EVALUATING DOCKLESS BIKE-SHARE INNOVATION AND BIKEABILITY IN A CAMPUS SETTING

A Dissertation

by

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ABSTRACT

Physical activity at colleges can be improved through bicycling. Cycling can be performed easily and develop into a life-long activity. College campuses have a unique opportunity to promote cycling behaviors for a large number of young adults. Bike-share environmental interventions can make biking more accessible in these settings. This dissertation has three aims:

1. Examine usage and factors predicting bike-share adoption and explore themes related to bike-share use on campus after an innovative dockless bike-share system launch through a multi-method approach using surveys and focus groups. The Diffusion of Innovations Theory guided the analysis.
2. Conduct a scoping review to summarize recent studies that describe a tool or method for measuring bikeability. The review searched both EBSCO and transportation databases, described the tools, and provided an analysis of tool characteristics using practical comparisons.
3. Using student participation, assess both objective measures and perceptions of bikeability in terms of safety, quality, and comfort. The multi-method approach included bike-share user focus groups and mapping activities along with a direct observation audit.

For the first aim, survey data from 2,845 students, faculty, and staff revealed that 33.6% had used bike-share. Bike users were more likely to be students, freshmen, living on campus, current bikers, and have confidence in their biking ability. Focus groups revealed that safety was a concern, knowledge about how the program worked was low among non-users, cost was a barrier, and bike parking needed improvement. For the second aim, eighteen recent studies were identified that used ten unique bikeability tools. All but one tool assessed environmental features at the microscale level. The variety of tools were applied in a broad range of settings, from large cities to college campuses, among cycle commuters and those with biking experience. The tools included a wide variety of variables, and it is unclear which accurately predict bikeability. For aim three, student perceptions of bikeability on five commonly-used routes did not match the objective assessments of those routes. Perceptions of campus bikeability (for safety, quality, and comfort), as reflected in the focus groups, were poorer than the ratings scored in the environmental audits.

DEDICATION

To Paul, Abigail, and Elizabeth, for your love and support on this ride.

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CHAPTER I

INTRODUCTION

Problems of obesity and chronic conditions like diabetes, heart disease, and some forms of cancer are associated with physical inactivity (McGuire, 2014). Unfortunately, only one in five adults in the United States (U.S.) meets the Centers for Disease Control and Prevention recommended physical activity (PA) guidelines of 150 minutes of moderate aerobic activity per week (Centers for Disease Control and Prevention, 2015; Tucker, Welk, & Beyler, 2011). Healthy PA habits often diminish, and sedentary lifestyles develop, when young adults transition to college and beyond (Gropper, Simmons, Connell, & Ulrich, 2012; Lewis et al., 1997; Small, Bailey-Davis, Morgan, & Maggs, 2013; Yong, Kuller, Rutan, & Bunker, 1993). Many youth may be active through participation in athletics during their primary and secondary educational years, and then end involvement in sports altogether during college. Only half of U.S. college students engage in recommended levels of PA (Keating, Guan, Piñero, & Bridges, 2005).

Individual level strategies to change physical activity behaviors have had little impact on improving PA on a large scale and for the long term (van der Bij, Laurant, & Wensing, 2002). Making the healthy choice to increase PA is not always easy, especially for college students who may have new and increased demands on their time. When considering how best to intervene and promote PA, an ecological perspective may provide the best approach (Cochrane & Davey, 2008; Paracchini et al., 2014). Sallis and Owen describe personal and social factors, physical settings, and environmental policies that may impact PA (Sallis et al., 2006; Sallis, Owen, & Fisher, 2015). Considering a multi-level approach, activities that can be performed regularly, as part of a daily routine, and supported by policies and infrastructure, may have a significant impact on students developing life-long PA habits, meeting PA guidelines, and improving health.

Cycling can be performed easily by most people and may develop into a life-long activity. Most people learn to ride a bicycle when they are young, when they may often ride for recreational purposes. Over time though their purpose for cycling may change from recreational to utilitarian (Underwood, Handy, Paterniti, & Lee, 2014). For adolescents and adults, cycling may be performed more for active transport. Active transport includes walking, cycling and public transportation use, because they all depend on some form of PA (Shannon et al., 2006). Public transportation is included in the concept of active transport, because often riders walk or bike what is considered "the last mile" to their homes or vehicles (Shaheen, Guzman, & Zhang, 2010). Biking from parking lots to destinations on campus could utilize the "last mile" as well. Underwood and colleagues found that cycling behaviors diminish as children grow into adults (Underwood et al., 2014). Despite this, over 50% of college students report having ridden a bike in the past 12 months (American College Health Association, 2018). Bicycling is a low-impact activity that most people have engaged in that can reduce risks of chronic conditions (Albert, 1999).

College campuses have a unique opportunity to address a large number of young adults at a unique point in time, in a defined space, to promote cycling behaviors. As of 2009, more than 18 million young adults in the U.S. attended some form of college (Snyder, 2010). Promoting cycling on college campuses has the potential to influence the PA of a large segment of the population. Increasing student active transport through cycling provides colleges with additional benefits like less demand for parking, reduced traffic congestion, and improvements in air quality (Arnott & Inci, 2006; Balsas, 2003). College campuses offer unique environments for cycling with roads and paths often protected from vehicles, and with most buildings located a relatively short distance from one another. Campuses also have a high population density with many destinations of interest (Li et al., 2016). In addition to positive health outcomes, cycling can provide a cost benefit as well (Cavill & Davis, 2007). If bikes are readily available, students can get around campus and on and off-campus easily, and they may not have to use cars at all. Increasing cycling on college campuses, both for recreation and transportation purposes, can have a great impact on student activity levels and improve public health (Shannon et al., 2006).

Biking has become more accessible over the years with the introduction of bike-share. The concept of bike-share is that individuals share the same bike, and they only use it for short periods of time. In the Netherlands in the 1960s, bikes were painted white and set out for public use (DeMaio, 2009). Theft of the bikes kept the program from continuing. In the 1990s technology improved so that bikes could be tracked and docked in electronically-locking racks (Fishman, 2016). By 2015, a new innovation was introduced called dockless bike-share where bikes could be tracked with global position systems (GPS) and locked, un-locked, and paid for using mobile phone technology (Tian, Wang, Wang, & Zhang, 2018). New ways of accessing bikes and new bike technology may change how colleges shape policies and environments for cycling.

Despite the benefits of cycling and the accessibility of bike-share, barriers to cycling exist. Campuses may lack infrastructure that allows cyclists to share the road and walking paths safely with other travelers (Wegman, Zhang, & Dijkstra, 2012). Even when biking infrastructure is present, students may still perceive the environment to be unsafe. Environments and policies on college campuses will either support or hinder cycling activity. Recent studies have found a connection between the built environment and physical activity (National Research Council

(US). Committee on Physical Activity, Land Use, Transportation Research Board, & Institute of Medicine, 2005; Saelens, Sallis, & Frank, 2003). University provision of bike-share and campus infrastructure that enables safe and efficient bike travel may see increased cycling behavior among students. Understanding the relationship between policies, the environment, and behavior is important in evaluating the success of interventions. Introducing bike-share would be considered an environmental intervention, and introducing dockless bike-share, given how new it is, would be considered a diffusion of innovation.

In an effort to promote health, reduce traffic, and ease the burden on the university bus system, Texas A&M University brought dockless bike-share to its campus in March of 2018. A pilot program with just over 800 bikes was brought to campus with very little introduction. Texas A&M Transportation contacted the Texas A&M School of Public Health to seek input and help with evaluation and promotion activities. Serendipitously, this is when my dissertation study began. Given the short time-line for the first round of evaluation, approval was obtained from the Texas A&M Institutional Review Board (IRB), and I developed my initial questions and strategies for answering them. The first study, which is outlined in Chapter 2 of this dissertation, addressed questions about adoption of bike-share, and barriers and facilitators of bike-share use among university students, faculty, and staff using both a survey and focus group discussions. The results of this study indicated the need for understanding how the environment, and consequently bikeability, impacts cycling behavior. This led to a review of the literature as to how bikeability is measured. A comprehensive review from 2003 assessed 31 walkability and bikeability environmental audit instruments and factors that affect walking and biking (Moudon & Lee, 2003). To date, there have been no published reviews that address current bikeability tools and that include both subjective and objective assessment methods. Chapter 3 of this dissertation describes the methods and results of a scoping review that expands on research reviewing tools for measuring bikeability. Results of this review found several tools and methods that may be appropriate for evaluating bikeability in a campus setting. Most promising were those studies that directly involved the community and addressed both subjective and objective assessments of the built environment. Few studies have researched bikeability on college campuses (Bopp, Kaczynski, & Wittman, 2011). Based on the results of the first study and success of similar studies in the scoping review, I decided that another multi-method approach would be used to evaluate if the environment on Texas A&M's campus is supportive of bike-share. The examination of bikeability was based on student bike-share users' perceptions in focus group discussions as compared to physical indicators obtained through environmental audits. The methods and results of this study are described in chapter 4. This dissertation seeks to increase an understanding of how to promote health by increasing cycling activity on college campuses through the implementation of dockless bike-share programs and bikeable environments.

CHAPTER II

EVALUATION OF DOCKLESS BIKE-SHARE ON A UNIVERSITY CAMPUS USING A MULTI-METHOD APPROACH

Bicycling as active transport provides important health benefits, reduces pollution, and alleviates traffic problems (de Nazelle et al., 2011; Pucher, John, Dill, & Handy, 2010; Pucher, John et al., 2010; Weaver & Garber, 2011). Increasing physical activity levels through cycling has the potential to improve heart health, lower BMI, and reduce the incidence of type 2 diabetes in individuals (Oja, Vuori, & Paronen, 1998; Wannamethee, Shaper, & Alberti, 2000). A benefit of biking as opposed to other forms of physical activity is that the low impact nature of the activity causes less physical harm to joints and muscles (Albert, 1999; Nieman et al., 2014). Cycling also has the unique dual benefit of improving health and providing efficient transportation options. Healthy People 2020 objectives are to increase trips to work via bicycle by 10% (U.S. Department of Health and Human Services, 2018).

Countries like the U.S. and Canada, and several European countries have seen a growth in bike use over the past twenty years (Pucher, John R. & Buehler, 2011; Su, Winters, Nunes, & Brauer, 2010; Xing, Handy, & Mokhtarian, 2010), and the acceptance of bike use as a method of transport, while still low, has increased over time as well (Zhang, Thomas, Brussel, & van Maarseveen, 2016). According to the 2012 National Survey of Pedestrian and Bicyclist Attitudes and Behaviors, 7% of those who bike do so for purposes of commuting to and from work and 4% do so for commuting to and from school (Schroeder & Wilbur, 2012). The concept of bike-sharing started in the Netherlands in the 1960s with white painted bikes available for public use.

Problems with theft led to a slow growth in the effort until technology improved in the 1990s when bikes were made sturdier and could be tracked (DeMaio, 2009). The next phase of bike-share included electronically-locking racks, or docks, and access and payment through mobile phone technology. By 2009, there were over 120 of these docked bike-share systems around the world (DeMaio, 2009; DeMaio, 2018). In 2015, bike-share technology with dockless bikes, also known as smart bike sharing, became available (Tian, Wang, Wang, & Zhang, 2018).

Dockless bike-share relies on global positioning systems (GPS) to track bikes, and mobile phones are used for sign up in the program and payment. The bikes also use a mobile-controlled wheel lock, so bikes can be left in bike racks, or any designated area, without needing to be docked. Payments are much less expensive than docked bike-share, often costing approximately $1.00 per hour-long ride. Bike-sharing, especially dockless bike-share, has tremendous potential for increasing bike use, reducing pollution, and improving public health (DeMaio, 2009; Hamilton & Wichman, 2018; Nadal, 2007; Shaheen, Susan, Guzman, & Zhang, 2010). According to a 2017 report of the National Association of City Transportation (NACT), there were 35 million bike-share trips in the U.S., up 25% from 2016 (National Association of City Transportation Officials, 2018). While this increased flexibility is highly valued by the user, haphazard parking of bikes can lead to difficulties. Dallas, Texas, for instance, eliminated its dockless bike-share program after more than 18,000 bikes clogged the streets.

Dockless bike-share is an innovation that appears to provide strategic advantages over other forms of transportation including personal bicycles, docked bike-sharing programs, and other modes of transportation. Most innovations proceed through various stages while they are disseminated and before they are widely adopted and accepted. Rogers' Diffusion of Innovations theory posits that new ideas or practices go through a process of adoption, and that not all organizations or individuals adopt at the same rate (Rogers, 2003). The Diffusion of Innovations theory outlines the following stages of diffusion: innovation development, dissemination, adoption, implementation, and maintenance (Rogers, 2003). Rogers explains there are a number of attributes of an innovation that determine the speed and extent of its diffusion. Several of the following attributes are evident in the dockless bike-share innovation: relative advantage, compatibility, complexibility, trialability, observability, impact on social relations, reversibility, communicability, time, risk and uncertainty level, commitment, and modifiability (Rogers, 2003). The theory also explains five different categories of adopters that are important to understand when promoting an innovation. Rogers illustrates these five categories in a bell curve: innovators (2.5%); early adopters (13.5%); early majority (34%); late majority (34%); and laggards (16%) (Rogers, 2003). Innovators may be described as those adventurous few who want to try something just because it is new, and they are likely to be the ones developing new ideas. Laggards, on the other hand, tend to be more conservative in their approach and the least likely to try something new, unless they are pressured into it. Most people fall somewhere in the middle of the continuum, adopting new innovations at a different rate. Understanding behavior through the lens of this theory may help in interpreting dockless bike-share evaluation results and in shaping future programs.

Large universities face challenges moving students, faculty, and staff across campus efficiently. Studies have shown the benefits of cycling as active transport for universities, especially in helping to alleviate parking and transportation problems (Arnott & Inci, 2006; Balsas, 2003a; Shang, Lin, & Huang, 2007). According to the American College Health Association, in 2015, over 50% of college students had ridden a bike in the past 12 months

(American College Health Association, 2018). This population, in particular, may be accepting of cycling, especially if bikes are accessible through a bike-share program. Other studies have confirmed that cycling, among adults over the age of 16 is most popular among the youngest age category (16-24 year olds), males, those who use public transit, and those who are already physically active (Harris, 2011; Moudon et al., 2005). Younger populations are also more likely to be willing to adopt new technologies (Rogers, 2003). In addition to the health benefits, cycling among workers may decrease absenteeism, increase productivity, and improve mobility (Pucher, John et al., 2010). Problems with using personal bikes on a college campus include possible theft and not having the bike where you need it when you need it, since personal bikes require round trip rides. Implementing a mobile bicycle-sharing system providing dockless bikes with GPS tracking and smart phone technology may promote physical activity through increased bike usage and solve transportation problems for students, faculty, and staff. This is the first study to our knowledge evaluating the use of the dockless bike-share innovation on a college campus. This study seeks to examine usage and factors predicting bike-share adoption and explore themes related to bike-share use on a large college campus after an innovative dockless bike-share system launch.

Methods

Setting

This study took place at a large land-grant university that spans 5,200 acres on the main campus, with over 68,000 students (53,672 undergraduate and 14,931 graduate) and 3,039 faculty and 7,306 staff (Texas A&M University, 2018).

Study Design

In the Spring of 2018, a large public university located in Texas launched a pilot dockless bike-share program through a public-private partnership with a bike-share company. The program included 850 bikes, making it the largest dockless bike-share program ever offered on a college campus with plans to increase the bikes to 3,000 the following Fall semester. A multi-method study was used to assess how much use the bikes received, who used the bikes, and why some people decided not to use the bikes. An additional goal was to examine the unintended consequences of the program. Three types of data were collected: bike usage, a quantitative survey of faculty, staff, and students, and focus groups of users and non-users of the bikes. All study protocols were approved by the University Insitutional Review Board, and participants were provided informed consent.

Bike Usage Data

The bike-share company collects ongoing usage data about bike ridership based on GPS units on the bikes and participant app sign-ups. Data were used to calculate program sign ups, active riders, number of rides, and total miles traveled between the program launch on February 27, 2018 through the end of May 2018.

Quantitative Surveys

In April, 2018 an online Qualtrics survey link was emailed to over 75,000 university students, faculty, and staff, and of those, 26,267 emails were opened. Participants were eligible if they were over the age of 18 and either a student, faculty, or staff at the university. Within a two-week period, 3,219 surveys were returned for analyses, with a response rate of 12.3%. The brief 10-item survey asked about class rank, campus residency, employment status, age, gender, current bike usage, cycling confidence, and bike share usage.

Survey Measures

The following survey measures are detailed in Table 2.1: bike share use, campus residency, employment status, class rank, age, gender, current biking, and biking self-efficacy.

Table 2.1. Survey Measures.

Measure	Detail
Bike-share use	Staff, faculty, and students responded to the following questions: “Have you tried riding the [company name] bikes?” Possible responses were the following: no; yes, once; yes, 3-5 times; and yes, more than 5 times. For purposes of this analysis, yes responses were collapsed into a single yes category, so that the variable was a yes/no response dichotomous variable.
Campus residency	Students clicked on separate survey links depending on their residency status either off campus or on campus.
Employment status	Staff and faculty were asked if they were currently a staff or faculty member at the university.
Class rank	Student respondents were asked their class rank: indicating freshman, sophomore, junior, senior, or graduate student.
Age	Staff and faculty were asked to indicate their age.
Gender	Everyone was asked if they were male or female.
Current biking	Everyone was asked if they currently ride a bike and responded by choosing one of the following: yes, at least weekly; yes, but infrequently; no, but in the past year; no, but I did 1-5 years ago; No, it has been more than 5 years since I regularly rode a bike; no, I do not know how to ride a bike; and no, but there are times I wish I had acces to a bike. These responses were collapse into two categories: yes, currently riding and no, not riding.
Biking self-efficacy	Staff, faculty, and students were all asked how confident they were that they could ride a bike for one mile safely on campus. Responses included the following: very confident, confident, neither confident or unconfident, not confident, and not very confident. The very confident and confident responses were collapsed into a yes confident response, and the neither confident or unconfident, not confident, and not very confident responses were collapsed into a not confident response.

Analysis

Of the 3,219 surveys returned, 2,845 responded to the bike use question and were retained for further analysis. Chi-square tests were conducted to compare differences between staff, faculty, and student bike-share users and non-users, and other survey items. Logistic regression analyses were conducted on student data only since few faculty and staff respondents had used the bikes. A dichotomous outcome variable of bike-share usage was used to determine associations with residency on campus, class rank, gender, current bike usage, and cycling confidence. Results of logistic regression analyses are presented as odds ratios and 95% Confidence Intervals (CI). A *p*-value of less than 0.05 was considered statistically significant. Variables had different amounts of missing data, and analyses were conducted using complete data. All analyses were performed in Stata/SE 15.1

Focus Groups

At the end of the online survey, respondents indicated whether they would be willing to be contacted to participate in an hour-long focus group. Four hundred forty-six respondents expressed willingness to be contacted. Interested respondents were contacted via email and asked to participate on specific days in May, 2018. The email included a consent form stating the purpose of the focus groups to evaluate student, faculty, and staff usage of the campus bike-share program and to explore barriers and facilitators of use. Participants were recruited until sessions filled to capacity. A total of 35 survey respondents participated in the focus groups, 46% of whom were female. In May 2018, four focus groups were held: one for students who had tried the bike-share (n=10), one for students that had not tried the bike-share (n=8), one for faculty and staff who had tried bike-share (n=8), and the other for staff/faculty who had not tried (n=9).

Focus group participants were asked about their perceptions of and experiences with bike-share and cycling around campus. Two separate semi-structured focus group discussion guides were developed to explore experiences with bike-share and biking in general, one guide for participants who had tried the bike-share on campus and the other for those that had not tried the bike-share on campus (Table 2.2).

Table 2.2. Focus Group Discussion Guides.

Focus Group Type	Discussion Items
Participants who had tried the bike-share on campus	Why did you first try riding the bikes? How often do you use the bike-share bike and for what purpose? What other mobility modes did you use to get around campus before the bike-share program? What do you like better about the bike-share than other mobility modes around campus? What do you like less about this bike-share than other mobility modes around campus? How could the bike-share be improved? Explain what you think to be the "rules" of the bikes. What are your thoughts about the "rules" (racking the bike, going off campus, etc.)? What would help in getting users to be more compliant with the "rules"? Describe your thoughts about safety with the bikes.
Participants who had **not** tried the bike-share on campus	How do you usually get around campus? Have you seen the bike-share bikes on campus? Did you know that this university has a bike-sharing program on campus? Talk about what you know about the program (cost, sign-up, drop-off, area). What would encourage you to try bike-share? Why would you not try bike-share? Explain what you think to be the "rules" of the bikes. What are your thoughts about the "rules" (racking the bike, going off campus, etc.)? What would help in getting users to be more compliant with the "rules"? Describe your thoughts about safety with the bikes.

Focus groups were conducted by two authors on this paper who were trained in qualitative research methods. Discussions took place in a central location on campus over the course of two weeks. Focus groups were audio-recorded, and consent was obtained prior to the start of the discussions. Participants received small gifts as a token of appreciation.

Recordings were transcribed verbatim and then coded using thematic analysis (Burnard, Gill, Stewart, Treasure, & Chadwick, 2008). An initial coding scheme was developed by two interviewers based on one separate transcript for each. The coding scheme was updated after additional transcripts were coded. Interviewers coded each transcript independently. After an iterative coding process and several meetings, consensus was reached on emerging themes. Direct quotes associated with each theme were also recorded using Microsoft Word. Results are presented as themes and quotes associated with each theme in Table 2.5. Coding was done using qualitative software NVivo 12.0

Results

Overall Bike Usage

Over the three months of the pilot study, there were 19,504 registered users, 24,371 different riders, 165,854 rides, and 85,778 miles traveled. The average trip length was 0.52 miles and lasted 8.3 minutes.

Participants

The analyzed survey sample consisted of 2,845 respondents. Seventy-three percent (n=2,066) of respondents were students. Six percent of total respondents identified as faculty (n=183) and 21% indicated they were staff (n=596). Seventy-three percent of students responding currently live off campus (n=1,498) and 28% live on campus (n=568). Fifty-eight percent of respondents were female (n=1,652).

Descriptive Data

Frequencies and percentages in Table 2.3 highlight bike-share use by categories of staff, faculty, and students and current biking and confidence in biking status. Nine hundred and fifty-five respondents used the bike-share (33.6%). The overall student usage rate was 42.4% (n=2,066). 56.7% of students living on campus who responded to the survey reported that they used the bikes (n=322) as compared to 37% of survey respondents living off campus who said they tried riding the bikes (n=554). Staff were non-significantly more likely than faculty to have used the bike-share (13.7% vs. 9.1%, $p = 0.07$), but overall usage by faculty and staff was lower than the students at a rate of just 10% (n=779). Among students, seniors had the lowest rate of bike-share use at 27.4%. Almost twice as many freshmen reported using the bikes (55.9%). While 47.8% of sophomores, 41.7% of juniors, and 39.7% of graduate students reported using the bikes. In the total sample, females reported trying the bikes less often than males (29.5%, vs. 39.2%, $p < .05$). Bike-share usage was significantly more popular with current bike riders, as opposed to those that did not regularly ride a bike (55.7 %, vs. 17.6%, $p < 0.05$). Those who felt confident that they could safely ride on campus were more likely to have tried bike-share than those who were not confident (38.6% vs 15.7%, $p < .05$).

Table 2.3. Bike-share User Demographics (n = 2,845).

Variable		**% who have used bike-share (n)**	**% who have not used bike-share (n)**
Campus Residency			
	Student off campus	37.0 (554)	63.0 (944)
	Student on campus	56.7 (332)	43.3 (246)
Employment Status			
	Staff	9.1 (54)	90.9 (542)
	Faculty	13.7 (25)	86.3 (158)
Class Rank			
	Freshman	55.9 (241)	44.1 (190)
	Sophomore	47.8 (170)	52.3 (186)
	Junior	41.7 (194)	58.3 (271)
	Senior	27.4 (116)	72.6 (308)
	Graduate student	39.7 (155)	60.3 (235)
Gender			
	Female	29.5 (488)	70.5 (1,164)
	Male	39.2 (461)	60.8 (714)
Current Biking			
	Yes currently biking	55.7 (667)	44.3 (531)
	No not currently biking	17.6 (288)	82.4 (1,348)
Confidence in Biking Ability			
	Yes confident	38.6 (858)	61.4 (1,365)
	No not confident	15.7 (97)	84.3 (521)

Logistic Regression

The overall logistic regression result, as shown in Table 2.4, was significant (χ^2=320.94, p < .001). Statistically significant factors (p < .05) included campus residency, student class rank of senior or graduate student, current biking, and confidence in biking. Students living off campus were significantly less likely to ride bike-share than students living on campus (OR=.62, CI=4.7-.79, p < .001). After controlling for other factors, females were not significantly less likely to have tried bike share than males (OR=.94, CI=.77-1.15, p = .54). Seniors (OR=.44, CI=.31-.63, p < .001). and graduate students (OR=.69, CI= .48 - .99, p < .05) were less likely to ride than freshmen. Sophomores and juniors were not significantly less likely to ride than freshmen were. The odds of riding bike-share increased when individuals identified as current bike riders (OR=3.1, CI=2.49-3.77, p < .001). Finally, those confident in riding a bike safely on campus were more than twice as likely to ride bike-share as those who were not confident (OR=2.18, CI=1.65-2.89, p < .001).

Table 2.4. Predictors of Bike-share Use.

Used Bike-share	*OR*	*95% CI OR*	*p*
Campus Residency-Off	.61	.47, .79	< .001
Female	.94	.77, 1.15	0.54
Sophomore	1.0	.72, 1.42	0.95
Junior	.79	.57, 1.11	0.17
Senior	.44	.31, .63	< .001
Graduate	.69	.48, .99	< 0.05
Current Biking-Yes	3.1	2.49, 3.77	< .001
Confidence in Biking-Yes	2.2	1.65, 2.89	< .001

Note. OR, odds ratio; CI, confidence intervals; variables sophomore, junior, senior, and graduate are in reference to freshman.

Focus Group Results

Results indicated a mix of opinions about bike-share on campus. Groups where participants had tried the bike-share tended to be more positive about bike-share than those who had not tried bike-share. The following themes emerged from the four focus group discussions:

1) bike safety; 2) bike-share program knowledge; 3) unintended consequences; and 4) cost and savings. The themes and accompanying quotes are summarized in Table 2.5.

Table 2.5. Themes Identified by Staff, Faculty, and Students: Bike-share Use and Biking (n=35).

Theme		Example Quotes
Bike Safety		
	Infrastructure	“One problem is that the streets here are designed in a way that seems to be intentionally insulting to bicycles in many cases.” (Faculty bike-share rider)
		“We just need the infrastructure for a bike culture in this town. And I think we can do it. They’re already making strategies towards that so some of it’s just going to take time. But I think a lot of it’s just going to be education and establishing the culture.” (Staff non-rider)
	“types of riders”	“…you hit the nail on the head when you said it increases the number of bicycles being used by people who aren’t bicyclist per se.” (Staff non-rider)
		“…I don't see how either the company or the university can instill the level of personal responsibility that's required to make these things safe because there's no way.” (Student non-rider)
	Helmets	“I tend to shy away from them, because there's no helmets.” (Staff bike-share rider)
Bike-share Program Knowledge		
	About the Company	“[the bike-share] claims that it will decrease car usage. I don't see that. I see it decreasing foot traffic and increasing bicycle traffic.” (Faculty non-rider)
		I would not ride that because some random company just dropped off these bikes here and trying to—I don’t know—exploit college students who don’t have a lot of money or something like this. (Student non-rider)
	Rules	“I think the students are going to have to learn some responsibility with them and some rules. Or else we're going to get real tired of them.” (Staff bike-share rider)
Unintended Consequences		
	For Students	“…these bikes are a menace and they're all over the city.” (Student non-rider)

Table 2.5. Continued.

Theme		Example Quotes
Unintended Consequences	For Faculty	"I've had a lot of people be cautionary to me from other places, colleagues and friends, seeing that these end up where the bikes go to places where people aren't, don't need them, like to the neighborhoods and stuff and so then they get left there and then they're not where you need them." (Staff bike-share rider) "our bike rack for our customers to use is full of [bike-share] bikes and so my staff and we can't use the racks that are close to us." (Staff bike-share rider)
Cost and Savings		
	Free vs. Fee	"…basically during that free time frame, I rode, I don't know, four or five times around, just to use them. Kind of get familiar with them. I will probably grab one to ride back across to where I need to be after this thing's over if there's one sitting out there." (Staff bike-share rider) "All I really knew is that it was really popular at first because it was free. I guess it was on trial period. And I know it's not as sought out anymore because you have to pay for it now. " (Student bike-share rider)
	Time	"So it's like, if I walk, it at least takes me 10-15 minutes. So this bike is very convenient." (Staff bike-share rider) "It's just really convenient for exercise too and not having to like wait 30 minutes for the bus." (Student bike-share rider) "I use it pretty much every day. I think that even when the bus service ends. So sometimes I stay late in my office like till midnight so I use the bike to ride home. It usually takes 10 minutes for me to reach home from my office." (Student bike-share rider)

Bike safety**.** Concerns about the safety of bike-share riders, other bikers, and pedestrians were echoed throughout the four discussion groups. Participants talked about the lack of cycling infrastructure at the university and within the community and described how vehicle drivers were not aware enough about sharing the road with cyclists. Participants described places on campus that were particularly confusing and dangerous for pedestrians and cyclists. Other concerns for safety centered around the “types of riders” who use the bike-share. A sentiment emerged that those who would be drawn to bike-share would not know how to ride safely. Current bike riders seemed particularly negative about sharing riding space on campus with bike-share riders. There was some discussion focused on helmet use and how bike-share does not easily support this safety feature.

Bike-share program knowledge**.** There was a general feeling of confusion about the bike-share program. Some students had no idea the program was university-sanctioned, and faculty and staff seemed to lack information about how the dockless program worked. Some participants were suspicious of the bike-share company because it was not an American company, and they expressed negative comments about the claims that the bike-share would improve traffic congestion. On the other hand, some participants (mostly bike-share users) described how they took time to research the program and investigated the app fully. A substantial amount of time was spent in the focus groups with non-bike-share riders discussing the rules of the program. Some participants talked about how rules do not really matter if the consequences for breaking them are minor.

Unintended consequences**.** Participants talked about how bike rack space was being taken up by bike-share bikes and there was no longer room for regular bikes. Concerns were expressed that the dockless bikes were “everywhere,” and that they were being ridden outside of the appropriate parameters and left there. Participants talked about the pranks where students (presumably) left the bikes in inappropriate places, like in trees or on sculptures on campus. Final concerns about the bike-share program was the clutter of the bikes and how the bright color was not appealing and how bikes were not being parked in appropriate places.

Cost and savings**.** Student participants talked a lot about the cost of the program. Some tried the bike-share when it was free, but used it less when they had to pay. Students described how the bus system on campus is free, so paying for another form of transportation may not be as desirable. Conversely, those that used the bike-share talked about how convenient it was and how it saved time. Even those who drove a vehicle to campus liked that they could find a bike near the parking lot and bike to their building, instead of walking. One graduate student described how she used the bike-share late at night outside the library when the buses were no longer running, so she could get to her apartment more quickly and safely.

Discussion

The purpose of the evaluation was to examine usage and factors predicting bike-share adoption and explore themes related to bike-share use on a large college campus after an innovative dockless bike-share system launch. Findings suggest that a substantial number of people in the campus community were willing to try the dockless bike-share innovation. Within just three months of piloting the program, there were over 24,000 different riders, and 33.6% of survey respondents reported that they had tried the bike-share program. This finding supports national data on the popularity of bike-share programs. For example, the 2017 report from NACT notes the increasing uptake of bike-share around the U.S. with 34 million trips (National Association of City Transportation Officials, 2018).

Attributes

Several attributes of the dockless bike-share program may have likely contributed to this relatively quick uptake in usage. The Diffusion of Innovations theory posits that certain attributes of an innovation may help in the adoption of that innovation. For example, the trialability attribute, which allows people to try an innovation with little or no cost before making a decision to adopt was present in this case. The straightforwardness of downloading the program app and the minimal fees involved in trying the bike-share made it easy to try. In the pilot phase of the program, rides were free for a several week promotional period. After that, each ride only cost $0.50.

Another attribute of the innovative bike-share system is relative advantage. Relative advantage refers to the comparison of the innovation to what currently exists. In this case, walking, riding a personal bike, or using the university bus system were methods of transport prior to the bike-share installation. The program provided a convenient one-way system of transportation that was more efficient than waiting for buses and less time-consuming than walking. Cost, risk of theft, and the ability to use bike-share bikes for one-way trips advantaged bike share over personal bike ownership. In a 2016 literature review of bike-share, convenience was a primary motivator of use, and financial savings motivated those with a low income (Fishman, 2016).

A third attribute of the innovation was its impact on social relations. The impact on social relations refers to the extent that the innovation disrupts the current social environment. Both student and faculty/staff users reported in focus groups that the social aspect of the program was appealing and that riding with others was enjoyable and very social. In fact, faculty and staff were motivated to use the bike-share when a group of colleagues would plan a ride for going to lunch. Undergraduate students also discussed their use of the bikes when groups of students would ride together. Perhaps less bike-share use by upperclassmen and graduate students in this study is indicative of the nature of their social interactions and the fact that they do not live in large groups in campus housing, but instead are spread out in off campus locations. Having a companion has been shown to be a determinant of physical activity in adults (Wendel-Vos, Droomers, Kremers, Brug, & van Lenthe, 2007). In addition, research has shown that an increased number of walkers and cyclists increases perceptions of safety, so the presence of more bicyclists around you, even if they are not close friends, can improve the social atmosphere for cycling (Jacobsen, 2003).

The attribute of compatibility is also relevant to our findings. Compatibility refers to how well an innovation fits with existing values, past experience and the needs of potential adopters. When an innovation fits the needs of potential users, it is more likely that the innovation will be adopted. The intended audience for the bike share is all university faculty, staff, and students. For students, findings indicate that students living off campus were 40% less likely to ride bike-share than students living on campus. Since the current geo-fence for the bike-share system at the university does not include many off campus locations, students are penalized (points are deducted from their bike-share accounts) when they leave the geo-fence. A lack of compatibility may explain the low level of off campus use of the bike-share. Opening up the bike-share geo-fence and working with community partners to include more of the community may improve compatibility and increase bike use students other than freshmen. Once a class of freshmen are familiar with the system, they may continue use of bike-share as they progress through the university setting. Future evaluations of bike-share on a college campus should include a temporal component to better understand factors that support ongoing or longer term use of the bike share program and the values and needs of users. Additionally, the cycling infrastructure off campus may make the innovation less compatible for those living further away. Some bike lanes on major roadways are available within the community, but only inconsistently so. Improving infrastructure and connectivity to campus may make the use of bike-share compatible to all students and faculty and staff. Studies have shown mixed associations between increasing infrastructure like bike lanes and bike trails and the likelihood of bicycling, but perhaps bike-share is a unique form of transportation that would see more uptake (Moudon et al., 2005; Smith et al., 2017; Wendel-Vos et al., 2007).

Modifiability is an important attribute that determines bike-share uptake. Modifiability is the ability of the innovation to adapt as needed over time. Some modifications to the program may see an increase in usage. In the focus group discussions, current bike riders shared a variety of suggestions for bike-share program modifications. Some expressed concerns about the new program "pushing out" the riders who bring their own bikes to campus—leaving little room in the bike racks and clogging up pathways with unsafe, inexperienced riders. The adoption and maintenance of a new bike-share system needs to address how to incorporate those who continue to ride their own bikes into the overall program. A modification to the program would be to open up bike rack space by allowing dockless bike-share parking to occur in designated areas (e.g., painted blocks) near parking lots and buildings. The racks themselves are not necessary for dockless bike-share. A number of focus group participants expressed concerns about the safety of the program. Bike-share programming could also be modified to include cycling education and training in order to increase bike confidence and address concerns about safety and inexperienced riders.

Complexibility and communicability are similar attributes that help explain ease of use and understanding relevant to the bike share program. Complexibility refers to how easy or complex an innovation is to use. The innovation is relatively easy for users that are familiar with app-based technology. Development is needed within the app to make it more usable for novices and to explain the "rules" of the program, which will in turn ensure compliance among all users and reduce complexity. It may be helpful to provide “how to” videos on a campus website or in a link delivered in a campus-wide email, so that users that are new to app-based technology and new to bike-share can see how the app and the whole program works. Demonstrations around campus could be offered as well.

Communicability refers to how easily and clearly the innovation is communicated. The bike-share innovation has the potential to be understood clearly and easily, but issues with communicability may have been the biggest deterrent in use and adoption. People may have been willing to try the bike-share if they were given more information about the program. Most users and non-users did not understand the “point system” incorporated into the program, and the geo-fence on the app was not readily apparent, the result of which may have explained the bike-share bikes being parked incorrectly around campus and within the community. Results from the focus group discussions highlight a number of other misunderstandings surrounding the innovation. Social marketing approaches may be needed to better communicate how the program is used.

Rogers’ Diffusion of Innovation theory addresses the attribute of risk and uncertainty as one of the potential barriers to adoption. Risk and uncertainty refer to whether the innovation can be adopted with minimal potential for harm and with confidence. This study found that use of the bike-share program had strong positive associations with confidence in biking, with those who felt confident that they could safely ride on campus being more likely to have tried bike-share than those who were not confident. Adopting the dockless bike-share involves some risk. The bikes may seem heavy and unwieldy to first-time users, and no helmets are provided with the program. Those that felt less confident in biking ability or who had not ridden a bike in a long time may have felt more at risk and chose not to try it. Sharing the roads and sidewalks with vehicles and pedestrians in the current setting, with limited infrastructure for cycling, may have left potential adopters feeling uncertain. Some non-riders discussed expressed concerns for safety because of other bike-share riders. Focus group participants who expressed concerns about the safety of the program hold views similar to focus group participants in the 2016 Bikesharing and Bicycle Safety report who noted it is the unpredictability of bike-share riders and their not knowing the rules that are cause for concern (Martin, Cohen, Botha, & Shaheen, 2016).

Categories of Adopters

The Diffusion of Innovation Theory also describes five different categories of adopters that are important to understand when promoting an innovation: innovators, early adopters, early majority, late majority, and laggards (Rogers, 2003). Innovators may be described as those who develop knew innovations and early adopters are those few who want to try something as soon as it becomes available. The Diffusion of Innovations theory posits that that younger populations will be the innovators and early adopters of new innovations. Our findings support this premise—42% of students surveyed had tried riding the bikes, whereas only 10% of faculty and staff had tried. This finding is similar to previous results from studies that found that younger adults are more likely to ride than older adults (Moudon et al., 2005; Shaheen, Susan A., Martin, Cohen, Chan, & Pogodzinski, 2014). Additionally, findings suggest that freshmen were significantly more likely to ride the bikes than any other class rank. Freshmen are more likely than upperclassmen to live on campus, so their residency in addition to their age could influence use as well.

Limitations

There were several limitations to this study. The data from the bike share company provides overall usage data. However, we cannot tell if the users were affiliated with the university or were community members or visitors to campus. The quantitative survey was completed by less than 15% of the university community. There may have been systematic differences in those who responded versus those that did not. The focus groups were selected from this sample and may have had opinions and experiences that differed from the larger university community. Since this was cross-sectional, we only examined trialability of the innovation, not longer term adoption.

Conclusion

This exploratory study serves as a starting point in understanding issues around dockless bike-share use in a university setting. For innovative bike-share programs to progress to the maintenance stage of diffusion, future studies should continue to address questions about the who, where, when, and why of bike-share use and the overall influence of bike-share on physical activity and health. Also, interventions should address 1) marketing efforts to increase bike-share use and acceptance among later adopters and laggards, like faculty and staff; 2) education campaigns to address communicability and complexibiltiy of the innovation in order to resolve confusion about bike-share use and the rules of the program; and 3) infrastructure developments to improve compatibility and reduce risk and uncertainty in order to address the safety needs of bike-share riders, other cyclists, pedestrians, and motor vehicle drivers.

CHAPTER III

METHODS FOR ASSESSING BIKEABILITY: A SCOPING REVIEW

Even though regular physical activity has been linked to improved health, most U.S. adults do not meet physical activity guidelines (Centers for Disease Control and Prevention, 2015; Tucker, Welk, & Beyler, 2011; US Department of Health and Human Services & Office of Disease Prevention and Health Promotion, 2012). Bicycling holds promise as a health promoting activity that can be performed easily and for both recreational and utilitarian purposes (Oja, Vuori, & Paronen, 1998). Over a quarter of all trips taken by car are just a mile away from individuals and another 13% of trips are less than 2 miles away—both distances easily accessible by bike (Moudon & Lee, 2003). According to the Nationwide Personal Transportation Surveys and the National Household Transportation Surveys, between 1977 and 2009, the number of bicycle trips in the U.S. increased by three times but is still low (Buehler & Pucher, 2012). There are a number of factors that influence the experience and uptake of bicycling, including perceptions of safety, accessibility to destinations, traffic, quality of roads, terrain, and weather, but much is unknown about individual decisions to bike or not (Landis, Bruce, Vattikuti, Ottenberg, McLeod, & Guttenplan, 2001; Porter, Suhrbier, & Schwartz, 1999).

Environmental level strategies may see more improvement in PA levels than those strategies at the individual level, but the built environment is not always conducive to bicycling. Objective and subjective assessments may help to determine what makes a route, an area, or even a community more or less bikeable. The notion of bikeability is relatively new and grew out of the research related to walkable communities and the concept of walkability (Muhs & Clifton, 2016a). While there are some similarities between the two concepts, there are key differences in how the two are assessed. Similarities between bicycling and walking are that they are a direct interaction with individuals and their environment, they both can be performed for transport or recreation, both are friendly to the environment, and both allow a relatively small travel range (Nielsen & Skov-Petersen, 2018). Cycling, however, requires some equipment and a level of expertise, and infrastructure plays a more important role with this form of PA than with walking. Bicycles, if they are used for transport, need a place to be parked. The biggest difference between the two activities is the speed at which they are performed, which also impacts distance traveled and potential for injury (Muhs & Clifton, 2016b; Nielsen & Skov-Petersen, 2018).

There is a growing body of literature assessing essential environmental factors influencing bicycling in a community, but a bikeable environment has been defined in a number of ways and assessed using a variety of tools. Assessment tools can be used to systematically evaluate biking facilities and identify areas for improvement. Bikeability is essentially the extent to which the environment is conducive to bicycling. Other words used to describe bikeability are bicycle comfort, bicycle compatibility, and bicycle accessibility. Examples of attributes of the built environment related to bikeability are surface quality, presence of bike lanes, existence of buffers from other path users, and slope. Measuring the qualities of an environment to determine bikeability can be done using both objective and subjective methods. Subjective methods measure perceptions and may include surveys, interviews, or discussions. Objective tools measure physical characters of an environment and may include direct observation, audits, or spatial data such as global information systems (GPS) (Brownson, Hoehner, Day, Forsyth, & Sallis, 2009; Maghelal & Capp, 2011; Sallis, 2009). Moudon and Lee in their 2003 review described 31 existing audit instruments for assessing walkability and bikeability of environments, 13 of which were related to bikeability (Moudon & Lee, 2003). Table 3.1 provides the bikeability instruments reviewed and their citations. Since 2003, there have been no published reviews of newly-developed bikeability tools. A scoping review is a helpful method to broadly review a topic, and this type of review can be used to summarize the literature, identify research gaps, and inform stakeholders (Arksey & O'Malley, 2005). My research question was: What tools have been developed since 2003 to measure aspects of bikeability in built environments?

Table 3.1. Bikeability Assessment Tools Reviewed in 2003.

Assessment Tool	Reference
Bicycle path level of service	(Botma, 1995)
Measuring environmental indicators	(Anderson, Cook, & Hoehner C., 2002)
Bicyclist performance measures	(Dixon, 1996)
Bikeability checklist	(US Department of Transportation, 2002)
Bicycle compatibility index	(Harkey, Reinfurt, Knuiman, Stewart, & Sorton, 1998)
Level of service for bicycle use	(Eddy, 1996)
Bicycle level of service	(Landis, Bruce, Vattikuti, & Brannick, 1997)
Bicycle interaction hazard score	(Landis, Bruce W., 1994)
Latent demand score	(Landis, Bruce W., 1996)
Internet-based Delphi technique with GIS	(Mescher & Souleyrette, 1996)
Systematic pedestrian and cycling environmental scan	(Pikora, Terri et al., 2002)
Bicycle stress level	(Sorton & Walsh, 1994)
Latent bicycle traffic demand	(Teichgraber & Ambrosius, 1983)

A useful framework when studying how contextual factors affect behavior and how they interact with one another is an ecological model. McLeroy and colleagues in their socio-ecologic model identify five levels of influence: intrapersonal, interpersonal, institutional, community, and public policy (McLeroy, Bibeau, Steckler, & Glanz, 1988). The institutional, community, and public policy levels are often condensed into one level labeled community (Rimer & Glanz, 2005). Influencing physical activity with built environment interventions would intuitively fall within the community level of influence in the ecological framework. Sallis et al., have applied this ecological model to active living (Sallis et al., 2006). The behavioral setting is one level of influence on behavior. There is value in measuring characteristics of behavioral settings in order to make improvements in those environmental settings in order to increase PA behaviors of bicycling. The aim of this study was to conduct a scoping review to broadly research and summarize recent studies that describe a tool or method for measuring bikeability. This chapter describes the tools themselves, and provides an analysis of the characteristics of the tools using practical comparisons.

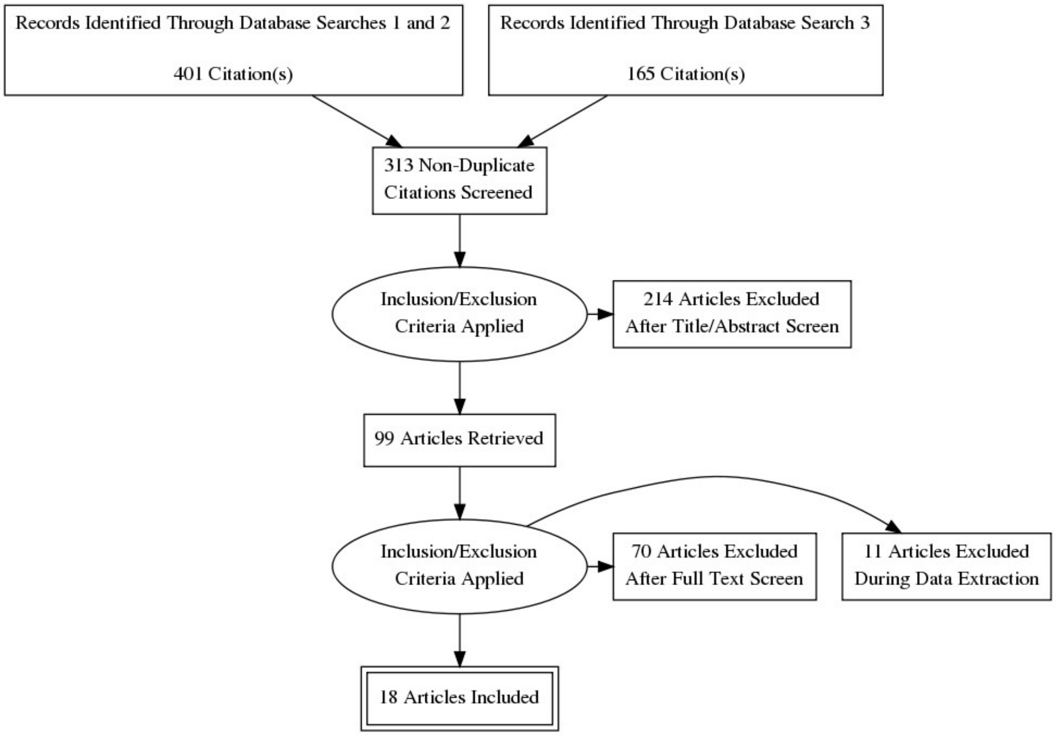
Methods

Search Terms and Strategy

Several steps were involved in identifying literature for this study. Figure 3.1 depicts the process as guided by the Preferred Reporting items for Systematic reviews and Meta-Analyses (PRISMA) guidelines (Moher, Liberati, Tetzlaff, & Altman, 2009). First, an initial search was conducted using these terms related to bikeability: bikeab* or ((bike* or bicycle*) and n1 score*). The search was run using the following EBSCO databases : Academic Search Ultimate, Applied Science & Technology Source Ultimate, Energy & Power Source, Engineering Source, Environment Complete, GreenFILE, Hospitality & Tourism Complete, Humanities Full Text (H.W. Wilson), Humanities Source, MEDLINE Complete, Science & Technology Collection, Science Full Text Select (H.W. Wilson), SPORTDiscus with Full Text, Sustainability Reference Center, Urban Studies Abstracts, Architectural Digest Archive, Business Abstracts with Full Text (H.W. Wilson), Business Source Ultimate, CINAHL Complete, Communication Source, EconLit with Full Text, Education Full Text (H.W. Wilson), Education Source, ERIC, PsycINFO, Public Administration Abstracts, Social Sciences Full Text (H.W. Wilson), and Sociology Source Ultimate. One hundred-ninety six citations were retrieved. After the first search a decision was made to broaden the scope by including transportation databases.

A second search using similar search terms bikeab* or ((bike* or bicycle*) and score*) was conducted using TRID: the TRIS and ITRD database, TRB's Transportation Research Information Services (TRIS) Database and the OECD's Joint Transport Research Centre's International Transport Research Documentation (ITRD) Database. Another attempt using search terms (bikeab* or ((bike* or bicycle*) adj1 score*)).mp. was conducted in TRANSPORT (Ovid). An additional 205 articles were retrieved.

Figure 3.1. PRISMA Flow Diagram of Literature Search.



After consultation with experts in built environment research, a decision was made to conduct a third search that included the search term “cycle” since some studies out of the U.S. may refer to bicycles as cycles. A search was conducted in previously mentioned databases using search terms (bikeab* or ((bike* or bicycle*) n1 score*)) OR (((bike* or bicycle* or cycle or cycling) n1 score*)). One hundred sixty-five more citations were retrieved.

Screening of Abstracts and Full-text Citations

A free web resource called Rayyan was used for organizing articles and excluding and including studies in the initial review stage based on a preliminary abstract and title review (Qatar Computing Research Institute (Data Analytics), 2018). The research question: ‘Does the article use a tool developed since 2003 to measure bikeability?’ was applied to each Rayyan entry. Citations were excluded if they were not in English, published before 2003, or if they did not measure an aspect of bikeability. Those articles in English measuring bikeability with a new tool were retained. The same question was applied to full text review of articles. Those citations that only measured one aspect of bikeability (e.g., a tool only measuring conflicts between vehicles and bikes) were excluded. If a study demonstrated a method (e.g., manipulating photographs) rather than the use of a more widely available tool that could be shared with other researchers, it was excluded. Those studies that included a tool employing an adaption of Level of Service (LOS) methodology were excluded, given the extensive review of LOS in the 2003 study (Moudon & Lee, 2003).

Data Extraction

The following data were extracted from the full-text articles: study title, authors and publication year; and assessment tool name, data collection method (e.g., self-report survey, GIS data, direct observation audit), where studies were applied, scale (macro or micro), type of measure (subjective or objective), and a tool description. An analysis of characteristics of the tools included the following: reliability and validity, if tested; intended users, expertise level required, estimated cost of use, time required, and additional comments. Expertise level was assigned using the following criteria: **low** would include lay people like students or untrained individuals, **medium** would include practitioners like public health professionals, and **high** would include highly-skilled researchers who have been trained to employ statistical analysis techniques. Estimated cost was determined using the following criteria. **Low** is use of the tool costing less than $100. **Medium** would cost between $100 and $1000, and **high** would be costs over a $1000. Time required to conduct an assessment was determined with the following criteria: low would include assessment that takes several weeks or less, medium time would take several months to a year, and high would take more than a year to conduct an assessment with the tool. Articles were excluded during the data extraction stage if they only measured one aspect of bikeability.

Results

A total of 566 entries were loaded into Rayyan and titles and abstracts were reviewed. Two hundred fifty-three duplicate records were removed. At the abstract review stage, studies were kept if they included a measure of concepts related to bikeability, bike comfort, bike safety, bike suitability, or similar terms. Examples of articles that were excluded were those not written in English, those not related to methods of measuring bikeability, those only related to cycling behavior, like safety training, or those that only discussed one issue related to bikeability, such as traffic or crash data. In addition, LOS and BLOS articles were excluded, given the large number of studies that employ this methodology and the fact that the methodology was reviewed in 2003. After this initial abstract review, 214 articles were excluded.

The included 99 articles were retrieved and moved into RefWorks. After a full text review, 29 articles were determined to directly address the study of tools measuring bikeability. After data extraction, nine articles were removed that were either published before 2003, found to address a Level of Service (LOS) methodology, or only explored one aspect of bikeability. Data were extracted from 18 final studies addressing 10 tools measuring bikeability.

Out of 566 articles in the search, 18 publications are included in this review, and summarized along with their references in Table 3.2. All the publications date within the past fifteen years and were applied to a number of types of cyclists and settings. Most of the studies, twelve of the eighteen, were applied to settings outside of the United States. Six of the eighteen studies employed the use of a self-report survey, including one that used a survey in combination with a direct observation audit. Five studies examined bikeability using spatial data, like GIS. Seven studies used a direct observation audit—one using a mobile app and another using virtual observation techniques.

The ten tools are described briefly in Table 3.3. Nine tools assess the environment at a micro scale while one tool, Bike Score®, uses macro scale components. Two tools used subjective measures, five tools used objective measures, and three tools used both. A large number of variables were included in the ten tools. All tools included components related to safety and route quality. Two of the ten tools included elements specific to crowding or congestion. Methods for organizing variables varied considerably among the tools. For example, “social” variables were defined differently depending on the tool.

Table 3.2. Summary of Bikeability Assessment Tool Studies.

Study Title	Reference	Assessment Tool Used	Data Collection Method	Where Study was Applied
The active commuting route environment scale (ACRES): development and evaluation	(Wahlgren et al., 2010)	Active Commuting Route Environment Scale (ACRES)	Self-report survey	Among active commuters in Stockholm, Sweden
Bikeability and methodological issues using the active commuting route environment scale (ACRES) in a metropolitan setting	(Wahlgren & Schantz, 2011)	Active Commuting Route Environment Scale (ACRES)	Self-report survey	Among active commuters in Stockholm, Sweden
Exploring bikeability in a metropolitan setting: stimulating and hindering factors in commuting route environments	(Wahlgren & Schantz, 2012)	Active Commuting Route Environment Scale (ACRES)	Self-report survey	Among active commuters in Stockholm, Sweden
Exploring bikeability in a suburban metropolitan area using the Active commuting route environment scale (ACRES)	(Wahlgren & Schantz, 2014)	Active Commuting Route Environment Scale (ACRES)	Self-report survey	Among active commuters in Stockholm, Sweden
Mapping Bikeability: a spatial tool to support sustainable travel	(Winters et al., 2013)	Bikeability Index (becomes Bike Score®)	GIS data	Among current and potential cyclists in Metro Vancouver, Canada
Bike Score: Associations between urban bikeability and cycling behavior in 24 cities	(Winters et al., 2016)	Bike Score®	GIS data	24 U.S. and Canadian cities
Income Inequalities in Bike Score and bicycling to work in Canada	(Fuller & Winters, 2017)	Bike Score®	GIS data	8 cities in Canada
Exploring the synergistic economic benefit of enhancing neighbourhood bikeability and public transit accessibility based on real estate sale transactions	(Li & Joh, 2017)	Bike Score®	GIS data	Austin, Texas
Assessing the Walkability of the Workplace: A New Audit Tool	(Dannenberg, Cramer, & Gibson, 2005)	Healthier Worksite Initiative Walkability Audit	Direct observation audit	10 federal agency work campuses
Sneakers and Spokes: an assessment of the walkability and bikeability of U.S. postsecondary institutions	(Horacek et al., 2012)	Adapted Healthier Worksite Initiative Walkability Audit: Bikeability and Walkability Environmental Score	Direct observation audit	15 U.S. postsecondary education campuses
Path analysis of campus walkability/bikeability and college students' physical activity attitudes, behaviors, and body mass index	(Horacek et al., 2018)	Adapted Healthier Worksite Initiative Walkability Audit: Bikeability and Walkability Environmental Score	Direct observation audit	13 U.S. university campuses
The Bikeability and Walkability Evaluation Table	(Hoedl et al., 2010)	Bikeability and Walkability Evaluation Table (BiWET)	Direct observation audit (on bike)	Graz, Austria

Table 3.2. Continued.

Study Title	Reference	Assessment Tool Used	Data Collection Method	Where Study was Applied
Bicyclists' preferences for route characteristics and crowding in Copenhagen – A choice experiment study of commuters	(Vedel et al., 2017)	Copenhagen Study	Self-report choice experiment survey	Among bike commuters in Copenhagen, Denmark
Assessing the validity of facilitated-volunteered geographic information: comparisons of expert and novice ratings	(Kalvelage et al., 2018)	Facilitated-voluntary geographic information (f-VGI)	Direct observation audit using a mobile app	Among expert and novice auditors who were able to cycle (no city defined)
Assessing Walking and Cycling Environments in the Streets of Madrid: Comparing On-Field and Virtual Audits	(Gullon et al., 2015)	Madrid Systematic Pedestrian and Cycling Environment Scan (M-SPACES)	Virtual direct observation audit using Google Street View	Madrid, Spain
Using mental mapping to unpack perceived cycling risk	(Manton et al., 2016)	Mental Mapping	Mapping, self-report survey, and spatial data	Among bike commuters in Galway City, Ireland
Development and reliability of a streetscape observation instrument for international use: MAPS-global	(Cain et al., 2014)	Microscale Audit of Pedestrian Streetscapes (MAPS-Global)	Direct observation audit	Major cities in Australia, Belgium, Brazil, Hong Kong, and Spain
Influence of infrastructural compatibility factors on walking and cycling route choices	(Koh & Wong, 2013)	Safety and Accessibility Index	Self-report and direct observation audit	Among those existing rail stations in residential areas of Singapore

Table 3.3. Description of Assessment Tools.

Asssessment Tool Name	Scale	Type of Measure	Description of Elements Assessed
ACRES	Micro	Subjective	Self-report survey with 33 items broken into 3 categories: physical environment (e.g., bicycle paths, greenery, hilliness), traffic environment (e.g., fumes, noise speed), and social environment (e.g., road user conflicts).
Bike Score	Macro	Objective	An index based on spatial data related to five factors: bicycle route density, bicycle route separation, connectivity of bicycle-friendly roads, topography, and density of destinations.
Bikeability and Walkability Environmental Score	Micro	Objective	Pencil and paper audit tool using 12 criteria: 4 on safety (e.g., cycling facilities); 7 on quality (e.g., path size); and 1 on comfort (e.g., shade).
BiWET	Micro	Objective	Pencil and paper audit tool to be used while cycling. The following attributes are noted every 10m (if there is a change in the segment): traffic safety, attractiveness, land use, and walking/cycling infrastructure.
Copenhagen Study	Micro	Subjective	Web-based choice experiment survey investigating the following attributes: cycle track, crowding, stops, environment/road type, green surroundings, and travel distance.
f-VGI	Micro	Subjective and Objective	Utilizes public data collection, whereby volunteer citizens collect data using a mobile app. Items related to bikeability (quality and safety) from the PEDS* tool were used in the app. Volunteers bike to locations and rate them using the app.
M-SPACES	Micro	Objective	Pencil and paper audit tool (SPACES**) was adapted into a virtual audit tool using photographs from Google Street View. Bikeability attributes are cycling function, safety, aesthetics, and destinations.
Mental Mapping	Micro	Subjective and Objective	Participants use a base map and green, yellow, and red markers to identify their perceptions of personal cycling routes as safe, unsafe, or very dangerous. They then complete a 28-item survey on their experiences and preferences. Spatial data were used to compare perceptions with objective data.
MAPS-Global	Micro	Objective	Pencil and paper audit tool based on original MAPS. The global version includes a bicycling component. The tool includes six environmental measures relevant to biking/walking: destinations and land use; streetscape characteristics; aesthetics & social characteristics; crossings/intersections; street segments; and cul-de-sacs.
Safety and Accessibility Index	Micro	Subjective and Objective	A self-report survey is administered to pedestrians/cyclists in the field regarding infrastructure and distance; their stated routes are audited; a Safety and Accessibility Index is created.

**PEDS is the Pedestrian Environmental Data Scan. **SPACES is the Systematic Pedestrian and Cycling Environment Scan.*

Table 3.4 provides characteristics of each of the bikeability tools. Six of the ten tools were tested for reliability, three were tested for both reliability and validity (ACRES, f-VGI, and M-SPACES), and four of the tools did not report reliability or validity results. Most of the tools tested for reliability showed moderate to perfect agreement between raters or users. Only one tool had low inter-rater agreement (M-SPACES). Most of the tools were intended for planners and policy makers, while one tool was intended for use by community members (f-GVI). One tool addressed a variety of intended users that included cycling advocates (Mental Mapping). Four of the ten tools required a low level of expertise, three required a medium level, and three required a high level of expertise. Six tools would cost below \$100 to use, two would cost \$100 to \$1000, and two would cost more than \$1000. Most of the tools required a medium amount of time—several months to a year to use (n=7). Three tools required a low amount of time (several weeks), and none would take more than a year. The development of each tool is described further below.

Active Commuting Route Environment Scale (ACRES)

The ACRES tool was tested in Stockholm, Sweden to assess cyclist and pedestrian perceptions of their commuting environment. Active commuters along with expert panelists were recruited to respond to the 18-item scale. Items in the scale were divided into the physical, traffic, and social environments and responses were along a 15-point scale. The test-retest reliability of the tool was moderate (.42) to almost perfect (.87), and the tool had acceptable criterion-related validity between commuters and experts. The tool was used in three other related studies by the same authors (Wahlgren & Schantz, 2012; Wahlgren & Schantz, 2011; Wahlgren & Schantz, 2014).

Bike Score®

The Bike Score® tool grew out of the concept of Walk Score®, a private company started in 2007 that quantifies walkability in neighborhoods in the United States, Canada, and Australia (Walk Score, 2018), and from a bikeability index developed by Winters and colleagues (Winters, Brauer, Setton, & Teschke, 2013). The index was not tested for reliability or validity. Bike Score® assigns a score between 1 and 100 based on street connectivity and distance to destinations such as shopping, parks, schools, and drinking and dining establishments. This "destination and connectivity" score is incorporated into the bike score concept. Bike Score® assigns a score between 1 and 100 based on three environmental components: Bike Lane Score, Hill Score, and Destinations and Connectivity Score. Recently, Bike Score® in the United States also includes a social score of number of bike commuters. Data for calculating the score are from the United States Geological Survey (USGS), Open Street Map, and the U.S. Census. Several studies have used Bike Score® to examine cycling behavior and neighborhood inequalities in the U.S. and Canada based on income and real estate (Fuller & Winters, 2017; Li & Joh, 2017; Winters, Teschke, Brauer, & Fuller, 2016).

Bikeability and Walkability Environmental Score

Horacek and colleagues adapted the Healthier Worksite Initiative Walkability Audit to evaluate campus walking and biking paths at fifteen U.S. postsecondary campuses (Horacek et al., 2012). The tool assessed path safety, quality, and comfort. Stakeholders at each university were gathered to participate in the study and, using campus maps, to help identify areas for evaluating walkability and bikeability. The tool was adapted by adding features unique to college campuses (e.g., emergency call boxes), and components from the Systematic Pedestrian and Cycling Environmental Scan (SPACES) were included. The tool had high (93-97%) inter-rater agreement. It tool was not tested for validity. The tool was used in two university campus studies.

The Bikeability and Walkability Table (BiWET)

BiWET was developed in 2007 in Graz, Austria (Hoedl, Titze, & Oja, 2010). The tool is made up of 15 characteristics organized by the following physical environment attributes: traffic safety, attractiveness, land use, and walking/cycling infrastructure. BiWET is based on evaluation of 10 meter segments. After testing the tool, it was found to be an efficient method of data collection, averaging 16.4 minutes per kilometer. Evaluators cycled down a street and noted which characteristics were observed every 10 meters. There was no need to stop unless something in the environment changed. In this study, the observer evaluated the right-hand side of the street. The data were organized in a table format with rows including the 10 meter segments and the columns representing the presence of characteristics, like bicycle lanes, green space, trees, sidewalks, etc. The inter-rater reliability was high at 89%.

Copenhagen Study

This assessment of commuter perceptions of cycling environments asked participants in an online survey to make choices about their preferences for cycling routes in order to see if cyclists would take longer routes to avoid undesirable features. They were given six choice sets where they could choose between two scenarios (or neither). Each choice set included text and a picture drawing. The survey included the following attributes: road environment, cycle track (i.e., lane), green surroundings, crowding from other cyclists, stops on the route, and route length. The survey was not tested for reliability or validity.

Facilitated-Voluntary Geographic Information (f-VGI)

This tool is a direct observation audit (based on the PEDS tool) that has been adapted into mobile application format. The intended users of the tool are untrained citizens. The study employed expert and novice auditors to test it as a reliable instrument. Novice auditors did so by biking the provided routes and rating them with the app tool, while the expert auditors biked the routes and evaluated with the pencil and paper tool. The tool had moderate to perfect agreement (80%) between novices and experts.

Madrid Systematic Pedestrian and Cycling Environment Scan (M-SPACES)

A 2015 study by Gullón et al., tested M-SPACES (Gullon et al., 2015), an adaption of the SPACES tool that has also been used in the U.S. and New Zealand. It was developed by Australian researchers as 37-item observational tool assessing four factors related to physical activities of walking and biking: function, safety, aesthetics, and destinations (Pikora, T. J. et al., 2006). The M-SPACES study uses the tool in a virtual audit using open-access mapping sources like Google Earth, Google Street View, and Microsoft Visual Earth. The study found that the M-SPACES tool is successful in measuring environments for physical activity. For the most part the virtual audit was in agreement with the physical audit (ICC > 60), and therefore the tool is a valid instrument. The inter-rater agreement between the two types of auditors was low.

Mental Mapping

This tool utilized a base map where 104 participants drew their commonly-used cycling routes. They then colored each route in either green (safe), amber (unsafe), or red (very dangerous). After the mapping activity, participants completed a 28 item stated-preference survey. A transportation infrastructure inventory was completed to objectively measure 38 road sections of routes. The survey tool was not tested for reliability or validity.

Microscale Audit of Pedestrian Streetscapes (MAPS)-Global

A 2018 paper by Cain et al., described the development and reliability of MAPS-Global (Cain et al., 2018). The original version, MAPS, was developed in the United States in 2014 with 120 items for surveying pedestrian environments (Cain et al., 2014). The MAPS-Global was designed to be more appropriate for international use with eight tools added that address physical activity attributes relevant to each continent. The original MAPS focused just on pedestrian activity, and MAPS-Global now includes a bicycling component. The tool is comprised of six sections: destinations and land use, streetscapes, street crossings, cul-de-sacs/dead-ends, aesthetics and social, and street segments (Cain et al., 2018). To test inter-observer reliability of the tool in five countries (Australia, Belgium, Brazil, China, and Spain), two auditors from each country collected data by walking routes between 0.25-0.45 of a mile from a residence toward a commercial destination. The data collection took on average 26.1 minutes for each route. Commercial destination blocks were also audited and took an average of 15.8 minutes to complete. All items and scales of the tool had either “good” or “excellent” agreement (ICC $\geq$ .60). The tool was not validity tested.

Safety and Accessibility Index

The index was created based on route details gathered from people leaving rail stations in residential areas of Singapore. Participants answered survey questions about infrastructure and distances for walkability and bikeability. They also drew a map of their usual routes from the railway stations. The commuter routes were then audited, and an index for each route was formed. The tool was not tested for reliability or validity, and specific information about the survey items or the audit tool were not provided.

Table 3.4. Characteristics of Assessment Tools.

Assessment Tool Name	Reliability	Validity	Intended Users	Expertise Level Required	Estimated Cost of Use	Time Required	Comments
ACRES	Moderate (.42) to almost perfect (.87)	Acceptable criterion-related validity	Health and Transport Professionals	High	High	Medium	Scale is specific to active commuters but could be used among other populations and in other settings.
Bike Score	Not tested	Not tested	Planners and policy makers	Low	Low	Low	High level of expertise required for high level of analysis using the tool. Quick results for a lay user just using the website.
Bikeability and Walkability Environmental Score	High agreement between 93-97%	Not tested	Planners and health advocates	Low	Low	Medium	Specific modifications for post-secondary campus audits.
BiWET	High agreement at 89%	Not tested	Planners and policy makers	Low	Low	Low	Feasibility of auditing on a bicycle is questionable. Detailed audit handbook available.
Copenhagen Study	Not tested	Not tested	Planners and policy makers	High	High	Medium	Photographs in the experiment would need to be adapted to different settings.
f-VGI	Moderate to perfect agreement 80% between novices and experts	Not tested	Community members, planners, and policy makers	Low	Low	Low	Based on the Pedestrian Environment Data Scan (PEDS) tool.

Table 3.4. Continued.

Assessment Tool Name	**Reliability**	**Validity**	**Intended Users**	**Expertise Level Required**	**Estimated Cost of Use**	**Time Required**	**Comments**
M-SPACES	Inter-rater agreement was low. It was higher for the physical auditors than the virtual ones.	Substantial (ICC > 60) to almost perfect agreement on all but one element (cycling infrastructure)	Planners and policy makers	Medium	Low	Medium	Based on the SPACES tool. On-field auditing was faster than virtual auditing.
Mental Mapping	Not tested	Not tested	Engineers, planners, policy makers, cycling advocates	Medium	Medium	Medium	This was a multi-method approach with both mapping, self-report surveys, and spatial data.
MAPS-Global	86.6% of items showed excellent agreement (ICC≥0.75) and 13.4% showed good agreement (ICC=0.60-0.74)	Not tested	Planners, practitioners, and policy makers	Medium	Low	Medium	Tested the inter-observer reliability in five countries.
Safety and Accessibility Index	Not tested	Not tested	Planners, policy makers, and traffic engineers	High	Medium	Medium	It is not clear what tool was used for the direct observation audit.

Discussion

The purpose of this scoping review was to explore the literature for studies employing bikeability tools that have been developed since 2003 and to describe characteristics of those tools in relation to one another. Eighteen recent studies were identified that used ten unique bikeability tools. All but one tool (Bike Score®) assessed environmental features at the microscale level. Microscale measuring may be more effective using direct observation, but macroscale measurement of bikeability, like land use or population density, may be better suited to using GIS data. The variety of tools were applied in a broad range of settings, from large cities to college campuses, among cycle commuters and those with biking experience. Both subjective and objective measures were used, and some studies included both. A wide variety of variables were included in the ten tools, and similar to the findings of Moudon and Lee in 2003, tool development is challenging, and it is unclear which variables accurately predict the bikeability of an environment (Moudon & Lee, 2003). A universal definition of bikeability may drive development of more streamlined tools.

Another finding was that direct observation audits are still being used to conduct environmental assessments but innovative adaptations to the traditional pencil and paper approach are being used. The Bikeability and Walkability Environmental Score is what one may consider a typical direct observation audit tool. It is a checklist of twelve criteria that are scored on a five-point scale (Horacek et al., 2012). The benefit of this tool was that it was short and easy-to-use. It would require low amounts of time and cost. The use of mobile app technology (f-VGI) and virtual audits (M-SPACES) were tested as techniques that may also save time or lessen the need for high levels of auditing experience. Given that the virtual audits took more time to conduct and there was low agreement between on-site and virtual auditors when testing M-SPACES, more consideration should be given to, even with its advantages, the learning curve required to assess details of the environment from a computer screen (Gullon et al., 2015). Another problem with using map resources like Google Street View to conduct virtual audits is that you may not have the most up-to-date data especially in areas that are newly developed. In contrast, little experience was necessary when regular “citizens” were invited to audit an environment using the adapted PEDS audit tool in a mobile app in the f-VGI study, and novices and experts had moderate to perfect agreement on the items audited (Kalvelage et al., 2018). This finding suggests that everyday users of a biking environment may have enough experience with their routes to accurately assess its features.

This study found that spatial data, maps, and mapping technology like GPS are being used more frequently when assessing environments. Some mapping technology like Google Street View make it easier to assess an environment without having to take the time to travel to a route, but fine details like road surface quality or presence of bike lanes may be more difficult to assess. Bike Score® is easily accessible and available in United States, Canada, and Australia; it is an excellent tool for comparing bikeability among cities (Winters et al., 2016). The Bike Score® tool, drawing on GPS and other spatial data, allows any internet-user to enter a zip code and check the bikeability of a community or neighborhood—but mostly at a macro level. The ease of accessing this kind of data so quickly is having impacts on real estate transactions and community demographics. Bikeability and walkability of neighborhoods may influence home purchases. While these are often seen as positive features of neighborhoods, one unintended consequence that Li notes is that improvements in infrastructure may draw young professionals, drive up home prices, and displace residents out of their current communities (Li & Joh, 2017). Bike Score® is continually updated which can be helpful for keeping research current, but less helpful if examining bikeability over time. Because Bike Score® is owned by a private company, the specific algorithms are proprietary and therefore there may be some concern over the quality of the underlying data.

In this review, innovate methods were found to be promising, but they may require more rigorous testing. In their 2003 study, Moudon and Lee found this lack of testing of instruments as well (Moudon & Lee, 2003). About half of the tools in this study were tested for reliability and only three conducted a validity test. Perhaps there is difficulty with so many types of tools for so many purposes to identify a "gold standard" for comparison in validity testing. Validity testing may be understood differently in different disciplines. The v-FGI tool tested by Kalvelage and colleagues compared novice auditor ratings with expert ratings to establish validity (Kalvelage et al., 2018). The M-SPACES tool tested by Gullon and colleagues compared field auditor ratings with virtual auditor ratings (Gullon et al., 2015).

Several innovate methods combined both objective and subjective measures. "Mental Mapping" was an innovative tool that combined a mapping activity with a survey and compared perceptions to objective factors collected using spatial data

(Manton, Rau, Fahy, Sheahan, & Clifford, 2016). This approach combines many of the features of the other tools and lays the groundwork for studies that compare perceptions with objectively-measured attributes that consider user preferences for specific routes. The Safety and Accessibility Index also asked participants to use a map to identify their usual routes and then respond with survey questions. The routes were then audited in order to create an index (Koh & Wong, 2013). Both studies, while comprehensive in gathering mapping, subjective, and objective data, did not provide enough information about the surveys and audits used to be applied by other researchers. Neither the Mental Mapping or Safety and Accessibility Index were tested for reliability or validity. One study that also employed both subjective and objective measures and had moderate to perfect agreement between novice and expert users was the f-VGI tool (Kalvelage et al., 2018).

The variety of tools required different levels of expertise, resources, and time. The MAPS-Global was able to evaluate bikeability and walkability with good to excellent inter-observer reliability in different settings around the world (Cain et al., 2018). While the MAPS-Global is a comprehensive audit tool with 123 items, it may be difficult for practitioners to use. Both the auditor training and actual data collection could prove to be time-consuming. MAPS-Global would be an appropriate microscale tool for those studies with enough resources to provide appropriate training and ongoing supervision. In contrast, the BiWET only included 15 characteristics to assess, and it is easily accessible to a practitioner (Hoedl et al., 2010). It is unique in that the audit is conducted on bicycle, allowing more area to be observed. Though it could be dangerous to observe and collect data while riding, and it may require frequent stops. The BiWET may be most appropriate for use when in need of an efficient microscale tool that can be implemented easily. Innovative audit strategies may drive down the costs required in executing studies.

Self-report surveys were described as measuring perceptions of cyclists (or potential cyclists), and therefore more subjective in nature; whereas direct observation audits were described as more objective measures of cycling environments. The Copenhagen Study used an innovative approach to survey perceptions of active commuters. The survey was a choice experiment where respondents decided a preference for a route given two scenarios (Vedel, Jacobsen, & Skov-Petersen, 2017). Even though the study took place in Copenhagen, it appears as though the survey items could be adapted to other urban environments. The ACRES tool was a well-developed survey developed in Stockholm, Sweden with 33 items that measured cyclists' perceptions of the physical, traffic, and social environments (Wahlgren, Stigell, & Schantz, 2010). Ma and Dill found that user perceptions matter just as much, if not more, than objective environment attributes in their study of neighborhood bikeability (Ma & Dill, 2015).

How we think about perceptions is important though. Given that a self-report survey like ACRES asks respondents questions, for example, about the presence of bike lanes on their routes, may raise a question as to what makes this response labeled a subjective response rather than an objective one. Consideration should be given to the role of perceptions in both traditionally-understood subjective and objective measures.

Even when using a direct observation audit tool like the Bikeability and Walkability Environmental Score, the auditor's perceptions and experiences may affect the score of a route. Perhaps that is why there is some variability in auditors' scores on a number of the tools. Certainly when using the volunteered geographic information approach with the f-VGI tool, the assessment of the environment is based on inexperienced auditor's interactions with their own environment. Implications of this finding is that highly trained auditors may not be necessary to collect information about a biking environment. The best data may come straight from the users of that environment.

In addition to the elements highlighted in the tools in this review, thorough evaluation of bikeability environments should consider additional influences. The types of riders who use a route for different purposes may experience that route differently. For example, bike-share riders using a bike to tour a city for 30 minutes may have quite different levels of cycling experience and purpose for the environment than riders who commute to work every day on their own bikes. If cyclists are surveyed and not asked about their levels of cycling expertise and the purposes for which they ride, we may not know how these variables interact with their view of the environment. Time of day can influence objective measurement and perceptions of an environment as well. The Copenhagen Study found that crowding can be a substantial problem with urban bike commuters, and rush hour times of day may increase the number of cars, bikes, and pedestrians on the roads and sidewalks (Vedel et al., 2017). If an auditor is not evaluating during rush hour, he or she may not capture the environment at its most risky time. Weather, too, affects bikeability. Snow, ice, rain, and extreme heat can change the bikeability of an environment.

Overall, the newer tools and methods described in this paper offer a wide variety of resources to practitioners, community members, and researchers for objectively measuring and understanding bikeability. To select the most appropriate tool, researchers and planners should consider the purpose of their study and the expertise, time, and resources available to undertake an assessment. Unique and important public health approaches like global comparisons, community participation, and attention to income equality and access were present in several studies. Future study may include more rigorous testing of the tools in new settings, consideration of bike-share and its impact on communities, and evaluating the impact of bikeability on health behaviors and outcomes.

CHAPTER IV

COMPARING OBJECTIVE AND PERCEIVED MEASURES OF BIKEABILITY ON A UNIVERSITY CAMPUS

Active transport is the act of traveling between destinations using some form of physical activity, such as walking or biking. Active transport can also include the physical activity generated getting to and from public transportation (Villanueva, Giles-Corti, & McCormack, 2008). University campuses are unique settings for promoting active transport because users travel frequently between destinations rather than stay in just one building. This is especially the case with students who may need to travel between dormitories or apartments, classroom buildings, dining halls, recreation centers, and within the larger community itself. A study of 23 large universities found that 59% of students live less than one mile from campus (Daggett & Gutkowski, 2003). Faculty and staff may need to travel around a campus to get to various meetings or to teach in multiple buildings. Distances around and within a university campus can vary substantially, depending on the size of the student population, the campus setting, and limitations on the use of motor vehicles.

Bicycle riding is one form of active transport that helps users get around a campus efficiently—especially when travel distances exceed 0.6 miles (European Commission. Directorate-General for Regional Policy & Cohesion, 1999). Regular cycling for transport has the potential to increase physical activity levels among students, faculty, and staff (McCracken, Jiles, & Blanck, 2007). Bicycling can also reduce problems of pollution and traffic congestion and provide a faster method of travel than walking (de Nazelle et al., 2011; Pucher, John et al., 2010; Pucher, John et al., 2010). The introduction of bike-share innovations opens even more possibilities to use cycling for active transport around campuses (Fishman, 2016). Current dockless bike-share programs, mobile-enabled and global positioning systems (GPS) tracked bike-share, allow users to find bikes near them and use them for single, relatively inexpensive rides. The ease of use may result in increased cycling behavior on those college campuses that adopt dockless bike-share systems.

The college campus built environment, however, may either support or hinder cycling. Safety has been found to be one of the most important features of bikeability for cyclists (Guthrie, Davies, & Gardner, 2001; Noland, 1995; Whannell, Whannell, & White, 2012). College campuses, even if they are in small towns, may have a high population density, with relatively large numbers of people occupying a small space (Balsas, 2003b). In spite of the inability to use motor vehicles to cross many campuses, off-street paths shared by many types of users (e.g., cyclists, pedestrians, and skateboarders) may face problems of congestion and confusion. Crowding and a lack of designated lanes on shared paths may increase the risk of collisions between cyclists and between cyclists and pedestrians (Moore, 1994; Vedel, Jacobsen, & Skov-Petersen, 2017). Helmets are used infrequently with current bike-share programs (Basch, Ethan, Rajan, Samayoa-Kozlowsky, & Basch, 2014; Bonyun, Camden, Macarthur, & Howard, 2012; Fischer et al., 2012), and cyclists without helmets are faced with greater risks—especially in congested areas where crashes may occur (Insurance Institute for Highway

Safety, 2019). The route environment may influence people's choices about where and when to cycle, walk, drive, or take a bus. Environmental assessments, therefore, are important to understand transport behaviors in a campus setting, to determine whether infrastructure improvements are necessary, to identify where the most problematic areas are located, and ultimately to improve safety.

Bikeability refers to how supportive the physical environment is for bicycling. Four methods are typically used to assess bikeability: surveys, global information system (GIS) data, audits, and observations (Maghelal & Capp, 2011). These methods can be further broken down into two broad categories of measures: objective (GIS, other spatial data, audits, observations) and perceived (interviews, discussions, surveys) (Brownson, Hoehner, Day, Forsyth, & Sallis, 2009; Sallis, 2009). Objective methods can provide information about a number of environmental characteristics such as the width of lanes, presence of parked cars, and absence of shade. But methods assessing perceptions provide information about users' feelings about safety and comfort with the environment.

Ewing and colleagues recognized the need to include perceptual qualities when characterizing the built environment for walkability or bikeability (Ewing, Handy, Brownson, Clemente, & Winston, 2006). A number of researchers have noted that perceptions of the built environment and the physical built environment have different effects on physical activity behaviors (Ball et al., 2008; Gebel, Bauman, & Owen, 2009; Gebel, Bauman, Sugiyama, & Owen, 2011; Kirtland et al., 2003; Lin & Moudon, 2010; Sallis et al., 2006a). In fact, there may exist a mismatch between perceptions of the environment and the reality of the environment (Ma & Dill, 2015). For example, individuals may perceive that a street feels unsafe for biking, when in fact, a number of measures, like bike lanes and slowed traffic, make the environment quite safe for this activity. This may also interact with the level of experience and skill of individual bike riders. Therefore, both perceptions of bikeability and the reality of bikeability will affect actual biking behaviors. In order to fully assess bikeability of an environment, it is important to consider user perceptions of the environment in addition to objectively measuring features of the environment. Few studies researching the built environment include both quantitative and qualitative methods (Amaratunga, Baldry, Sarshar, & Newton, 2002; Sallis et al., 2006b).

In the Spring of 2018, a large public university located in central Texas launched a dockless bike-share program through a public-private partnership with a bike-share company. A previous multi-method study assessed how much use the bikes received, who used the bikes, and why some people decided not to use the bikes. Several themes emerged during focus group discussions from this previous study—one of which was the importance of bike support, or bikeability, on and around the campus (Kellstedt, Spengler, Bradley, Steedly, & Maddock, 2019). The focus groups also brought to light the significance of community involvement and support when implementing an innovative program. The purpose of this study was to use student participation to assess both objective measures (physical indicators) of bikeability and bicyclist perceptions of bikeability on a large college campus, in terms of safety, quality, and comfort.

Methods

Setting

This study took place at a large land-grant university that spans 5,200 acres on the main campus, with over 68,000 students (53,672 undergraduate and 14,931 graduate) and 3,039 faculty and 7,306 staff (Texas A&M University, 2018).

Study Design

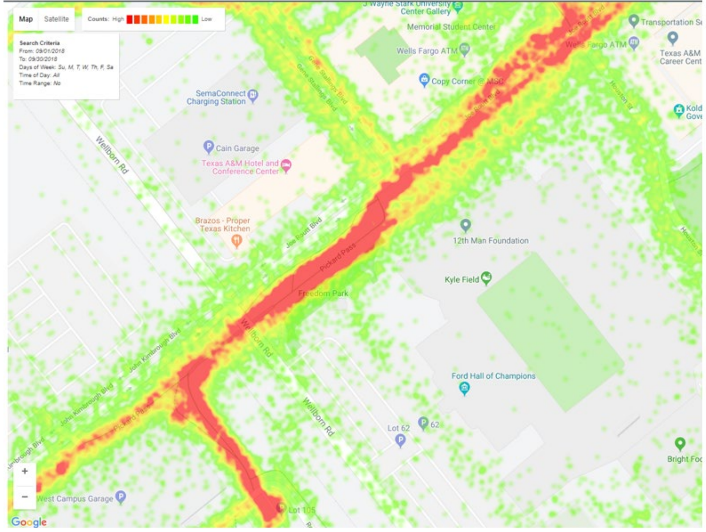
Using a multi-method participatory approach, we explored bicyclist perceptions of campus bikeability during focus group discussions and mapping activities, and we compared those perceptions to measures of campus bikeability based on physical indicators recorded through direct observation audits and bike counts. All study protocols were approved by the University Insitutional Review Board.

Focus Groups

Upon IRB approval, in the fall semester of 2018, 60,698 students enrolled on campus were contacted via email to ask whether they wished to participate in focus groups to discuss bike-share and bikeability issues on and around campus. Eligibility requirements included that participants be current students, 18 years of age and older, that have cycled with the bike-share bikes on campus at least five times in the past year, and their availability to participate in the group discussions on a given date in November 2018. The criteria that students had used bike-share at least five times in the past year would ensure that participants had some familiarity with how the bike-share program works in addition to experience with cycling on campus. The email included an information sheet stating the purpose of the focus groups to discuss perceptions of bikeability on and around the university campus. Participants were recruited and screened until sessions filled to capacity. Capacity of the focus groups, for this purpose, was a maximum of ten students.

In preparation for the focus group discussions, Texas A&M Transportation Services and the Texas Transportation Institute (TTI) provided bike-share mapping data that highlighted the most common bike routes on campus that were utilized with the bike-share bikes during September 2018. This is the period when the current fleet of bikes was fully implemented. Figure 4.1 is an example of a heat map that shows the most common route for bike-share biking during the month of September 2018. A total of three common routes were identified, each 0.4 of a mile in distance. These maps provided objectively revealed routes for bike-share and would be analyzed in comparison to the preferred routes stated by students during a focus group mapping activity.

Figure 4.1. Heat Map of the Most Common Route for Bike-share Biking.



Once the focus groups were filled, participants were sent a follow-up email with a link to a brief Qualtrics survey to be completed prior to the discussions. The survey asked for demographic information about each participant, including class rank, residency, and sex. In addition, it asked about bike-share use, personal bike use, and confidence and skill in bike-riding. Those that were not able to complete the survey prior to the discussions were given the opportunity to do so using a paper survey at the beginning of the focus group discussions. Thirteen students responded to the email to indicate willingness to participate and had availability on the given focus group date. Two hour-long groups were held on November 16, 2018. The first group had three students (two did not show up), and the second group had eight students.

Focus group participants took part in two activities. The first activity was a discussion of participant use of bike-share bikes along with their pereceptions of what makes routes on campus feel safe, of good quality, and comfortable for riding. Table 4.1 includes the focus group discussion guide. The purpose of this discussion was to discover whether student perceptions of the components of bikeability matched those of an audit tool to be used to conduct direct observation assessments on campus. The second activity was a mapping activity for students to identify biking paths for assessment. A similar mapping technique was used in recent studies to assess both pedestrian and cyclists route preferences (Agrawal, Schlossberg, & Irvin, 2008; Koh & Wong, 2013). Figure 4.2 is an example of a map that was used for this activity. Maps that included streets, buildings, parking lots and greens spaces were downloaded from https://aggiemap.tamu.edu/. Focus group participants were asked to individually use preprinted maps of the campus to reveal their most often-used routes for bike-share biking. Participants highlighted and evaluated preferred routes using green, yellow, and red markers, based on the themes of safety, quality, and comfort. Participants were instructed to use green to highlight routes they perceived to be very bikeable, yellow to highlight somewhat bikeable routes, and red to highlight the least bikeable routes. They were encouraged to write notes and circle any places on the maps that were either particularly problemetic or supportive for biking.

Table 4.1. Perceptions of Bikeability Focus Group Discussion Guide.

Item
1. Describe yourself, where you prefer to ride, and for what purpose.
2. Talk about what would make a route for biking feel safe or unsafe.
3. Talk about what would make a route biking feel like it was a good quality route or a not good quality route.
4. Talk about what would make a route for biking feel comfortable or not comfortable for a bike rider.

Figure 4.2. Map of Main Campus for Focus Group Mapping Activity (https://aggiemap.tamu.edu/).

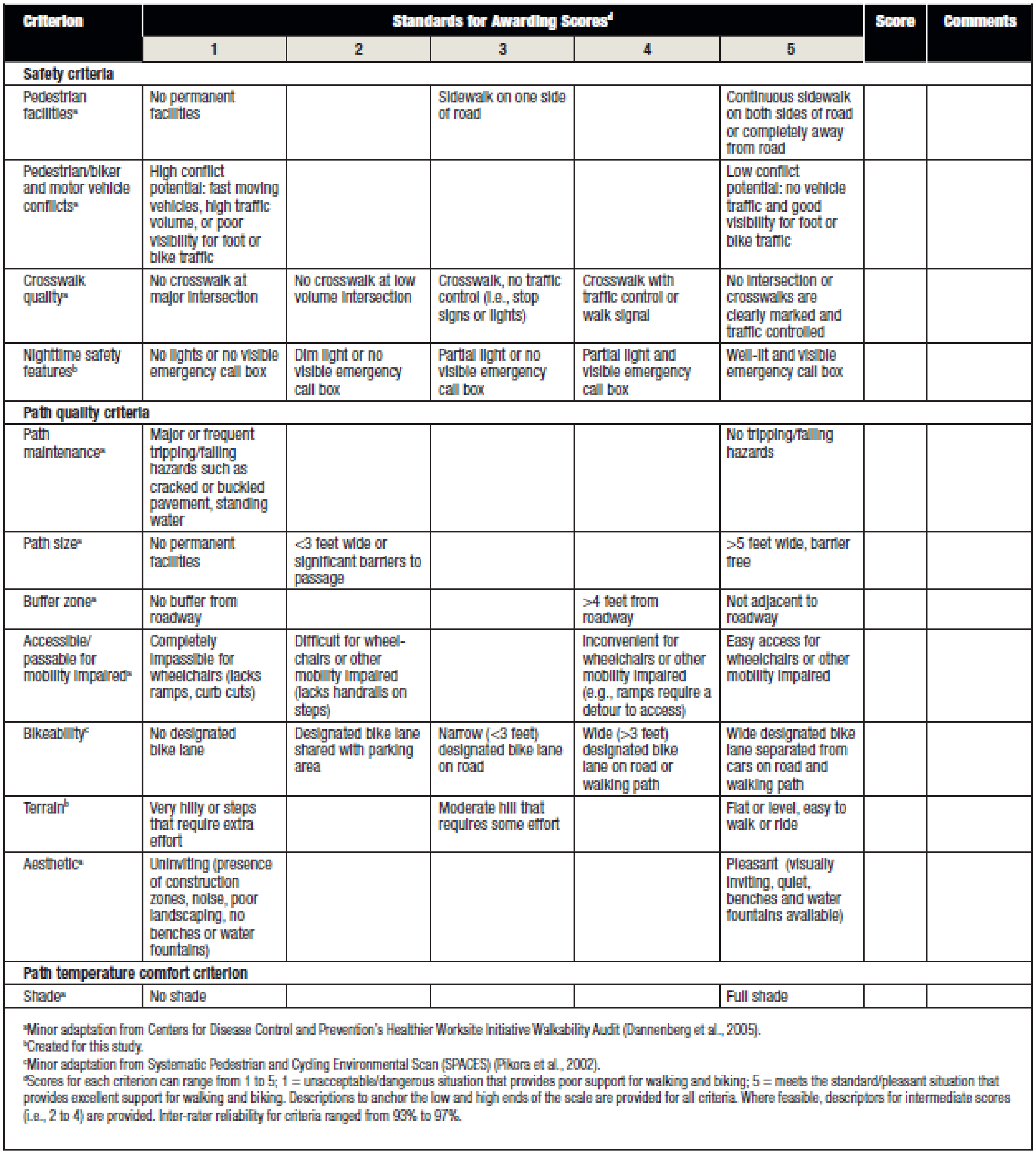
Recordings were transcribed and coded using thematic analysis (Burnard et al., 2008). A coding scheme was developed by two interviewers based on two separate transcripts for each. Interviewers coded each transcript independently. After an iterative coding process and meetings, consensus was reached on emerging themes. Direct quotes associated with each theme were recorded using Microsoft Word. Results are presented as themes and quotes associated with each theme. Coding was done using qualitative software NVivo 12.0. Maps were analyzed by counting the frequency of red, yellow, and green ratings for the most common routes that students identified. For purposes of comparison to audit data, a numerical score was then assigned to each route. After assigning a point value for each color: red = 0; yellow = 1; and green = 2, the total points for each route was divided by the highest possible points for each route based on how many participants rated the route and multiplied by 100 to come up with a score.

Direct Observation Audit and Bike Counts

After the focus groups were completed, and before the end of Fall semester, an environmental audit of the three common routes on campus provided by Texas A&M Transportation Services and TTI (along with two additional preferred routes that emerged from the focus group discussions) were conducted. The tool that was chosen for this assessment was an adaption of the CDC Health Worksite Initiative Walkability Audit (Dannenberg, Cramer, & Gibson, 2005). The adaption used by Horacek and colleagues in a 2012 study of walkability and bikeability on college campuses included measures of bikeability from the Systematic Pedestrian and Cycling Environmental Scan (SPACES) audit tool (Horacek et al., 2012; Pikora et al., 2002). The tool breaks safety, comfort, and quality into twelve criteria that are graded independently. Each criterion is scored on a scale of one to five where one is the least favorable environment for walking and biking, and five indicates the best environment. One criteria based on nighttime safety was removed from our analysis, since all audits were done during the daytime. The three remaining criteria cores for safety were weighted by three to reflect their relative importance. The seven criteria scores for quality were weighted by a factor of two, and the final criterion of shade was only multiplied by one according to published scoring guidelines. Segments that are audited receive a numeric score for each criteria, and the total score is converted in to a letter grade. Inter-rater reliability was high when Horacek and colleagues developed the tool (93%-97%), and the tool has the benefit of being easy-to-use (Horacek et al., 2012). Figure 4.3 displays the tool as used by Horacek et al., (Horacek et al., 2012). Researchers used the maps that focus group participants filled out to identify two additional routes for analysis, and they divided each route into segments. The lead author audited each route. In addition to the lead researcher's audit of the routes, School of Public Health students (both undergraduate and graduate) and one faculty member were recruited to audit the five routes and conduct bike counts. Auditors attended a two-hour long training session that included instruction and conducting test audits prior to data collection. Two auditors were assigned to each route. Each auditor was provided a clipboard, pen, instructions, a route map, assessment instruments (one for each segment), and a bike count summary sheet. The auditors were instructed to conduct audits between 9:00am to 5:00pm on weekdays between November

27 and December 5, 2018. This period took place during the typical university schedule and before classes were finished for the semester.

Figure 4.3. Reprinted Audit Tool (Horacek et al., 2012).



Criterion	Standards for Awarding Scores[d]					Score	Comments
	1	2	3	4	5		
Safety criteria							
Pedestrian facilities[a]	No permanent facilities		Sidewalk on one side of road		Continuous sidewalk on both sides of road or completely away from road		
Pedestrian/biker and motor vehicle conflicts[a]	High conflict potential: fast moving vehicles, high traffic volume, or poor visibility for foot or bike traffic				Low conflict potential: no vehicle traffic and good visibility for foot or bike traffic		
Crosswalk quality[a]	No crosswalk at major intersection	No crosswalk at low volume intersection	Crosswalk, no traffic control (i.e., stop signs or lights)	Crosswalk with traffic control or walk signal	No intersection or crosswalks are clearly marked and traffic controlled		
Nighttime safety features[b]	No lights or no visible emergency call box	Dim light or no visible emergency call box	Partial light or no visible emergency call box	Partial light and visible emergency call box	Well-lit and visible emergency call box		
Path quality criteria							
Path maintenance[a]	Major or frequent tripping/falling hazards such as cracked or buckled pavement, standing water				No tripping/falling hazards		
Path size[a]	No permanent facilities	<3 feet wide or significant barriers to passage			>5 feet wide, barrier free		
Buffer zone[a]	No buffer from roadway			>4 feet from roadway	Not adjacent to roadway		
Accessible/ passable for mobility impaired[a]	Completely impassible for wheelchairs (lacks ramps, curb cuts)	Difficult for wheel-chairs or other mobility impaired (lacks handrails on steps)		Inconvenient for wheelchairs or other mobility impaired (e.g., ramps require a detour to access)	Easy access for wheelchairs or other mobility impaired		
Bikeability[c]	No designated bike lane	Designated bike lane shared with parking area	Narrow (<3 feet) designated bike lane on road	Wide (>3 feet) designated bike lane on road or walking path	Wide designated bike lane separated from cars on road and walking path		
Terrain[b]	Very hilly or steps that require extra effort		Moderate hill that requires some effort		Flat or level, easy to walk or ride		
Aesthetic[a]	Uninviting (presence of construction zones, noise, poor landscaping, no benches or water fountains)				Pleasant (visually inviting, quiet, benches and water fountains available)		
Path temperature comfort criterion							
Shade[a]	No shade				Full shade		

[a] Minor adaptation from Centers for Disease Control and Prevention's Healthier Worksite Initiative Walkability Audit (Dannenberg et al., 2005).
[b] Created for this study.
[c] Minor adaptation from Systematic Pedestrian and Cycling Environmental Scan (SPACES) (Pikora et al., 2002).
[d] Scores for each criterion can range from 1 to 5; 1 = unacceptable/dangerous situation that provides poor support for walking and biking; 5 = meets the standard/pleasant situation that provides excellent support for walking and biking. Descriptions to anchor the low and high ends of the scale are provided for all criteria. Where feasible, descriptors for intermediate scores (i.e., 2 to 4) are provided. Inter-rater reliability for criteria ranged from 93% to 97%.

The bike count was taken along each route during a peak period of high traffic and during a non-peak period using the *Go Counter* mobile app (Rails to Trails Concervancy, 2018). Peak minutes were chosen based on the university-wide daily class schedule. Peak times were identified as those on weekdays between class sessions when foot, bike, and car traffic would be at its highest. Non-peak times included all other times during the 9:00am to 5:00pm period. For a period of thirty minutes on each route (15 peak minutes and 15 non-peak minutes), the auditors counted how many bike-share bikes and how many personal bikes rode past the observation location.

The three criteria scores for safety were weighted by three to reflect their relative importance. The seven criteria scores for quality were weighted by a factor of two, and the final criterion of comfort in terms of shade was only multiplied by one. Each segment and route audited by the lead researcher was scored with a bikeability score based on this calculation: score = (((3 * safety criteria score total) + (2 * quality criteria score total) + shade)/120) * 100.

The scores for lay auditors of each route were calculated the same way and were tested for inter-rater reliability. The inter-rater reliability of the scores was tested using a weighted Kappa statistic, to take into account that a one rating difference between raters was not as extreme as a two or three difference in rating. Weighted Kappa analyses were performed in Stata/SE 15.1. Using the Altman benchmark scales for Kappa values: < .20 = poor inter-rater reliability; .21 to .40 = fair inter-rater reliability; .41 to .60 = moderate inter-rater reliability; .61 to .80 = good inter-rater reliability; and .81 to 1.00 = very good inter-rater reliability (Altman, 1991).

The audited routes were assigned letter grades based on their numeric scores. A score greater than 85% received an A; a score of 70 to less than 85% received a B; a score of 55 to less than 70% received a C; and a score less than 55% received an F. Each route score assessed by the lead researcher was compared to the summarized focus group assessments of the routes for safety, quality, and comfort. Counts of bike-share and personal bikes during peak and non-peak times were compared.

Results

Focus Groups

Table 4.2 summarizes the demographics and biking behaviors of the sample of students. Out of the 11 participants, 36.4% lived on campus (n=4), and 54.6% were female (n=6). Each class was represented with three participants that were freshmen, three that were sophomores, two that were juniors, one that was a senior, and two that were graduate students. Most of the participants indicated they were average level bike riders (72.7%), and almost all participants expressed that they were very confident in their bike riding ability (80%). None of the focus group participants used a personal bike around campus; five participants said they used the bike-share bikes often, while four said they used the bike-share bikes sometimes.

Table 4.2. Focus Group Participant Demographics (n = 11).

Variable	% (n)
Campus Residency	
Student on campus	36.4 (4)
Student off campus	63.6 (7)
Class Rank	
Freshman	27.3 (3)
Sophomore	27.3 (3)
Junior	18.2 (2)
Senior	9.1 (1)
Graduate student	18.2 (2)
Sex	
Female	54.6 (6)
Male	45.5 (5)
Type of Bike Rider	
Beginner	18.2 (2)
Average	72.7 (8)
Advanced	9.1 (1)
Confidence in Biking Ability	
Very confident	80.0 (8)
Somewhat confident	20.0 (2)
Not confident at all	0.0 (0)
Personal bike use around campus	
Yes	0.0 (0)
No	100.0 (11)
Frequency of ofo bike-share riding around campus	
Rarely	18.2 (2)
Sometimes	36.4 (4)
Often	45.5 (5)

The first half of the focus group was spent discussing the open-ended items in Table 4.1 organized by the following themes: purpose for using bike-share, problems with bike-share, bikeability on campus in terms of safety, bikeability in terms of quality, and bikeability in terms of comfort. The discussions of the components of bikeability had considerable overlap in terms of safety, quality, and comfort. Table 4.3 provides the themes along with select poignant quotes from participants.

Table 4.3. Focus Group Themes and Quotes.

Theme	Quotes
Purpose for using bike-share	"My purpose of the ofo is essentially to get to North Gate or just to get anywhere that's further than halfway across campus" *Senior On Campus* "And I usually use the ofo for getting to class when either I'm running late or just need to go somewhere far like the outer edge of campus." *Freshman On Campus* "I am a doctoral student in my first year, so -- Well I live off campus and I usually ride ofo from my apartment to my class." *Graduate Student Off Campus*
Problems with bike-share	"I'm always in a rush by the time I need it, and then every time I like scan it with my phone like most of the ones I see are broken, they're not working." *Freshman Off Campus*
Bikeability: safety	"I would say like you said, the crowded comment, there's a lot of [people]– I mostly bikes on main campus, and there's a lot of blind corners I guess you would say, and people don't watch on bikes or off bikes. And so you're turning the corner and you're afraid you're going to hit someone or you're going to have a bike accident." *Sophomore Off Campus* "So, you'll be riding your bike and you're riding it where the pedestrians are as well and you're having to dodge them in the first place and there are cars that are speeding past you swerving out of the way to miss them and it happens every day to me." *Junior Off Campus* "… even if there is a bike lane sometimes it's just cars think they own it or people think they own it. It's not too clear sometimes or people don't care." *Sophomore On Campus*
Bikeability: quality	"It's always flooded on that one sidewalk so like she said everyone's in the street and there's a fence on the street as well, because of the construction. So you're like riding it like this and cars are barely missing you." *Junior Off Campus*
Bikeability: comfort	"… they use the bike lane and they just put it over storm drain. So you're riding on it like a … degree slant for drainage. So it seems when they do plan for drainage it is bad, and when they don't it's also bad." *Senior On Campus*

Purpose. Students used bike-share because it saved time. When students were in a hurry or running late, using the bike-share was faster than walking and more reliable than the bus system. If students had too far too walk, they preferred to use the bike-share. If students had to travel more than half the distance of campus, they felt it was too far to walk. Participants also used the bike-share to ride off campus to friends' apartment buildings and to the nearby bar district. Bike-share was also used to get out of the off campus entertainment district in order to avoid surcharges with ride-shares like Uber. Finally, participants used the bike-share after driving in and parking on the perimeter of campus. The bike-share helped them get to the middle of campus more efficiently than walking. Students liked the bike-share because it was less expensive than owning a bike (with the potential of it getting stolen or broken).

Problems**.** Students were concerned about the price of the bike-share and that $1.50 seemed too expensive for a single ride. They also expressed that the bike-share bikes were not where they needed them—in the middle of campus. When students did find a bike, many were broken and not usable. Some found the bike-share bikes to be uncomfortable and loud.

Bikeability in Terms of Safety**.** Students expressed concerns that the quickest routes on campus did not have designated bike lanes, including those off-street paths that were shared with pedestrians. Some routes (both off-street and on-street) did have bike lanes but did not indicate which direction bikes should go. Blind corners were a concern. The on-street bike lanes were not necessarily connected, and even if they were present, cars or people may be in them. The lanes may also have problems with bumps and uneven surfaces. Participants expressed that they did not know the rules of the road and who should go first at an intersection with cars, bikes, and pedestrians. Sharing the sidewalks and off-street paths with pedestrians was problematic for cyclists. During peak hours of the day, sidewalks and paths, and even roads, were congested with pedestrians—some of whom were distracted by cell phones. Construction along routes meant pedestrians swerved to avoid it and ended up in the road or blocking bike lanes. Riders on personal bikes often rode much faster than bike-share bikers, which felt unsafe when sharing paths with them. Skate boarders could also cause some problems, because participants were uncertain whether they belonged in bike lanes. Some bike-share users were concerned about sharing the road in the on-street bike lanes so close to cars and expressed a desire for more of a buffer. Participants discussed how bike-share use does not lend itself to wearing helmets.

<u>Bikeability in Terms of Quality</u>**.** Participants explained how the irrigation system on campus often leaves large puddles that pedestrians and bikes swerve to avoid. Given the age of campus, some of the path surfaces on main campus have problems with tree roots pushing up and causing bumps. Some of the brick and gravel surfaces were not as good for riding, and some tree branches hung over on paths. Even if bike lanes were present, they may not stand out as bike lanes.

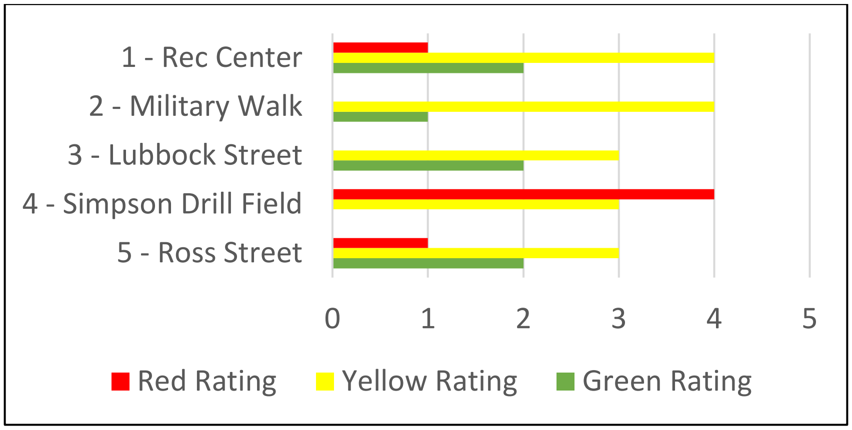
Bikeability in Terms of comfort**.** Participants talked about discomfort with uneven, jagged sidewalks. If the bike lane slanted as it approached the curb, it was uncomfortable for bike-share users. Finally, participants expressed their concerns with crossing roads on their bikes at intersections, given uncertainty about right-of-way with cars and pedestrians.

Focus Group Mapping

During the second half of the focus group, participants marked up maps using red, yellow, and green markers. Figure 4.4 is an example of one participant map for illustration. Figure 4.5 summarizes five routes that emerged and how focus group participants rated them by color. Route 1 (Rec Center) is a three segment route located between the campus memorial student center and the recreation center. The route contains one segment that includes a protected road (only certain vehicles and buses are allowed) and the remaining segments become an off-street path that goes through a tunnel that is completely protected from car traffic. Route 2 (Military Walk) is a three-segment off-street path that runs from the student center to a large dining hall on campus along a large academic plaza. Route 3 (Lubbock Street) is a four-segment route that heads east and contains low-traffic roads from the student center toward a central parking garage. Route 4 (Simpson Drill Field) is a three segment route that starts near a large green space and heads under a bridge to academic buildings on the west side of campus. Half of the route is protected from car traffic along an off-street path. The other half contains a road with limited vehicle traffic. Route 5 (Ross Street) is a four segment route that runs east and west along a protected road from the main dining hall to the far east side of campus. All five routes are 0.4 miles in length. Routes 1, 2, and 3 were identified as the most used bike-share routes from the Texas A&M Transportation and TTI data. Routes 4 and 5 emerged as additional routes used by many of the focus group participants.

Figure 4.4. Sample Focus Group Participant Map.

Figure 4.5. Focus Group Ratings of Routes (by Number of Participants).



Route 1 was the most-used route by focus group participants, with seven out of eleven indicating they used the route. One participant gave the route a red rating, four gave it a yellow rating, and two gave it a green rating. Route 2 did not have any red ratings, but had four yellow and one green rating. Route 3 also did not have red ratings, but was given three yellow ratings and two green ratings. Route 4 had the highest number of red ratings with four participants assigning it a red and three giving it a yellow rating. Route 5 had one red rating, three yellow ratings, and two green ratings. Table 4.4 shows a numerical score for each route based on participants' color ratings. The Lubbock Street had the highest score at 70.0 whereas Simpson Drill Field had the lowest score at 21.4.

4.4. Focus Group Ratings of Routes with Numerical Scores.

Route	Number of Raters	Points Assigned (Red=0; Yellow=1; Green=2)	Highest Points Possible	SCORE (Points/Highest Points Possible *100)
Rec Center (Route 1)	7	8	14	57.1
Military Walk (Route 2)	5	6	10	60.0
Lubbock Street (Route 3)	5	7	10	70.0
Simpson Drill Field (Route 4)	7	3	14	21.4
Ross Street (Route 5)	6	7	12	58.3

Environmental Audit

Three commonly used routes for bike-share were identified from data provided by Texas A&M Transportation Services and TTI, and two routes were identified by researchers based on data provided by the November 2018 focus groups. Three of the routes had three segments each and two routes had four segments, for a total of 17 segments. The routes were numbered and named based on campus landmarks or street names. Each segment was also given a name/letter assignment. Table 4.5 summarizes the number score and grade for each segment and route, and provides an overall score and grade for the five routes. Seven segments (41%) received an A grade, while 10 segments (59%) received a B grade. Military Walk, a route with an off-street path cutting across campus and was completely protected from motor vehicles, received the highest score at 86.7%. The lowest score was attributed to the Ross Street route at 82.5%. The overall score for all routes evaluated was 84.4%. Routes 2, 3, and 5 had very good inter-rater reliability, whereas route 1 had moderate reliability, and route 4 had good inter-rater reliability. Table 4.5 provides the weighted Kappa scores for inter-rater reliability.

Table 4.5. Environmental Audit Scores.

Route Name	Segment	Number Score (%)	Letter Grade	Weighted Kappa (%)
Route 1 – Rec Center				
	Route 1 Segment A	80.0	B	
	Route 1 Segment B	81.7	B	
	Route 1 Segment C	95.0	A	
	Overall	**85.6**	**A**	**52.7**
Route 2 – Military Walk				
	Route 2 Segment A	82.5	B	
	Route 2 Segment B	85.8	A	
	Route 2 Segment C	91.7	A	
	Overall	**86.7**	**A**	**98.0**
Route 3 – Lubbock Street				
	Route 3 Segment A	75.8	B	
	Route 3 Segment B	85.8	A	
	Route 3 Segment C	83.3	B	
	Route 3 Segment D	90.0	A	
	Overall	**83.8**	**B**	**88.6**
Route 4 – Simpson Drill Field				
	Route 4 Segment A	84.2	B	
	Route 4 Segment B	89.2	A	
	Route 4 Segment C	77.5	B	
	Overall	**83.6**	**B**	**80.3**
Route 5 – Ross Street				
	Route 5 Segment A	87.5	A	
	Route 5 Segment B	79.2	B	
	Route 5 Segment C	79.2	B	
	Route 5 Segment D	84.2	B	
	Overall	**82.5**	**B**	**89.4**
TOTAL		**84.4**	**B**	

Table 4.6 shows the twelve criteria evaluated by segment. The first three criteria relate to safety, the next seven relate to quality, and the final criterion relates to comfort. Presence of pedestrian facilities and mobility impaired accessible paths received the

highest scores (5.0) across all segments. The lowest average score was for the criterion named “bikeability” at 1.9 due to lack of designated bike lanes and insufficient bike lane signage on various segments. For example, Figure 4.6 shows a photo of the sign for a bike lane on Route 5, but only does so at the very beginning of the street. Figure 4.7 shows a photo along that same route without any bike lane designation. Figure 4.8 shows a less visible bike lane signage on Route 1. The next lowest scores were 3.5 for potential pedestrian/biker/vehicle conflicts and 3.8 for crosswalk quality. All other mean scores fell between 4.0 and 4.9.

Table 4.6. Segment Scores by Criterion (n=17).

Criterion		**Mean Score**
Safety Criteria		
	Pedestrian facilities	5.0
	Pedestrian/biker/vehicle potential conflict	3.5
	Crosswalk quality	3.8
Path Quality Criteria		
	Path maintenance	4.7
	Path size	4.9
	Buffer zone	4.4
	Accessible/passable for mobility impaired	5.0
	Bikeability	1.9
	Terrain	4.6
	Aesthetics	4.7
Path Temperature Comfort Criterion		
	Shade	4.0

Figure 4.6. Photo with Bike Lane Signage on Route 5.

Figure 4.7. Photo without Bike Lane Signage on Route 5.

Figure 4.8. Photo with Less Visible Bike Lane Signage on Route 1.

Bike Counts

The peak vs. non-peak bike counts are summarized in Table 4.7. Route 5, Ross Street, had the highest number of bikes counted, with 91 bikes in a 15 minute peak time and 17 bikes in a 15 minute non-peak time. Route 1 had the next highest with a count of 67 bikes. The third highest count of bikes took place along Lubbock Street (Route 3) with a total of 56 bikes counted. These three routes were those identified by Texas Transportation Services and TTI as highly trafficked bike routes using a GPS heat map. Routes 2 and 4 had similar numbers of bike counts at totals of 36 and 35 bikes, respectively. These two routes were those identified as preferred routes by focus group participants.

Table 4.7. Bike Counts.

Route Name	Time of Day	Bike Counts
Route 1 – Rec Center		
	15 minutes peak	44
	15 minutes non-peak	23
	Total	67
Route 2 – Military Walk		
	15 minutes peak	23
	15 minutes non-peak	13
	Total	36
Route 3 – Lubbock Street		
	15 minutes peak	45
	15 minutes non-peak	11
	Total	56
Route 4 – Simpson Drill Field		
	15 minutes peak	29
	15 minutes non-peak	16
	Total	35
Route 5 – Ross Street		
	15 minutes peak	91
	15 minutes non-peak	17
	Total	108
TOTAL		**302**

Comparison of Focus Group and Audit Results

Table 4.8 summarizes the differences between the perceptions of the five identified routes as explored with student participants during focus groups and the direct observations of the routes as assessed during environmental audits. The focus group ratings of the routes were more varied and in, in general, lower than the audit scores of the routes. The closest match was on Route 3 with a score of 70.0 by focus group participants and an audit score of 83.8. The largest mismatch between focus group ratings and environmental audits was 21.4 and 83.6, respectively, on Route 4.

Table 4.8. Comparison of Focus Group Scores and Audit Scores and Grades by Route.

Route Name	Focus Group Score	Audit Number Score (%)	Audit Letter Grade
Route 1 – Rec Center	57.1	85.6	A
Route 2 – Military Walk	60.0	86.7	A
Route 3 – Lubbock Street	70.0	83.8	B
Route 4 – Simpson Drill Field	21.4	83.6	B
Route 5 – Ross Street	58.3	82.5	B
TOTAL	**53.4**	**84.4**	**B**

Discussion

In summary, the results show that student perceptions of bikeability on five commonly used routes on this specific campus did not match the objective assessments of those routes. Perceptions of campus bikeability (in terms of safety, quality, and comfort), as reflected in the focus groups, was poorer than the ratings scored in the environmental audits. Bike counts highlighted additional mismatch between perceptions and reality when considering potential user conflict along multi-use routes. The factor that most matched between perceptions and audits was the presence (or lack) of bike lanes. Most interestingly, the audit tool, while fairly reliable and easy to use, did not differentiate between routes. All scores were within three points of each other. This lack of variability in route scores did not help in identifying strengths and weaknesses of the cycling environment on campus.

Focus group participants highlighted more problems along common routes than the audit tool. Three of the five routes (Routes 1, 4, and 5) were given at least one red rating. Route 4 was graded particularly low by focus group participants with four red ratings and no green ratings, even though it received a “B” grade by the environmental audit. These results are not surprising given what the literature reports about the mismatch between user perceptions and the actual characteristics of the built environment. Ball and colleagues in their 2008 study found that there was a mismatch between perceptions and objective assessments of built environment features—especially among younger and older women, those with lower income, and lower physical activity (Ball et al., 2008). Gebel et al., found a fair match between perceptions and objective measurements of walkability in their 2009 study (Gebel et al., 2009). But mismatch occurred more often with individuals with lower levels of income and education and those that were less physically active. A recent study explored the match or mismatch of perception and objective measures of the environment for biking in Portland, OR and found that both the actual and perceived built environment influenced biking behavior (Ma & Dill, 2015). None of these studies, though, is specific to a university-wide population or setting.

A safety issue that emerged in the focus group discussions was congestion on campus. During certain times of the day, the potential for conflict between cyclists and pedestrians is quite high. Vedel and colleagues in a study about cyclists and crowding, found that cyclists were willing to ride out of their way to avoid potential conflicts if a route was too crowded (Vedel et al., 2017). An Amsterdam study of paths traveled by different types of users (but not vehicles), an increase in the number of users led to an increase in the number of conflicts (Zacharias, 1999). Even a potential for conflict can affect how a cyclists will use a route. Perhaps students are choosing to not even ride bike-share bikes in certain areas of campus because of the congestion at peak times. Several focus group participants shared that they only rode bike-share at night on campus, because it was too crowded during the day. The audit tool did not capture this potential for conflict accurately. In fact, the audit tool specifies that the conflict may involve vehicles and pedestrians/cyclists (criterion 2 under Safety). The mean score for this criterion was 3.5, quite high given the number of bikes counted along some of the routes and the foot traffic during peak hours. Auditors were instructed to consider potential conflicts between cyclists and pedestrians, but a tool that is specific to college campuses may wish to include these other potential conflicts, like pedestrians, personal bikes (that ride at higher speeds), bike-share bikes, skateboards, and scooters. Interestingly, the bike counts revealed that Route 5, Ross Street, had the highest amount of bikes during peak times at 91 bikes. But the Ross Street route was rated higher by focus group participants than Route 4, Simpson Drill Field. Route 4 only had 35 cyclists during peak times, so the low ratings on this route likely had more to do with the lack of bike lanes and the construction happening along this route than the potential for conflicts with other cyclists. Environmental assessments of campus should include criteria about the non-motor vehicle (cyclists, pedestrians, skateboarders, etc.) congestion on routes.

Another issue that reflected mismatch between perceptions and objective measures was the quality of the routes. Focus group participants described puddles because of irrigation system problems that led pedestrians to step off the sidewalk and into the street to avoid them. Participants also discussed sidewalks that were uneven due to bricks or tree roots pushing through that were difficult to ride on with a bike-share bike. Also, construction projects on campus closed sidewalks down and led walkers and bikers on to streets. Campuses are unique settings where construction may be continual and irrigation is a priority. All of these issues affect bikeability. Even though the focus group perceptions were quite negative about the quality of the paths on campus, the environmental audits rated them to be of good quality. In fact, the mean quality criteria scores were quite high (Table 4.6), with the exception of the "bikeability" criterion which is described next.

The focus group discussions also provided insight into the difference between perceptions of bike lanes on campus and the objective assessments of the bike lanes on specific routes. Participants reported that bike lanes were not apparent on common routes, and the low mean score of 1.9 for the "bikeability" criterion on the environmental audits ("bikeability on the tool referred to presence or absence of bike lanes) reflects that perception. When bike lanes did exist, markings were not consistent. Several routes only had small signs that indicated bike lanes existed at the beginning or end of the routes (Figures 4.6 and 4.7). If cyclists got on the routes somewhere in between they would not be aware that bike lanes existed on that route. On routes that were on off-street paths that crossed campus and tunnels (Routes 1, 2, and 4) that went under major roadways, bike lanes were not as apparent either. On Route 1, bike lanes exist but signage is positioned high and may be out of a cyclist's field of vision (Figure 4.8). Directionality of the bike lanes is not highly visible as well. Finally, even when bike lanes existed on streets or on off-street paths, cyclists were concerned about pedestrians walking in the bike lanes.

Overall, the CDC Health Worksite Initiative Walkability Audit as adapted by Horacek and colleagues was quite easy to use (Horacek et al., 2012). However, the tool was not helpful in differentiating between the routes that were audited. As recorded in Table 4.5, the route scores ranged between 82.5 and 86.7. This small amount of variability among route scores and the mismatch between the audits and user perceptions indicate that the tool in its current form may not be suitable for campus auditing of bikeability. The tool could be adapted to include more specific measures of bikeability. For example, the criterion "bikeability" could be broken down into subcategories to evaluate the bike lanes themselves. Even if bike lanes do exist, they may not direct bike flow appropriately, and some types of bike lanes may work better than others. As mentioned previously, the potential for conflict safety criterion could be expanded to include potential conflicts among all path users. Motorized vehicles may not be the biggest safety concern when cycling on a college campus. The inter-rater reliability as tested with the weighted Kappa showed moderate to very good reliability of the tool (Table 4.5). Route 1 had only moderate inter-rater reliability. Some of the differences between the raters on each segment of Route 1 were in assessing the shade and terrain criteria. More specification may be necessary on those criteria to get accurately aligned results. Auditors attended a two-hour training session prior to conducting audits. More training in the field may be necessary to increase the inter-rater reliability.

A strength of the study was the community-based participatory approach. Focus groups were comprised of students, and students helped to audit the routes. The focus group participants and the student auditors had varying levels of bike expertise but were all quite familiar with the campus. Researchers would likely have missed nuances of campus bikeability, such as irrigation problems and potential for conflicts during peak times, if students had not made them aware. The multiple methods aided in the understanding that both perceptions and objective assessments matter when evaluating bikeability. This methodology could be easily applied to studies at other campuses, or in comparative studies. In addition, the methods used for discussing and mapping bikeability in focus groups could be scaled up to include a larger sample using on-line mapping technology.

This study has a number of policy implications. Campuses would do well to consider both perceptions of student, faculty, and staff and campus-wide micro-scale audits when planning for bikeability improvements. In order for dockless bike-share programs to be safe and successful, cycling rules need to be communicated well and enforced. All modes of transport on a college campus need to be aware of each other and follow the rules of traffic, even pedestrians. Campuses that have well-marked paths for pedestrians, cyclists, and motor vehicles may see the most overall success when introducing a new bike-share system. Future research could explore the differences in bikeability of college campuses based on urban versus rural settings.

CHAPTER V

CONCLUSIONS

This work adds to the physical activity and built environment knowledge base by offering pragmatically conducted research, in partnership with stakeholders and community members, which examines dockless bike-share uptake among students, faculty, and staff; reviews the strengths and weaknesses of current bikeability tools; and conducts an environmental assessment of bikeability on a college campus.

There are a number of lessons learned from this work. Because of the broad and non-standardized definition of bikeability, studies and tools addressing bikeability vary widely. Different disciplines, such as transportation, public health, or urban planning, may address bikeability with different terminology and using vastly different approaches. It is difficult to compare tools for assessment when the jargon and fields of study differ extensively. Bikeability means different things to different people, depending on their cycling purpose. A common definition is needed. Another lesson was how innovations like dockless bike-share may draw strong opinions. Community members during the first phases of the implementation of the bike-share had much to say about the program, and the rapid and sizeable survey response in the spring of 2018 reflected that. A final lesson from this research was that perceptions do matter. As much as researchers may wish to give an "objective" score to an environment, we gain nothing if we do not understand how the users of the environment experience it. Involving community members through discussion, mapping, and auditing provides unique perceptual insights that may be missed without their participation.

This work is limited due to its cross-sectional nature. The two multi-method studies were conducted at one point in time and can only reveal the attitudes and activities taking place during the Spring and Fall seasons of 2018. Due to limited resources and time, four focus groups were conducted in the spring, and two were completed in the fall. Though the focus groups reached topic saturation quite quickly, with more resources, more discussion groups could have been held, allowing for even richer qualitative data. Also, because students were leaving for the semester, requiring a quickly-conducted survey in the spring, the survey instrument was not fully tested. Because these are the early days of bike-share, and especially dockless bike-share, there are few studies to guide as research examples. These limitations are common in pragmatic research and natural experiments since the demands for timely results do not always allow for pilot-testing and tool development, and the literature may not yet provide tested methods from previous research.

There are a number of implications and directions for further research regarding bike-share use. Given that there is at times tension in college communities between community members and the campus community, research may survey community members or include them in discussions about the bike-share programs and cycling infrastructure. Developed messaging could have made a difference in the acceptance of the dockless bike-share program on Texas A&M's campus. Future studies could include the evaluation of messaging campaigns on the use of bike-share. Research could be conducted to examine how the use of bike-share affects other modes of transportation around campus and to explore the economic impact. Additional surveys could be developed, tested, and administered among the campus community.

Future research that addresses the bikeability of environments could include more rigorous testing of assessment tools. Only half of the tools evaluated in the scoping study in chapter 3 provided results of any kind of testing of the tools. Economic evaluations could be conducted to explore whether bike use increases when biking infrastructure improvements are made. More research is needed to determine the full impact of the built environment on physical activity. Comparisons between college campuses could provide insight into regional differences in social and physical environments. A scaled up on-line version of the focus group mapping activity as described in chapter 4 could be administered widely in a number of different settings.

In order to address population health concerns, additional work could be done to explore attitudes and behaviors around cycling over time. Specific cycling interventions need to be developed and rigorously evaluated. If students use bike-share in college, how does this translate to future cycling, bike-share or otherwise? And how do cycling behaviors impact overall health? It is necessary to examine more closely the issue of safety and cycling. Educational programming could be developed to encourage safer practices among all users of an environment and to create a cycling culture in communities. Thought should be given as well as to how to mediate perceptions of safety. Research should be devoted to questions of equity. Do built environment interventions affect populations equally? How might creating bikeable communities help and hurt certain groups? Finally, consideration should be given to the next phase of bike-share, which may not include bikes at all. With the introduction of e-scooters in communities, biking and walking may be replaced by less safe and faster forms of transportation.

Overall, this work provided a comprehensive start to the relatively new field of bike-share and bikeability research on college campuses. A variety of methods were employed, and analysis laid the groundwork for a line of work that will impact the field of physical activity and the built environment—all in an effort to improve health.

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