, in 90th Annual Meeting of Transportation Research Board2010: Washington, D.C.

19. CycleUshare - North America's First Electric Bike Sharing System. 2012 July 7, 2012]; Available from: cycleushare.com.

20. Centers for Disease Control and Prevention. *Health Weight: Assessing your weight.* 2011 September 13, 2011 June 30, 2012]; Available from: http://www.cdc.gov/healthyweight/assessing/bmi/adult_bmi/index.html.

21. Weinert, J., et al., Electric Two-Wheelers in China: Effect on Travel Behavior, Mode Shift, and User Safety Perceptions in a Medium-Sized City. Transportation Research Record, 2008. **2038**(-1): p. 62-68.

22. REDDY, S., Law Pulls Plug on Electric Bikes, in The Wall Street Journal2011.

23. Durkin, E., City Council votes to ban motorized bicycles., in New York Daily News2013.

24. California Department of Motor Vehicles. *V C Section 24016 Motorized Bicycle Electric Motor Safety and Equipment Requirements.* 1996 January 1, 1996 [cited 2013 August 2]; Available from: http://www.dmv.ca.gov/pubs/vctop/d12/vc24016.htm.

25. Bureau of Transportation Statistics, *National Transportation Statistics*, R.a.I.T.A. U.S. Department of Transportation, Editor 2009.

26. Brustman, R., An Analysis of Available Bicycle and Pedestrian Accident Data: A Report to the New York Bicycling Coalition. , 1999: Albany, NY.

27. Leden, L., P. Garder, and U. Pulkkinen, *An expert judgment model applied to estimating the safety effect of a bicycle facility.* Accident Analysis and Prevention, 2000. **32**(2000): p. 589-599.

28. Carter, D.L., et al., *Bicyclist Intersection Safety Index.* Transportation Research Record, 2007. **2031**: p. 18-24.

29. Klobucar, M.S. and J.D. Fricker, *Network Evaluation Tool to Improve Real and Perceived Bicycle Safety.* Transportation Research Record, 2007. **2031**: p. 25-33.

30. Wang, Y. and N.L. Nihan, Estimating the risk of collisions between bicycles and motor vehicles at signalized intersections. Accident Analysis & Prevention, 2004. **36**(3): p. 313-321.

31. Schepers, J.P., et al., *Road factors and bicycle-motor vehicle crashes at unsignalized priority intersections.* Accident Analysis & Prevention. **In Press, Corrected Proof**.

32. Weinert, J.X., et al., *Electric Two-Wheelers in China: Effect on Travel Behavior, Mode Shift, and User Safety Perceptions in a Medium-Sized City* Transportation Research Record: Journal of the Transportation Research Board, 2007. **2038**(2007): p. 62-68.

33. Aultman-Hall, L. and F.L. Hall, *Ottawa-Carleton commuter cyclist on-and off-road incident rates.* Accident Analysis & Prevention, 1998. **30**(1): p. 29-43.

34. Bacchieri, G., et al., *Cycling to work in Brazil: Users profile, risk behaviors, and traffic accident occurrence.* Accident Analysis & Prevention, 2010. **42**(4): p. 1025-1030.

35. Boufous, S., et al., *Cycling Crashes in Children, Adolescents, and Adults-A Comparative Analysis.* Traffic Injury Prevention, 2011. **12**(3): p. 244-250.

36. Bacchieri, G., et al., A community intervention to prevent traffic accidents among bicycle commuters. Revista de Saude Publica [online], 2010. **44**(5).

37. Feenstra, H., R.A.C. Ruiter, and G. Kok, *Social-cognitive correlates of risky adolescent cycling behavior.* BMC Public Health, 2010. **10**.

38. Feng, Z., et al., Electric-bicycle-related injury: a rising traffic injury burden in China. Injury Prevention, 2010. **16**: p. 417-419.

39. Pucher, J. and L. Dijkstra, Promoting Safe Walking and Cycling to Improve Public Health: Lessons from The Netherlands and Germany. American Journal of Public Health, 2003. **93**(9).

40. Rasanen, M. and H. Summala, *Attention and expectation problems in bicycle-car collisions: an in-depth study.* Accident Analysis & Prevention, 1998. **30**(5): p. 657-666.

41. Moritz, W., *Adult Bicyclists in the United States: Characteristics and Riding Experience in 1996.* Transportation Research Record: Journal of the Transportation Research Board, 1998. **1636**: p. 1-7.

42. Wachtel, A. and D. Lewiston, Risk Factors for Bicycle-Motor Vehicle Collisions at Intersections. ITE Journal, 1994: p. 30-35.

43. Forester, J., *The Bicycle Transportation Controversy.* Transportation Quarterly, 2001. **55**(2).

44. Tennessee Department of Transportation. *Traffic History*. [cited 2013 June 8]; Available from: http://www.tdot.state.tn.us/TrafficHistory/.

45. Cherry, C. and M. He, Alternative Methods of Measuring Operating Speed of Electric and Traditional Bikes in China-Implications for Travel Demand Models. Journal of the Eastern Asia Society for Transportation Studies, 2010. **8**(2010): p. 1424-1436.

46. Pucher, J., et al., Walking and Cycling to Health: A Comparative Analysis of City, State, and International Data. American Journal of Public Health, 2010. **100**(10): p. 1986-1992.

47. Gordon-Larsen, P., et al., *Active Commuting and Cardiovascular Disease Risk: The CARDIA Study.* Archives of Internal Medicine, 2009. **169**(13): p. 1216-1223.

48. Terzano, K. and V.C. Morckel, Walk or Bike to a Healthier Life: Commuting Behavior and Recreational Physical Activity. Environment and Behavior, 2011. **43**(4): p. 488-500.

49. Franco, O.H., et al., *Effects of Physical Activity on Life Expectancy With Cardiovascular Disease* Archives of Internal Medicine, 2005. **165**(20): p. 2355-2360.

50. Ferrucci, L., et al., *Smoking, Physical Activity, and Active Life Expectancy.* American Journal of Epidemiology, 1999. **149**(7): p. 645-653.

51. Jonker, J.T., et al., Physical Activity and Life Expectancy With and Without Diabetes: Life table analysis of the Framingham Heart Study Diabetes Care, 2006. **29**(1): p. 38-43.

52. Johan de Hartog, J., et al., *Do the Health Benefits of Cycling Outweigh the Risks?* Environ Health Perspect, 2010. **118**(8).

53. Rojas-Rueda, D., et al., The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study. BMJ, 2011. **343**.

54. Gojanovic, B., et al., *Electric Bikes as a New Active Transportation Modality to Promote Health.* Medicine & Science in Sports & Exercise, 2011. **43**(11): p. 2204-2210.

55. Sperlich, B., et al., Biomechanical, cardiorespiratory, metabolic and perceived responses to electrically assisted cycling. European Journal of Applied Physiology, 2012.

56. Canadian Society for Exercise Physiology, *Physical Activity Readiness Questionnaire (PAR-Q)*, 2002.

57. Center for Disease Control and Prevention. *Physical Activity for Everyone: Measuring Intesity: Target Heart Rate*. 2011 March 30, 2011 [cited 2013 July 30].

58. Wilson, D.G., J. Papadopoulos, and F.R. Whitt, *Bicycling Science*. 3 ed2004, Cambridge, Massachusetts: The MIT Press. 485.

# VITA

Brian Casey Langford was born on June 11, 1983, and grew up in Gordonsville, Tennessee. After high school, Casey attended Tennessee Technological University, where he received his B.S. in Civil and Environmental Engineering in 2006. Following his undergraduate degree, he accepted a position with Crouch Engineering, P.C., in Brentwood, Tennessee, as a Project Manager. In 2008, Casey returned to school at the University of Tennessee to pursue a graduate education. He received his M.S. in Civil Engineering in 2009 with a concentration in transportation engineering before becoming a Ph.D. student in the same program. During this time, Casey received many scholarship and fellowship awards allowing him to participate in interesting research endeavors including the Dwight David Eisenhower Transportation Fellowship Program (partial award), the NSF East Asia and Pacific Summer Institutes program in China, and the International Research and Education in Engineering program sponsored by the NSF and Purdue University.

Casey research experiences and extensive work with the cycleUshare e-bike sharing system have made him an expert on cyclist user behavior. His research interests include continuing to study e-bike user behaviors as well as multi-modal transportation planning, non-motorized transportation, and the impacts of other new, alternative transportation options such as electric vehicles. Casey hopes to enter a career in academia where he can pursue these research interests and contribute to the education of future generations of transportation engineers and researchers.