Assessing Potential of Bike Share Networks and Active Transportation to Improve Urban Mobility, Physical Activity and Public Health Outcomes in South Carolina

Final Report

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October 2024

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Assessing Potential of Bike Share Networks and Active Transportation to Improve Urban Mobility, Physical Activity and Public Health Outcomes in South Carolina		5. Report Date October 21, 2024 6. Performing Organization Code
7. Author(s) William J. Davis, Ph.D., ORCID: 0000-0002-3812-8654 Kweku Brown, Ph.D., ORCID: 0000-0001-6497-8479 Morgan Hughey, Ph.D., ORCID: 0000-0003-4973-6150 Dimitra Michalaka, Ph.D., ORCID: 0000-0001-7001-0579 Daniel Bornstein, Ph.D., ORCID: 0000-0001-9948-1876 Nathan Hunyh, Ph.D., ORCID: 0000-0002-4605-5651 Andrew Kaczynski, Ph.D., ORCID: 0000-0001-8724-8241		8. Performing Organization Report No.
9. Performing Organization Name and Address The Citadel Dept. of Civil & Environmental Engineering 171 Moultrie St. Charleston, SC 29409		10. Work Unit No. 11. Contract or Grant No. 69A3551747117
12. Sponsoring Agency Name and Address Center for Connected Multimodal Mobility (C^2M^2) Clemson University 200 Lowry Hall Clemson, SC 29634		13. Type of Report and Period Covered Final Report (Aug 2019 - Aug 2023) 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Cities and communities across the U.S. are placing a greater emphasis on active transportation and implementing bike share systems through partnerships with private service providers and advocacy groups. This research project assessed impacts of the built environment and transportation infrastructure on physical activity, health and active transportation through a case study analysis located in Charleston, South Carolina with specific emphasis on a local bike share system. Use of active transportation travel modes, such as bike share systems, to accommodate short (3-miles or less) length urban trips provides a unique solution for improving mobility, reducing congestion, adopting sustainability concepts, increasing levels of physical activity, and influencing desirable public health outcomes. Charleston's initial bike share system, Holy Spokes, was launched in 2017 and included 27-stations, 250-bicycle fleet, and 13,000-registered members. During the initial year of operation users logged 49,000-trips and 105,000-miles of travel within the downtown peninsula district, which incorporates 8-square miles, or 5,120-acres. Specific research objectives focused on levels of physical activity benefits for bicyclists and use of suitable routes for bicycle travel.

17. Keywords	18. Distribution Statement		
Bike Share, physical activity, active transportation	No restrictions.		
19. Security Classif. (of this report)	**20. Security Classif. (of this page)**	**21. No. of Pages**	**22. Price**
Unclassified	Unclassified	45	NA

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EXECUTIVE SUMMARY

Cities and communities across the U.S. are placing a greater emphasis on active transportation and implementing bike share systems through partnerships with private service providers and advocacy groups. This research project assessed impacts of the built environment and transportation infrastructure on physical activity, health and active transportation through a case study analysis located in Charleston, South Carolina with specific emphasis on a local bike share system. Use of active transportation travel modes, such as bike share systems, to accommodate short (3-miles or less) length urban trips provides a unique solution for improving mobility, reducing congestion, adopting sustainability concepts, increasing levels of physical activity, and influencing desirable public health outcomes. Charleston's initial bike share system, Holy Spokes, was launched in 2017 and included 27-stations, 250-bicycle fleet, and 13,000-registered members. During the initial year of operation users logged 49,000-trips and 105,000-miles of travel within the downtown peninsula district, which incorporates 8-square miles, or 5,120-acres. Specific research objectives focused on levels of physical activity benefits for bicyclists and use of suitable routes for bicycle travel.

For assessment of physical activity benefits 2018 total bike share trips (n=34,551), average trip distance of 2.43-miles, average duration of 40-minutes, and average speed of five (5) miles per hour, were used to calculate physical activity for an average bike ride as 161 MET-minutes of energy expenditure. METs are a unit of metabolic equivalent, with one (1) MET defined as the energy expended when resting or sitting still. METs range from Light (less than 3 METs), Moderate (3-6 METs), and Vigorous (greater than 6 METs). The American Heart Association recommends at least 150-minutes of moderate intensity aerobic exercise each week for optimal cardiovascular health, which equates to 500 MET-minutes per week. The calculated value of 161 MET-minutes of energy expenditure via bike share trip provides 32 percent of recommended weekly exercise. Assuming users take multiple bike share system trips per week exceeding three (3) trips, this mode of travel could easily provide aerobic exercise benefits exceeding American Heart Association minimum recommendations.

For assessment of roadway suitability, April 2018 bike share trips (n=5,655), average length of 2.6-miles, average duration of 39 minutes, and total of 14,846 trip miles, were used to evaluate bike share system trips use of existing streets and roadways within Charleston's downtown peninsula district. Roadway conditions were rated using a Bicycle Level of Service (BLOS) methodology published in Transportation Research Record 1578 that uses motor vehicular traffic volume, trucks, number of lanes, lane width, speed, pavement condition. BLOS ranges from A to F, with suitability levels defined as: A (extremely high), B (very high), C (moderately high), D (moderately low), E (very low) and F (extremely low). Results indicated that 82.7 percent of bike share tips are made on accommodating BLOS A through C roadways, while 17.3 percent of bike share trips are made on unaccommodating BLOS D and E roadways. No bike share trips were made on BLOS F roadways. Several spot locations where bike share users traveled for a short distance of a block or more on high motor vehicle volume, high speed arterial roadways for which possible network solutions were recommended.

CHAPTER 1
Introduction

1.1 Bike Share Potential for Improving Urban Mobility

Cities and communities across the U.S. are placing an emphasis on active transportation and implementing bike share systems in cooperation with advocacy groups and private service providers. This research will assess impacts of the built environment and transportation infrastructure on physical activity, health and active transportation through a case study analysis in Charleston, South Carolina with specific emphasis on a local bike share system. 72 percent of trips less than 3-miles and 60 percent of trips less than 2-miles are made by private vehicles (NHTS, 2009). Using bike share and other active transportation techniques to accommodate these travel demands in urban areas, and other appropriate communities such as college campuses, provides a uniquely synergistic opportunity to improve mobility, reduce congestion, adopt sustainability concepts, increase levels of physical activity, and influence desirable public health outcomes. Producing integrated data sets, establishing methodologies, and defining evidence-based analytical relationships using a multidisciplinary approach will help communities pursue these desirable community objectives in a more informed and effective manner.

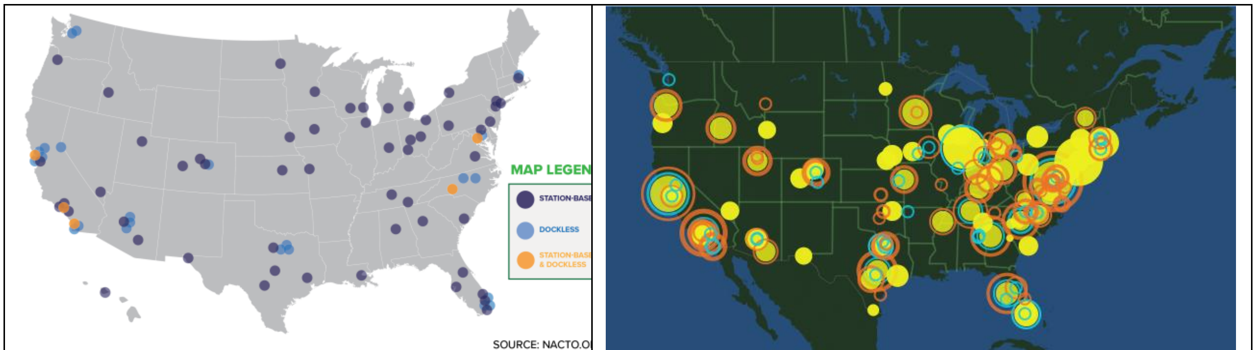
Conducting an evaluation of active transportation and a bike share system in Charleston, South Carolina comprises a desirable community setting to conduct an illustrative case study for exploring insightful relationships that will be informative to other communities. Charleston's bike share system, Holy Spokes, was launched in May 2017 including 27 stations with a fleet of 250 bicycles and 13,000 registered members. In the first year of operation users logged 49,000 trips and 105,000 miles of travel, primary within the downtown peninsula district, which incorporates 8 square miles, or 5,120 acres, see Figure 1

Bike Stations | Heat Map of Route Use | Holy Spoke Bike Share (n=250 bikes, 27 stations)

Figure 1 Holy Spokes Bike Share System, Charleston, SC, 2017-2022

A host of metrics over the past few decades have shown South Carolina has historically been one of the leading states in high traffic crash rates and fatalities, high obesity rates, high rate of mortality due to heart disease and diabetes, and minimal use of active transportation. High rates of obesity and chronic disease pose significant threats to public health, economic health, and national security. The National Household Travel Survey reports walking and biking has increased by over 21% since 2001, however, these mode shares make up only 11.5 % of travel in the U.S.

although over 45% of all trips are 3 miles or less (NHTS 2017). This research assesses impacts of built environment infrastructure on physical activity, health, and active transportation through a case study analysis in Charleston, SC, with specific emphasis on a local bike share system. Public and private sector stakeholders are working in cooperation to provide active transportation, often incorporating bike share systems. 35 million bike share trips were taken in the U.S. in 2017, 25% more than in 2016. With over 60 U.S. bike share systems in 2017 (NACTO 2018), and 136 Bike Share Systems in 2020 (BTS, 2020, results from this study of interest to help inform communities working to address short distance trips that reduces urban congestion, positively impacts physical activity and public health outcomes, see Figure 2.



Over 60 U.S. Bike Share Systems, 2017, NACTO | 136 U.S. Bike Share Systems, 2020, BTS

Figure 2 U.S. Bike Share Systems, 2017-2020

1.2 Bike Share System Potential for Improving Safety and Public Health

Charleston, SC, exhibits some of the worst transportation safety statistics in the state with respect to fatal automobile, bicycle, and pedestrian crashes. In 2016, Charleston County had the most total traffic collisions (16,515), injury collisions (4,452), and non-fatal injuries (6,587) in the state of South Carolina (2016 SC Fact Book). Additionally, South Carolina and Charleston County also experience disproportionately high prevalence of chronic diseases compared to other regions of the U.S. In 2016, approximately 67% of adults over 18 years old in SC were classified as overweight or obese, measured by body mass index, BMI (SCDEHC, 2016). Furthermore, cancer and heart disease are the two leading causes of death in Charleston Co., with 32% and 27% of deaths attributable to those diseases, respectively. Chronic conditions, like heart disease, and risk factors for chronic disease, like overweight and obesity, can be mitigated by achieving recommended amounts of physical activity. Growing research shows built environment conditions are key factors for individuals in promoting regular physical activity and preventing chronic disease (Sallis et al., 2012). This examination combines expertise and methodologies from the disciplines of exercise science, public health, and transportation engineering, associations between active transportation, built environment infrastructure and health outcomes.

1.3 Research Goals and Objectives

Goals: The goals of this research are to evaluate non-motorized use of the built environment by integrating disparate data sources to provide insight specific to Charleston, but translatable to other localities. Qualitative, quantitative, and geospatial methods will be used to identify areas of success, and areas of greatest need for improving multi-modal transportation, physical activity, and health.

Objectives: Objectives of this research are to study bike share operations through the following analyses, examinations, and evaluations.

1) Analysis of geospatial and quantitative data using an integrated multidimensional GIS (Geographic Information System) database and GPS (Global Positioning System) route tracking data from the bike share system will include:
    a. Analysis of trip distance, trip patterns, and trip characteristics.
    b. Identification of associations between type of bike share user (i.e., local vs. visitor)
    c. Examination of the prevalence of specific streets and routes used, and identification of transportation infrastructure network operational conditions.
    d. Determination of associations between use and prevalence of bikeshare routes and measured street characteristics, including lanes, lane width, traffic, and sidewalks,
    e. Investigation of potential for increasing bike share capture of 2-mile and 3-mile trips to improve urban mobility and reduce traffic congestion,
    f. Examination of active transportation and bike share use to improve physical activity and public health outcomes using health models such as Health Economic Assessment Tool, HEAT.
2) Examination of bicycling patterns in various types of built environments (e.g., greenways, multi-use biking paths) in Charleston, SC
3) Evaluation of user perceptions and motivations for biking and walking in Charleston, SC
4) Engagement of local officials, decision makers, and community stakeholders through effective summary of data analysis and results (e.g., infographics, formal meeting)

Publication and presentation of findings in national forums for the engineering profession, city planning officials, municipalities and stakeholders via strategic technology transfer channels.

CHAPTER 2
Literature Review

A review of the literature focused on the methods of assessing bike level of service and suitability is done in this section. In addition, an overview of the characteristics of current bike share systems in the state of SC and NC is provided and previous research on the public health outcomes related to bike share is provided.

2.1 Impact of Bike Share Systems on Urban Mobility and Public Health

Over the past two decades, there has been a noteworthy growth in the implementation and usage of bike share systems in cities and urban communities in the U.S. Two of the reasons for this growth, among many others (Midgley P, 2011; Rojas-Rueda David; de Nazelle, 2016; S. Shaheen et al., 2010; S. A. Shaheen et al., 2013; Woodcock et al., 2014), can be linked to the perceived and measurable benefits of bike share systems to urban mobility and public health. Research over the years have identified improving urban mobility through the alleviation of congestion (Barbour et al., 2019; Fuller, Gauvin, Kestens, Daniel, et al., 2013; S. Shaheen, Cohen, et al., 2013; S. Shaheen et al., 2010; S. Shaheen, Martin, et al., 2013) in urban areas and increased physical activity levels leading to healthier lifestyles (Barbour et al., 2019; Fishman et al., 2015; Fuller, Gauvin, Kestens, Daniel, et al., 2013; Otero et al., 2018; Rojas-Rueda David; de Nazelle, 2016; Woodcock et al., 2014) as two of the primary benefits of adopting more active transportation modes such as bike share systems in the community. There is extensive literature on the history, growth, impact and breadth of potential benefits of bike share systems that are beyond the scope of this research. Some noteworthy synthesis of bikeshare literature has been done by Fishman et al and by Si et al (Fishman et al., 2013; Si et al., 2019). These syntheses provide an in-depth review of bike share literature and could be referred to for review content outside the scope of this research. This section of the literature review focuses primarily on the impacts of bike share systems on urban mobility and public health.

The primary travel mode to, from and in most cities is the use of personal vehicles. Many cities across the country have worked on promoting alternative and active modes of transportation such as mass transit, biking and walking to mixed results. One of the primary roles of bike share systems is to provide a means of active transportation for short trips (3 miles or less) and to create connections and extensions to transit modes, popularly known as the first and last mile of transit (Midgley P, 2011). A study by Martin showed that the introduction of bike share systems in Minneapolis and Washington DC increased biking for surveyed bike share users by over 70% and reduce driving for these same bike share users by over 40% in both cities (Martin & Shaheen, 2014). A study by Fishman et al, also reported significant gains in car travel reduction as a result of bike share usage from a survey of bike share members across five cities: Melbourne (19%), Brisbane (21%), Washington D.C (7%), Minneapolis (19%) and London (2%) (Fishman, Washington, & Haworth, 2014).

However, the results of switching to bike share systems or away from driving are not as binary as presented above. The effects of introducing a bike share system are multifaceted and vary for different reasons and by city. Research has shown that the introduction of bike share systems would typically draw users from almost all modes of existing travel and could produce an increase or decrease in usage of other travel modes in the area (S. Shaheen, Martin, et al., 2013). Studies have shown changes in travel behavior and modes such as increase in train and bus usage (Bullock et al., 2017; Martin & Shaheen, 2014; S. Shaheen, Martin, et al., 2013) or a decrease in train, bus and walking (Fuller, Gauvin, Kestens, Morency, et al., 2013; Martin & Shaheen, 2014; S. Shaheen, Martin, et al., 2013). Overall studies have reported mixed results regarding the reduction of congestion as a result of the implementation of bike share systems. A study by Wang et al looked at effects of bike share systems in 96 urban areas in the U.S. The study modelling results suggested a reduction in per capita congestion in large cities but an increase in per capita congestion in wealthier cities (Wang & Zhou, 2017).

Similar to urban mobility, numerous studies have investigated the link between physical activity and public health outcomes. The general consensus on these studies is that residents of sprawling communities with a less connected transportation network were less likely to engage in physical activity. Therefore, increasing their risk for adverse health conditions such as obesity, hypertension and heart disease (Ewing et al., 2014; Frank et al., 2004; Koohsari et al., 2015; Lee et al., 2015). Active transportation modes such as walking and biking could be a major contributor to engaging in physical activity if part of a daily commute. Which is why bike share systems have been identified as a way to provide an efficient transportation option for short trips while still providing opportunity for riders to engage in physical activity.

A study by Woodcock et al in 2014, investigated the health impact of the London bike share system. Their results show that although overall individual increase in physical activity was minimal through the bike share, their models showed significant gains in health benefits for the population. The major benefit among men was the potential risk reduction of heart disease while reductions in risk of depression was the most significant for women (Woodcock et al., 2014). Also, a study by Otero et al in 2018 evaluated the health impacts of twelve bikes share systems across Europe. This study quantified health risks and benefits obtained by substituting car trips with bike trips from a mortality standpoint. That is how many deaths (fatal car crashes, death through poor health etc) could be avoided by actively using bike share rides for daily commute and activities. There were four scenarios studied where the impact of different levels of mode switch (5%, 12%, 50% and 100%) from car to bike share were investigated. The results of the study showed that in all cities and scenarios studied the health benefits outweighed the health risks for switching to more bike share use. Specifically, potential lives saved would be 5 (5% switch), 9 (12% switch), 37 (50% switch) and 74 (100% switch) for their respective mode switch percents (Otero et al., 2018). In addition, research by Barbour et al infers that Body Mass Index (BMI), a surrogate measure of obesity and overall health risk, is a strong predictor of bike share usage in that healthier individuals tend to continue to engage in active transportation. Whereas there is no evidence to show that those with higher BMIs would make the switch to active transportation (Barbour et al., 2019).

One of the concerns about bikes shares' net impact on public health has been the shift from other active modes of transportation such as transit and walking to bikeshare (Fuller, Gauvin, Kestens, Morency, et al., 2013). Particularly the concern is that there are reduced levels of physical activity in a bike trip compared to walk trip of equal distance (Fishman et al., 2015; Murphy & Usher, 2014), however, the premise is that users will now be able to take longer trips with bikes and make up any deficiencies in physical activity that might have been realized between the walk and bike trip. Further, few researchers have shown concern and have been critical of the emphasis on qualitative and perceived benefits of bike share systems and the lack of concrete empirical benefits from previous research. Referring to lack of evidence that bike share systems significantly reduce traffic congestion, carbon emission or pollution in deployed regions (Ricci, 2015). But even skeptics and critics of bike shares have alluded to the potential benefits of the system if it has a clear purpose, policy and resources are dedicated to its implementation, is implemented at a larger scale and more strategically, in ways to benefit low-income communities (Bauman et al., 2017; Médard de Chardon, 2019; Ricci, 2015).

This literature review on the bike share impact on urban mobility and public health has created an awareness of existing work and has created a launching pad for this project. Particularly the concerns of merely presenting qualitative findings will be addressed. Whereas previous studies have used self-reported surveys or telephone surveys in determining physical activity levels (Fuller, barbour) (Barbour et al., 2019; Fuller, Gauvin, Kestens, Daniel, et al., 2013; Fuller, Gauvin, Kestens, Morency, et al., 2013), our study utilizes actual individual ride share user data such as trip length, duration, ride speed etc to determine physical activity metrics for this research.

2.2 Evaluating transportation networks suitability to accommodate bicycles

The built environment plays a major role in creating a safe and efficient transportation system. The transportation system is complex and has to service modes and users with different needs. Cars and motor vehicles have been the dominant users of most transportation systems since the 1950s. In recent years, transportation agencies at the federal, state and local levels have focused on other modes and users of the transportation system such as transit, biking and walking. Over the past few decades, city planning has placed an emphasis on providing infrastructure and a safe environment for walking, biking and other active transportation modes as users of these modes are vulnerable road users.

The lack of bike infrastructure puts bicycle riders in unsafe situations when sharing the road with motor vehicles. Among vulnerable road users, bicyclists have the most exposure to vehicular traffic and are most at risk of an injury crash on the roadway. A survey in the UK reported that 86% of the surveyed population viewed biking as the highest risk of being involved in a traffic crash (Thornton et al., 2010). Feeling unsafe when biking is a major deterrent to members of the community engaging in this form of active transportation. A cycling study by the City of Toronto reported that over 72% of bikers felt comfortable riding in bike lanes while only 31% were comfortable sharing the road without bike lanes (Ipsos Reid, 2010). However, a study by Fishman et al concluded that the introduction of a bikeshare system ultimately reduced the crash risk for bicycles in general (Fishman & Schepers, 2016). These results corroborated a previous study by Woodcock who hypothesized similar low risk levels for bike share users (Woodcock et al., 2014). This lowering of risk due to implementation of bike share systems could be due to several reasons. Aside the increased visibility of biking services in the community, researchers found that in general increasing cycling flows results in a decrease in the odds of injury (Aldred et al., 2018).

The investment and provision of bike network improvements and facilities such as bike lanes and separated barriers provided a sense of security for bike share users and cyclists alike. Studies have shown that the presence of these facilities provide a safer environment for biking. Specifically, vehicles are able to pass bikes with more lateral clearance (Chuang et al., 2013; Mehta et al., 2015). Also, the overall risk and occurrence of crashes is significantly lower when bike facilities are present (Nosal & Miranda-Moreno, 2012; Reynolds et al., 2009). Other studies have shown correlation between bicycle safety and road infrastructure. With residential low speed roads showing the least risk to cyclists (Aldred et al., 2018). To add to the effect of the presence of bike lanes other studies have looked at more wholistic bike safety metrics such as 'Level of Traffic Stress (LTS) and Bike Level of Service (BLOS) which include factors such as traffic volumes (AADT), presence of vehicle parking and vehicle lane width. Research by Chen et al, found a geospatial correlation between injury bike crashes and higher LTS roadways (Chen et al., 2017). An extensive review of literature on the safety impacts of bicycle infrastructure design was conducted by DiGioia et al. This review provides valuable insight into methods, treatments and countermeasures that have been effective in creating a safer biking environment for bicyclists (DiGioia et al., 2017).

Factors that have historically guided the deployment of bike share systems have been connections to land use or activity centers and ridership potential. A study in Lyon by Tran et al, showed that most long term bikeshare subscribers use the system for commuting while other subscribers have more varying uses of the system (Tran et al., 2015). Other studies have shown that disadvantaged or low-income communities tend to be underserved by most systems (Fishman, Washington, Haworth, et al., 2014) or face more barriers to use the system (Qian & Niemeier, 2019; Ricci, 2015). In fact, studies have shown that most bikeshare systems users tend to be white, male, younger and of higher income (McNeil et al., 2017; Ricci, 2015)

Specific to this project, the research team have found no literature that shows strategic planning on if and how an existing road network would accommodate the propagation of a new bikeshare system from an efficiency and safety standpoint. One of the goals of this project is to retrospectively evaluate the Charleston road network's suitability for biking in general and for the existing bike share system, Holy Spokes which will include identifying 'safe' and 'unsafe' biking routes on the Charleston peninsula.

CHAPTER 3
Methodology

This chapter outlines the comprehensive methodologies used to evaluate Charleston's bike share system and related infrastructure. The study focused on analyzing bike share routes, assessing transportation infrastructure suitability, estimating physical activity and public health impacts, and gathering user perceptions. A combination of geospatial data analysis, direct observation, and intercept surveys was employed to provide both quantitative and qualitative insights into bike ridership patterns, infrastructure performance, and public health outcomes. These methodologies collectively ensure a robust understanding of the challenges and opportunities associated with bike share programs.

3.1 Bike Share Routes

3.1.1 Overview of Data Source

The research team accessed downloadable data from the Holy Spokes website through a data-sharing agreement with Gotcha Group (Holy Spokes). Data included trip summaries, periodic reports, and GPX files representing GPS tracking points. April 2018 was selected as the representative month for geospatial analysis based on bike usage patterns and data availability. The dataset formats included:

- PDF: Contained periodic usage summaries (e.g., daily, weekly, monthly reports).
- CSV: Included variables such as Ride ID, Start/End Time, Start/End Hub, Ride Duration, Membership Type, and Trip Length.
- GPX: Provided second-by-second latitude and longitude coordinates for bike trips.

3.1.2 Data Cleaning Process

The primary dataset needed to quantify the usage of existing infrastructure by bicycle (Objective 1c) was the routes dataset which identified and highlighted which routes (paths) were utilized by users of the bike share program. For this research, the routes data was extracted from bike GPS tracking points obtained from Gotcha Group for April 2018. The GPS raw dataset was in GPX format and contained over 800,000 GPS point locations. The GPX files contained GPS tracking point locations per second of bike usage. Each GPX file contained the latitude and longitude coordinate for each point within the downloaded dataset. Using geographic information system (GIS) geospatial analysis tools and models from ArcGIS software, the GPS points from the GPX file were geocoded to display the progression of points. Individual bike routes were created on a trip-by-trip basis using the extracted and geocoded GPS points. Approximately, 5600 bike routes were created with each bike route having a unique trip ID and a user ID as well. Each bike route was split or broken at roadway intersections. The roadway segments were defined as the roadway link between intersections (nodes). Breaking up the routes at intersections made it possible to account for multiple bike passes on a particular roadway link bike by the same user and hence possible to aggregate (count) the number of bike passes on a particular segment of the roadway.

3.2 Bike Suitability/Level of Service

3.2.1 Description of Formula for Suitability/Level of Service

To identify deficiencies in Charleston's transportation network (Objective 1c), a Bike Level of Service (LOS) analysis was performed. The analysis used Sprinkle Consulting's 2007 Bicycle LOS formula (Equation 1, Table 1), which evaluates roadway favorability based on traffic volume, speed limits, lane width, and pavement condition. Key input datasets included roadway network files from the City of Charleston and SCDOT, supplemented by surrogate values where necessary. Outputs from the formula were visualized in a GIS map displaying six Bike LOS categories.

Table 1. Bicycle Level of Service Model, Sprinkle 2007

Bicycle LOS = $a_1 \ln(\text{Vol15}/\text{Ln}) + a_2 \text{SPt}(1+10.38\text{HV})2 + a_3(1/\text{PR5})2 + a_4(\text{We})2 + C$
Where:
Vol15 = Volume of directional traffic in 15-minute time period = (ADT x D x Kd) / (4 x PHF)
where: ADT = Average Daily Traffic on the segment or link
D = Directional Factor
Kd = Peak to Daily Factor
PHF = Peak Hour Factor
Ln = Total number of directional through lanes
SPt = Effective speed limit
SPt = 1.1199 ln(SPp - 20) + 0.8103
where: SPp = Posted speed limit (a surrogate for average running speed)
HV = percentage of heavy vehicles (as defined in the 1994 Highway Capacity Manual)
PR5 = FHWA's five point pavement surface condition rating
We = Average effective width of outside through lane

Bicycle LOS Categories

The inputs to the formula were obtained from the attributes of the available roadway infrastructure datasets in Geographic Information System (GIS) format. The primary dataset used for the LOS calculation is the roadway network files from the City of Charleston and the South Carolina Department of Transportation (SCDOT). These files collectively contained: Functional Class, Traffic Volume, Posted Speed, Number of Lanes, Lane Widths and Paved Surface Widths. Surrogate values representing typical design values used in engineering practice were used for the inputs variables that were not readily available. The bike suitability (Bike LOS) was calculated for each roadway segment in the network. The geospatial output was in the form of a color thematic GIS map showing the 6 bike LOS classes.

Table 2. Bicycle Level of Service Score Ranges, Sprinkle 2007

LEVEL-OF-SERVICE	BLOS SCORE
A	≤ 1.5
B	> 1.5 and ≤ 2.5
C	> 2.5 and ≤ 3.5
D	> 3.5 and ≤ 4.5
E	> 4.5 and ≤ 5.5
F	> 5.5

3.2.3 Qualitative Assessment of Street Segments

To validate the LOS methodology, two senior investigators conducted qualitative assessments on 22 roadway segments in Charleston on September 6, 2020. The team biked 17.05 miles, recording observations on grades, speeds, and segment conditions. The evaluation was performed on Sunday, September 6, 2020 from 9:02 AM to 11:39 AM. Figure 1 shows the routes that covered the 22 segments. In total, a total of 17.05 miles was evaluated. The average moving speed was 10.2 mi/hr, with a maximum of 22.1 mi/hr which was achieved during the downhill section of the Arthur Ravenel Jr. Bridge. There is little elevation change along the routes, except for the segment involving the Ravenel Bridge. The Charleston side of the bridge has an average grade of 2.5%, which is a manageable grade for most bicyclists. The qualitative findings, aligned with LOS outputs, provided additional context for infrastructure suitability. The results of this assessment are presented in Chapter 4.

Figure 3 Charleston Sample Bike Routes Qualitative Bike Score Assessment

To qualitatively assess the Charleston cycling infrastructure, the following scale/rubric was used (source: https://www.walkscore.com/bike-score-methodology.shtml).

Table 3. Bike Score Service Levels, 0-100 Scale, Walkscore Professional

Bike Score	Description
90–100	**Biker's Paradise** Daily errands can be accomplished on a bike.
70–89	**Very Bikeable** Biking is convenient for most trips.
50–69	**Bikeable** Some bike infrastructure.
0–49	**Somewhat Bikeable** Minimal bike infrastructure.

3.3 Physical Activity Estimation, Greenway Usage, and Public Health Impacts.

Multiple study objectives addressed the physical activity and public health implications of biking and walking patterns in Charleston, SC. Two main data sources were used for this portion of the study.

First, summary data for all 2018 bike share rides was provided by Gotcha Mobility, and we used the provided characteristics from the bike share rides to estimate the physical activity of the bike share system in Charleston, SC.

Second, primary data was collected in Charleston, SC on three prominent greenways/trails to assess the use, physical activity patterns, and perceptions of biking and walking in spaces specifically designed for this use.

- Objective 1: Examination of active transportation and bike share use to improve physical activity and public health outcomes using health models such as Health Economic Assessment Tool, HEAT.
- Objective 2: Examination of bicycling patterns in various types of built environments (e.g., greenways, multi-use biking paths) in Charleston, SC
- Objective 3: Evaluation of user perceptions and motivations for biking and walking in Charleston, SC

3.3.1 Physical Activity Expenditure Calculation

As described above, excel files containing information for each bike trip made via the Holy Spokes bike share were utilized to estimate the physical activity, or energy expenditure, of the Charleston bike share system. The unit that was estimated is the metabolic equivalent, or the 'MET' value. One 'MET' value represents the energy expended during rest, with light, moderate, and vigorous activities increasing in their 'MET' value. The 2018 federal Physical Activity Guidelines for Americans recommends 150-300 minutes of moderate-to-vigorous physical activity per week for all adults, which is the equivalent of 500-1,000 MET-minutes per week.

The following steps were taken to estimate physical activity levels for the bike share rides from January 2018-December 2018:

a. **Step 1:** Data were cleaned to remove implausible values for the bike share rides. Rides that were under 1 minute in duration and over 10 hours in duration were removed (i.e., identified outliers)

b. **Step 2:** The duration of each ride, measured in total minutes, and distance of each ride, measured in miles, were used to calculate average miles per hour, or speed, of each bike ride.

c. **Step 3:** Using the calculated average speed (miles per hour), we then used the Compendium of Physical Activities to assign a MET value to each bike ride. The Compendium of Physical Activities was developed in the 1980s for use in epidemiologic and surveillance studies to standardize the MET intensities used in physical activity questionnaires and research. This resource is not intended to provide the exact energy costs of a specific individual, rather, to estimate the energy expenditure in population-based studies. The Compendium of Physical Activities suggests the use of the following MET values based on the speed of a bicycle ride.
    i. 3.5 METs for 5.5mph biking or below
    ii. 5.8 METs for 5.6mph to 9.4mph biking
    iii. 6.8 METs for 9.5mph to 11.9 mph biking
    iv. 8.0 METs for 12mph to 13.9 mph biking
    v. 10.0 METs for 14mph to 15.9 mph biking

d. **Step 4**: In the database, a new column was created with the MET value that corresponded to the average calculated speed of the bike ride.

e. **Step 5**: Finally, the assigned MET value for each bike ride was multiplied by ride duration, measured in minutes, to determine the total number of MET-minutes per bike ride.

3.3.2 Health Economic Assessment Tool (HEAT)

Increased physical activity leads to reduced premature deaths per year. The Health Economic Assessment Tool (HEAT v5.0.6) provides a methodology that quantifies physical activity benefits from bicycling and walking for specific populations. Input data for the model was taken from GPS data tracking data for average trip distance, average trip speed and average number of trips per day using the Charleston bike share system, Holy Spokes, in 2018. Results estimated economic benefits ranging from $551,000 to $1.7 million annually, underscoring the program's health and economic value. Input data and results are summarized in Table 4.

Table 4. Health Economic Assessment Tool, Holy City Bikeshare Trip Benefits

AVG Speed	mph	kph	AVG Dist.	Mi	Km
	5	8		2.6	4.2
	2018	AVG/Day			
AVG Riders	34,551	95	VSL (Value of Statistical Life) =		$ 5,580,000
HEAT Results					
Premature deaths prevented per year (1 year)				0.099	
Economic of prevention of premature death (1 year)				$ 551,000	LCU
Premature deaths prevented per year (1 year)				0.3	
Economic of prevention of premature death (1 year)				$ 1,700,000	LCU

3.3.3 Direct Observation & Intercept Surveys of Multiuse Paths in Charleston, SC

Direct observations and intercept surveys were conducted on three Charleston greenways. SOPARC methodology ensured consistent observations of user activity levels, demographics, and modes of physical activity. Surveys captured motivations and perceptions of greenway users, providing qualitative insights into biking and walking patterns. Data collection adhered to rigorous protocols, ensuring high reliability and validity.

Direct Observation: The second main method of quantifying physical activity levels for this study was through direct observation. The System for Observing Play and Recreation in Communities (SOPARC) is a direct observation methodology where trained individuals evaluate characteristics of an environment without altering the space. SOPARC is a valid and reliable tool that facilitates data collection on the number of users in a determined location, estimated demographic characteristics, and physical activity types and intensities. Previous studies have established construct validity for the activity intensity codes via accelerometers and heart monitors, and several studies have reported high inter-rater reliability among observations (e.g., over 80% agreement). This tool has been used extensively in health-focused research in parks and trails.

The SOPARC research guide was used to facilitate training of four research assistants. Specifically, research assistants were trained by completing a workshop that included reviews of the observation tool definitions, practice video observations, and practice observations in the field. Finally, research assistants visited all target areas prior to data collection to ensure consistency in data collection locations. Data collection days and times were selected based on prior research that indicated conducting observations on four, one-hour time periods on four days (two weekdays and two weekend days) in a week would result in a representative sample. Following these guidelines, from May-June 2018, data were collected on four days (two weekdays and both weekend days) and for four one-hour time periods (7:30AM (morning), 12:00PM (noon), 3:00PM (afternoon), and 6:30PM (evening) at each greenway. During the observations, research assistants collected information for each person that passed through the defined target area. Each record included mode of PA (e.g., biking, walking, running, other), PA intensity level (e.g., sedentary, moderate, vigorous), and estimated age group (e.g., child/teen, adult, older adult), gender (e.g., male or female), and race/ethnicity (e.g., White, African American/Black, Hispanic/Latino, Other). According to the SOPARC tool protocol, age groups were coded as follows: child (infancy to 12 years of age), teen (13 to 20), adult (21 to 59), and older adult (60 years and above). The training video provided specific instruction and practice observations for these categories. All data were collected via electronic tablets using a spreadsheet application.

Intercept Survey: In addition to direct observation, on-site intercept surveys were administered concurrently with direct observations at three greenway locations; direct observation and intercept surveys were conducted by different research assistants. Each greenway user was approached to take the survey as long as the research assistant was not already conducting a survey. The surveys lasted approximately 3-5 minutes, limiting the number of possible respondents per data collection period. Intercept surveys were used to obtain information from greenway and path users that could not be collected from direct observation alone. The survey was a total of 25 questions, which were derived from previously validated trail intercept surveys. The focus of the intercept survey for this study included five motivations for greenway use (exercise/being active, resting and relaxing, experiencing nature, spending time with family and friends, and transportation) and importance of five features for greenway use (safety/security, condition/maintenance, accessibility, connections to attractions, natural scenery). Survey respondents were asked to rate the level of importance for each of those motivations and features on a 5-point Likert scale ranging from not at all important (value of 1) to extremely important (value of 5); responses remained in this format for data analysis. Finally, the intercept survey included several demographic questions, including age (years), highest educational level attained (High school degree or less, some college or college degree, or advanced degree), gender (female or male), and race/ethnicity (categorized eventually as white or racial/ethnic minority). The final covariate that was included was mode of PA for the survey respondents, categorized as walking/running, biking, and other. All intercept survey respondents were age 18 years or older. All observation and survey data collection procedures were approved by the College of Charleston's Institutional Review Board (IRB).

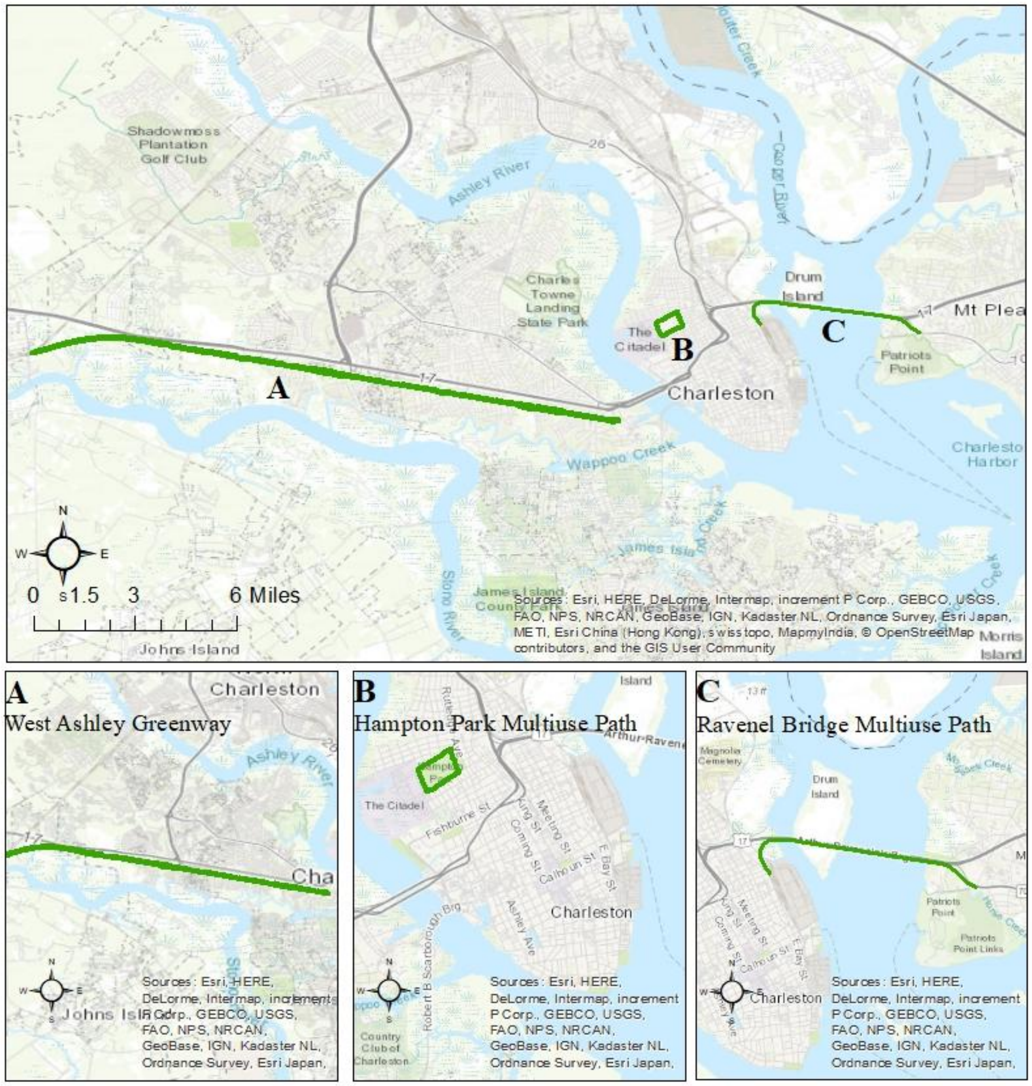


Figure 4 Locations of Direct Observations and User Intercept Surveys.

<u>Analyses:</u> Descriptive statistics were conducted to document sample characteristics for the direct observation and intercept survey participants. To examine differences in the mode of PA across three urban greenways, logistic regression was used with the outcome variable categorized as biking vs. walking/running and the primary covariate as greenway. Demographic characteristics were added to the logistic regression models to assess those associations with mode of PA. To analyze variations in greenway user motivation and features by age, gender, race/ethnicity, and education level, linear regression was used with each Likert scale item used as an outcome variable and demographic characteristics and PA mode as the primary covariates. All analyses were conducted with SAS 9.3.

CHAPTER 4
Results and Discussion

4.1 Physical Activity Estimation, Greenway Usage, and Public Health Impacts.

4.1.1 Summary of GIS Data Analysis

The bike share data used for this research was from April 2018, chosen as a representative month of bike activity and ridership. Holy Spokes reported 5655 total bike trips in April 2018 which was approximately 10% of total trips (54,761 trips) for the year 2018. Individual bike routes were created on a trip-by-trip basis using the extracted GPS points created from the GPX file provided on the Holy Spokes bike share dashboard. A total of 5,655 individual bike routes were created. Each bike route had a unique trip ID and a unique user ID. The average length of a trip in April 2018 was 2.6 miles with an average duration of 39 minutes. A breakdown of bike share trip length frequency distributions shown in Figure 5, providing an indication of potential for increasing bike share capture of 2-mile and 3-mile trips to improve urban mobility and reduce motor vehicle traffic. Figures 6, 7, and 8 provide a summary of road network usage by user type specifically including locals, riders generally familiar with the local road network and visitors, riders generally not familiar with road network conditions.

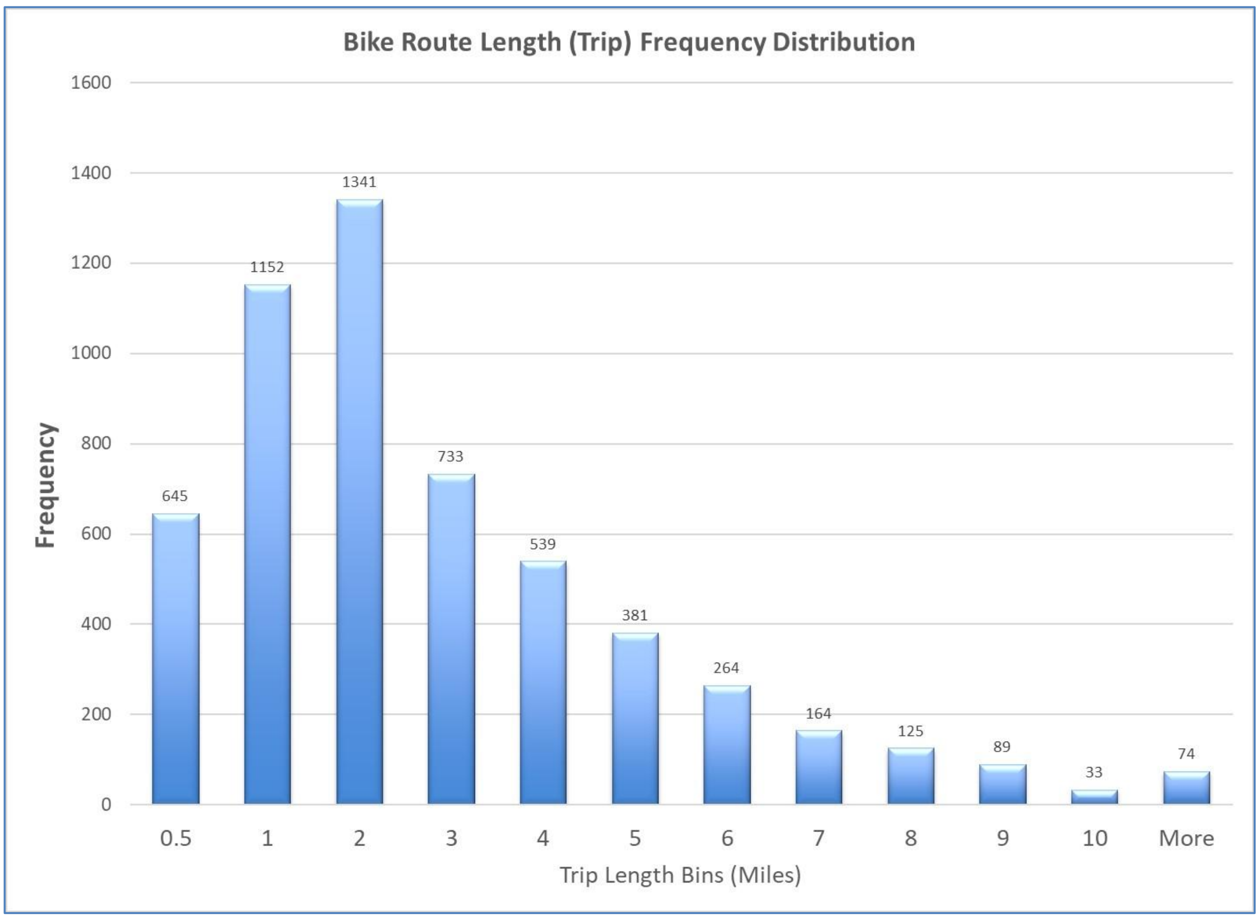


Figure 5 Bike Share Combined Trip Distance, Frequency Distribution

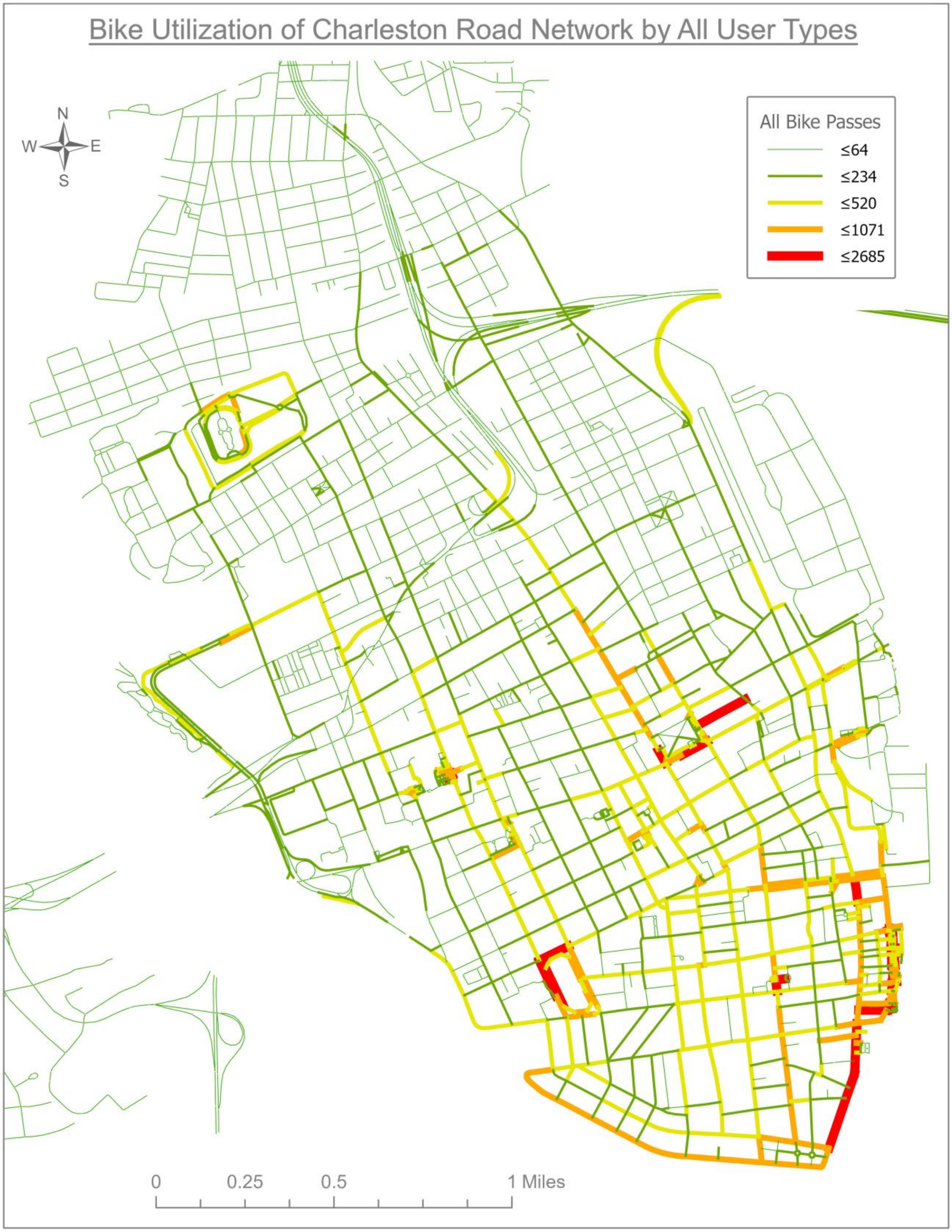


Figure 6 Bike Share Road Network Utilization, Combined Local and Visitor Users

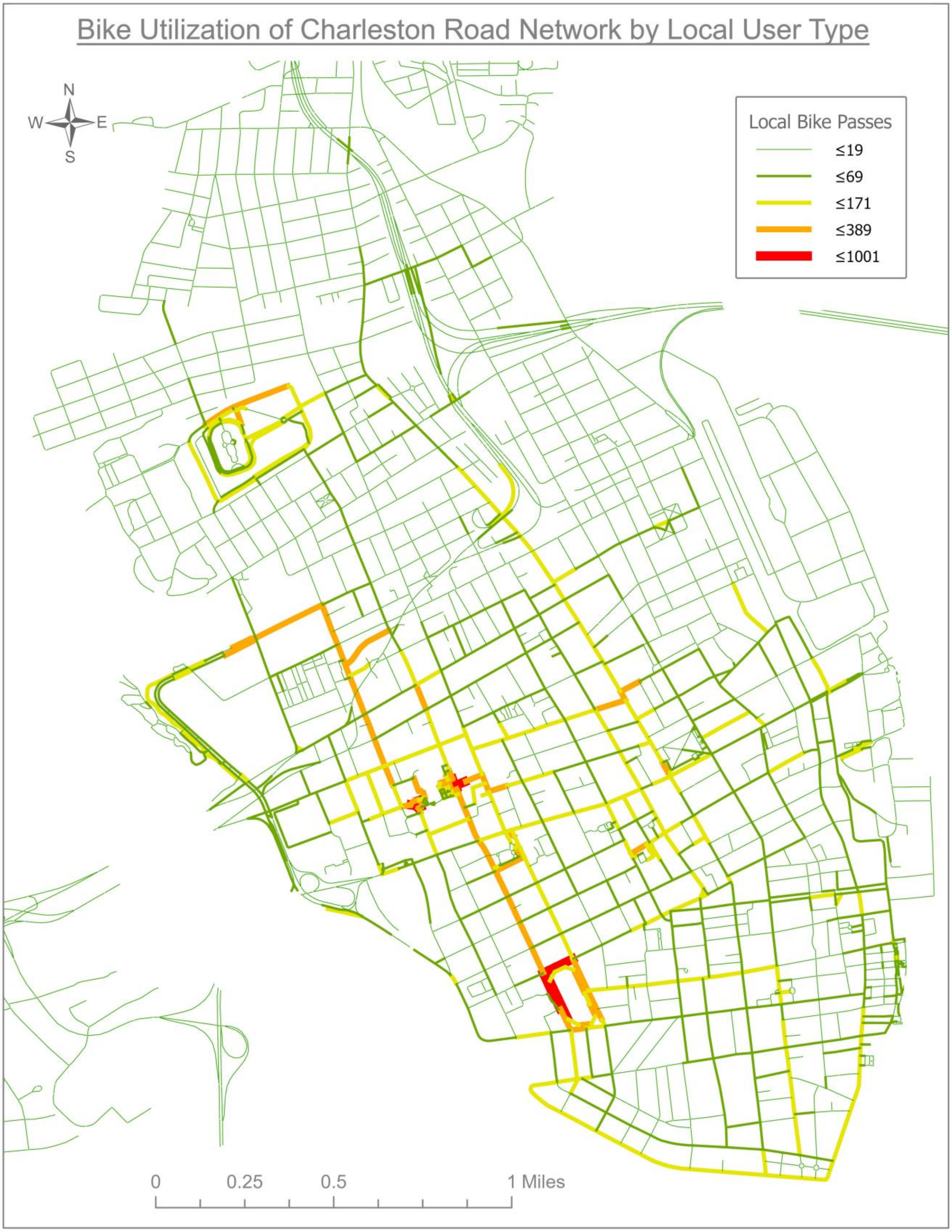


Figure 7 Bike Share Road Network Utilization, Local Users

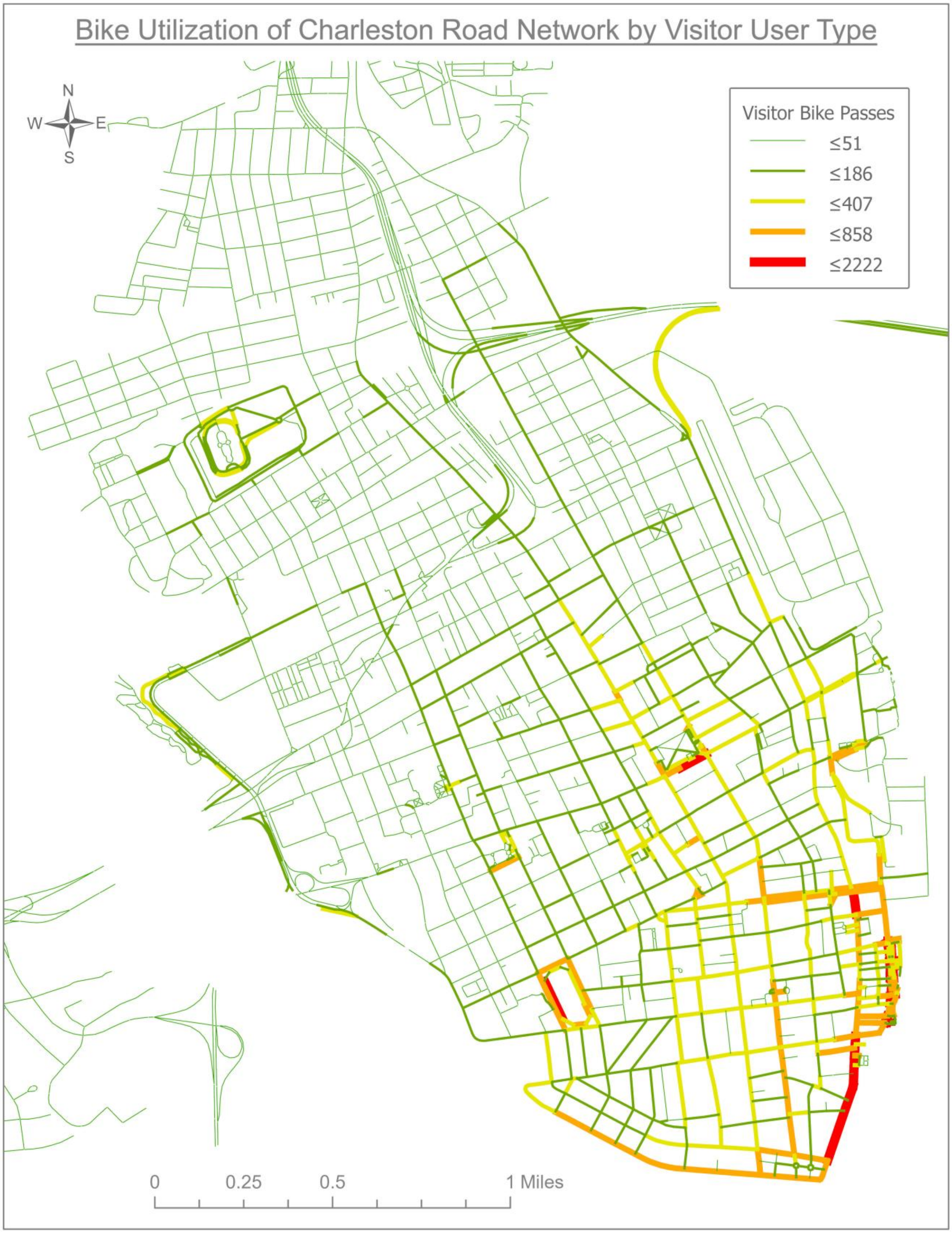


Figure 8 Bike Share Road Network Utilization, Visitor Users

4.2 GIS Process to Create Bike Suitability/Level of Service Maps and Classifications.

4.2.1. Roadway/Street Segments with Bicycle Suitability Analysis

A series of data analysis procedures were conducted using geographical information systems (GIS) tools. These procedures allowed aggregation of descriptive bike share user tables and tabulations showing percentage of street/road segments for each level of operational suitability for bicycle operation occurring along existing roadways including physical route characteristics and motor vehicle traffic conditions. Results are summarized and presented in a series of tables and figures including color thematic maps of roadway bike LOS, and graduated symbol maps of aggregated roadway trips, along with corresponding data summaries, which are presented in the following subsections.

4.2.2. Proportion of Bike Share Trips by Bike Suitability Level of Service (LOS)

Using the GIS created of the downtown Charleston, historic district, road/street network bike share GPS usage patterns, a series of descriptive tabulations were created and presented in figures 9-22 showing bike suitability level of service patterns.

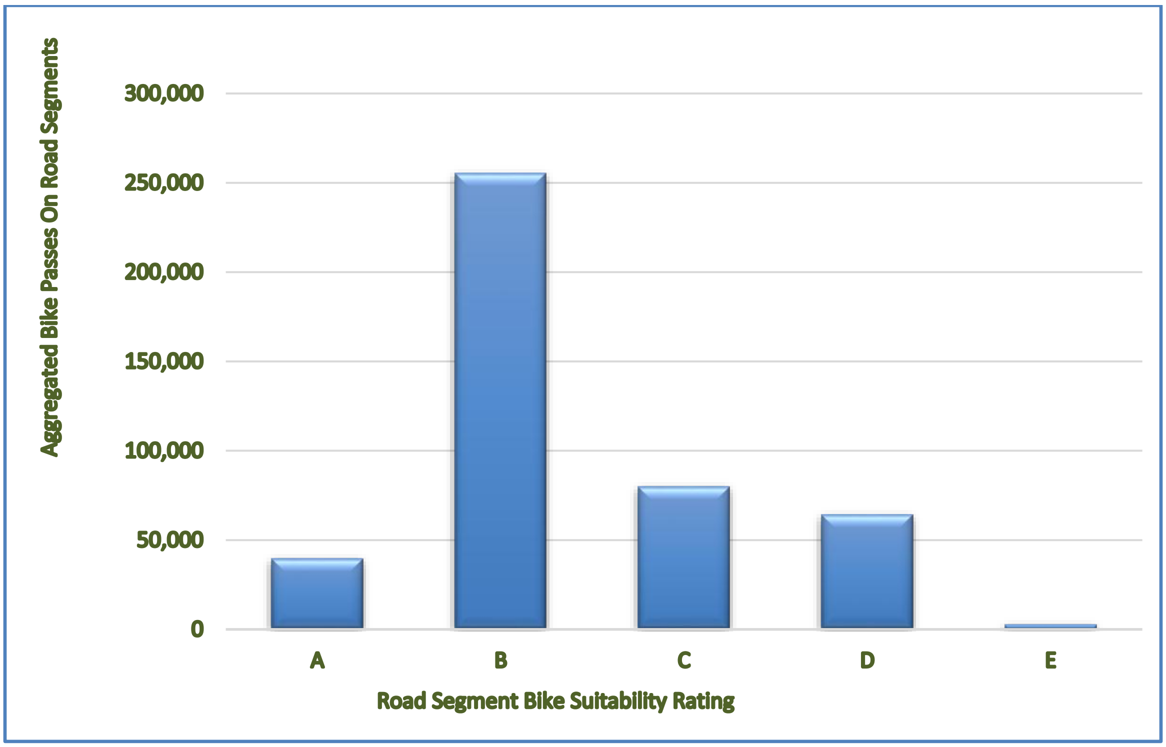


Figure 9 Cumulative Bike Share Segment Usage vs. Bike Suitability Level of Service

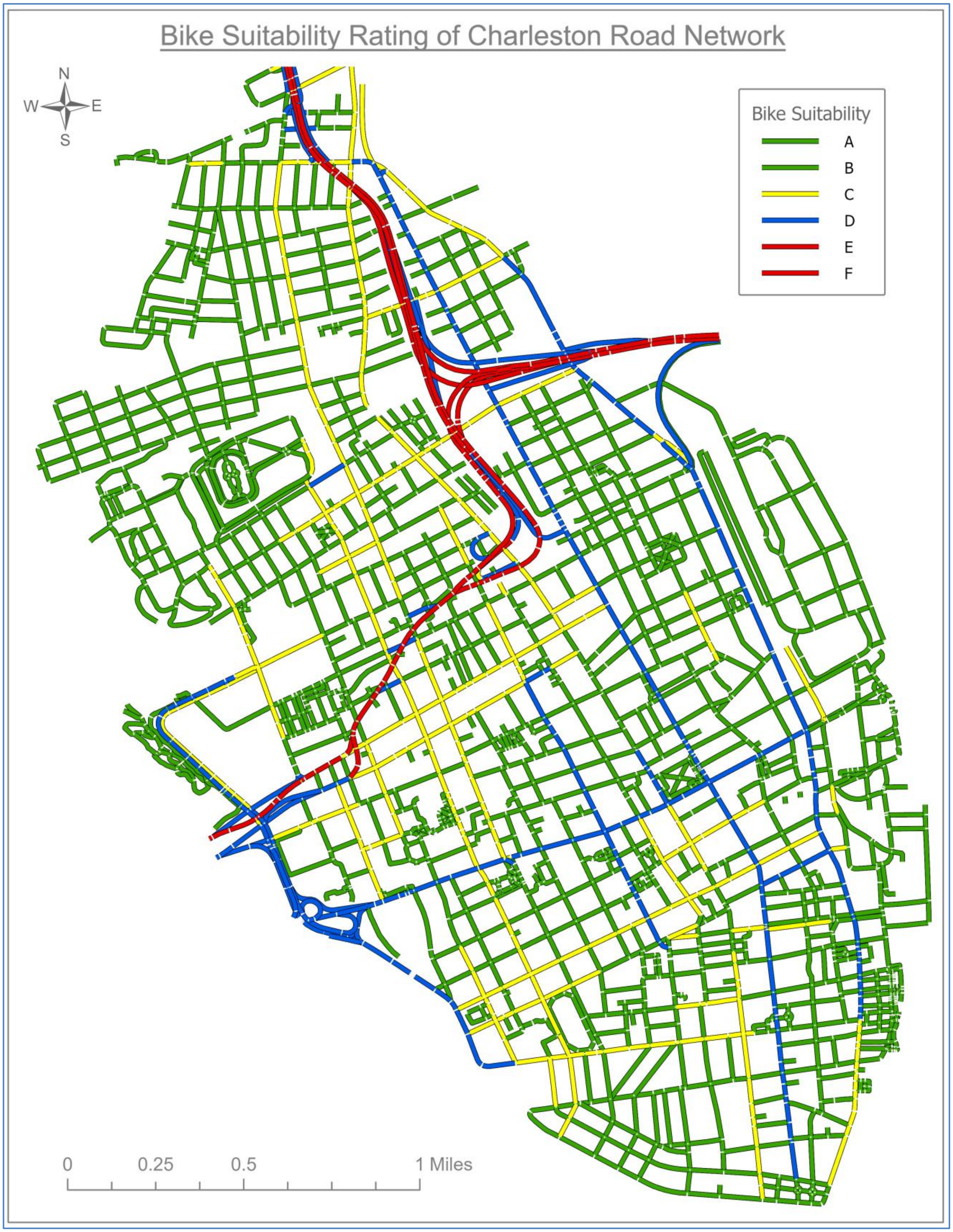


Figure 10 Bike Suitability Level of Service for Downtown Charleston Road/Street Network

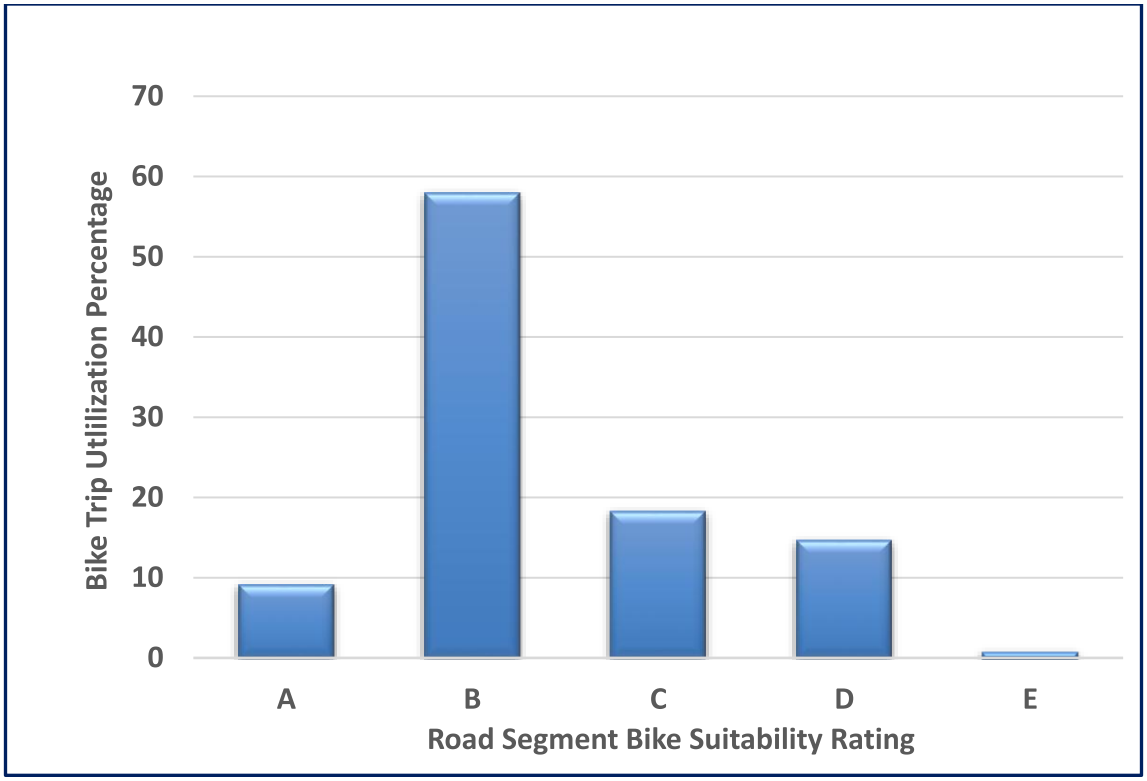


Figure 11 Bike Share Trip Utilization (%) vs. Road Segment Bike Suitability Rating

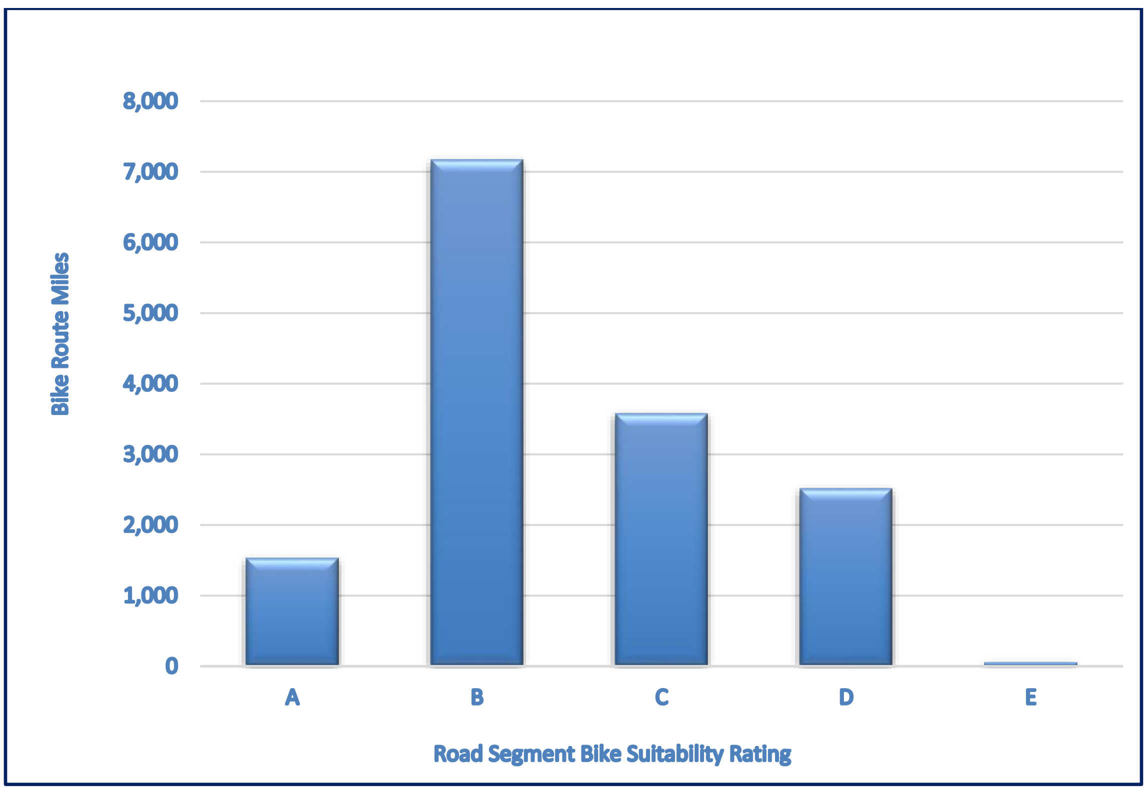


Figure 12 Bike Share Trip Utilization (%) vs. Road Segment Bike Suitability Rating

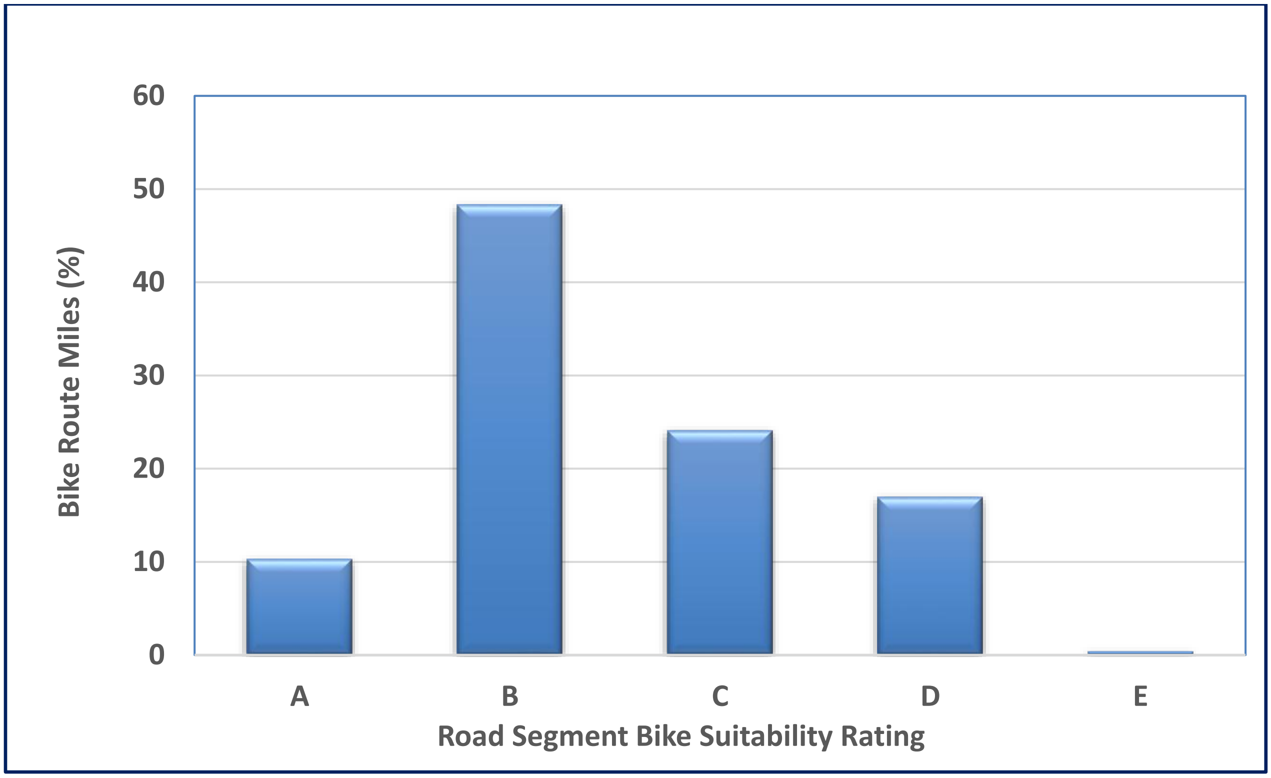


Figure 13 Bike Share Route Miles (%) vs. Road Segment Bike Suitability Rating

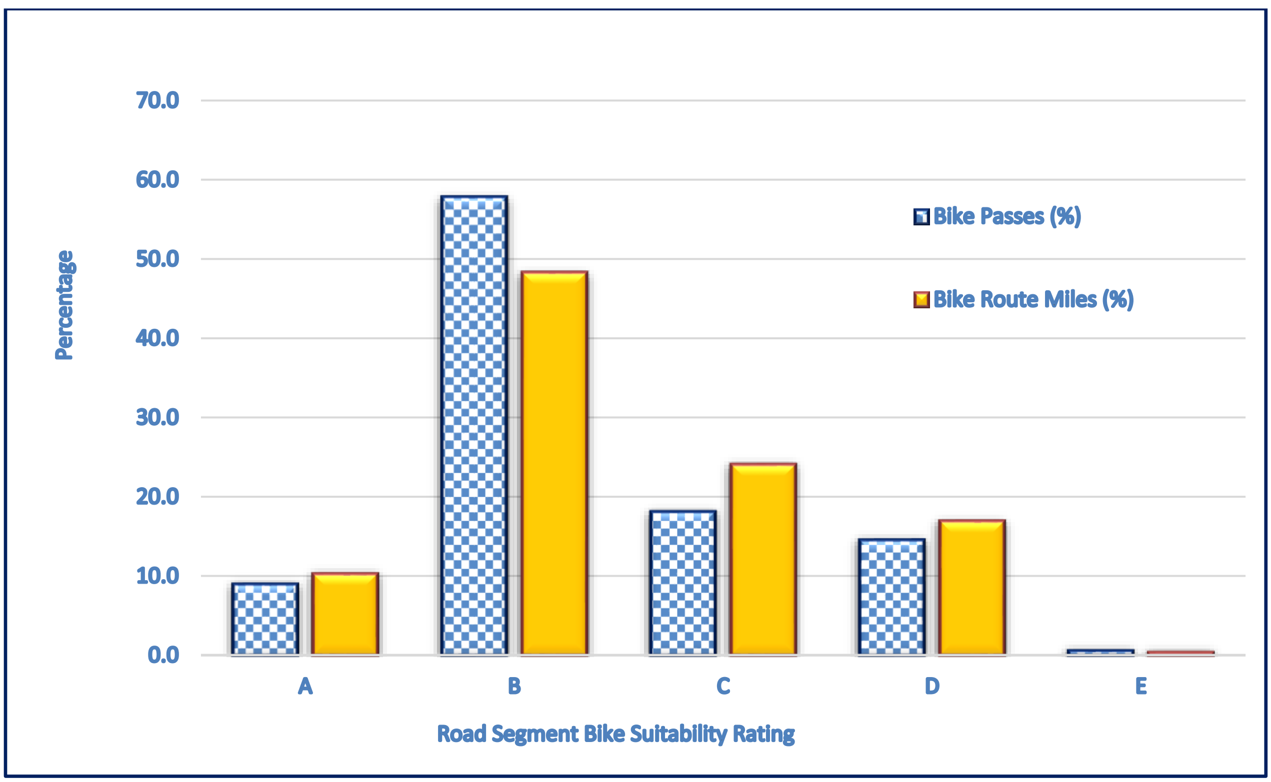


Figure 14 Bike Share Passes (%) and Route Miles (%) vs. Road Segment Bike Suitability Rating

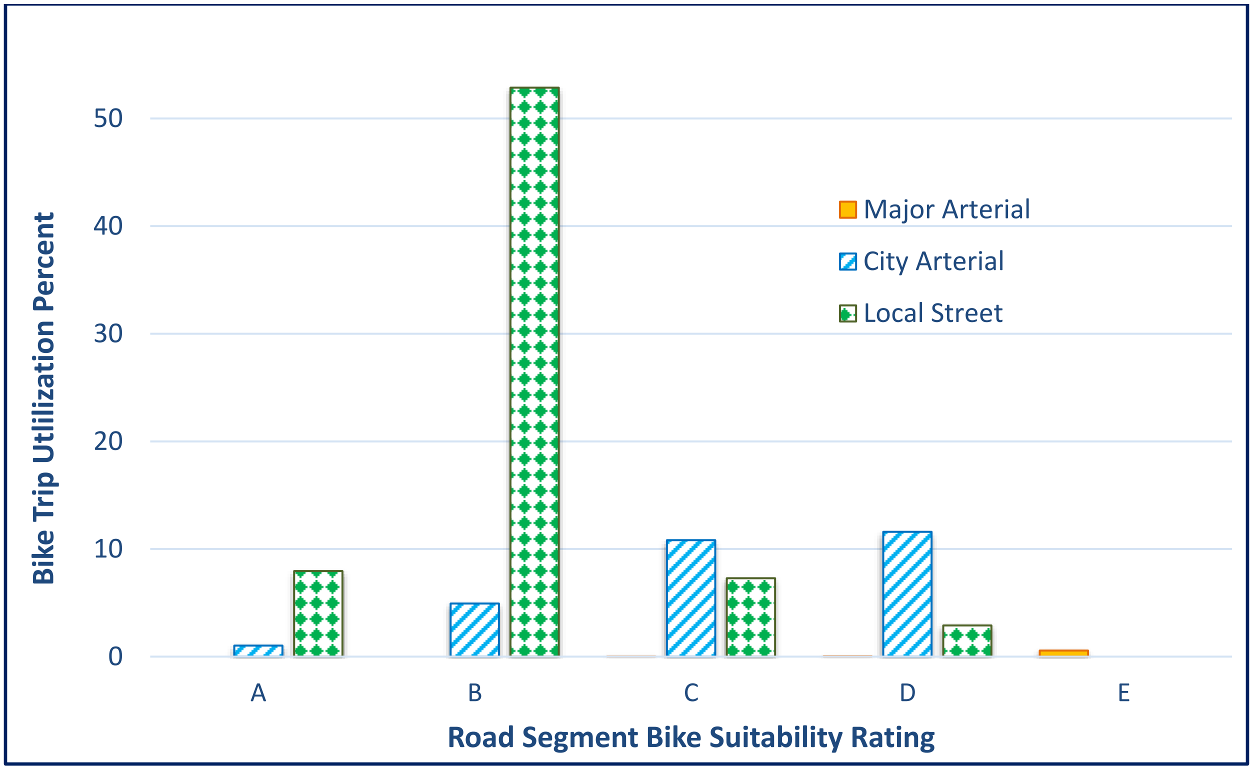


Figure 15 Bike Share Trip Utilization (%) vs. Roadway Functional Class & Bike Suitability Rating

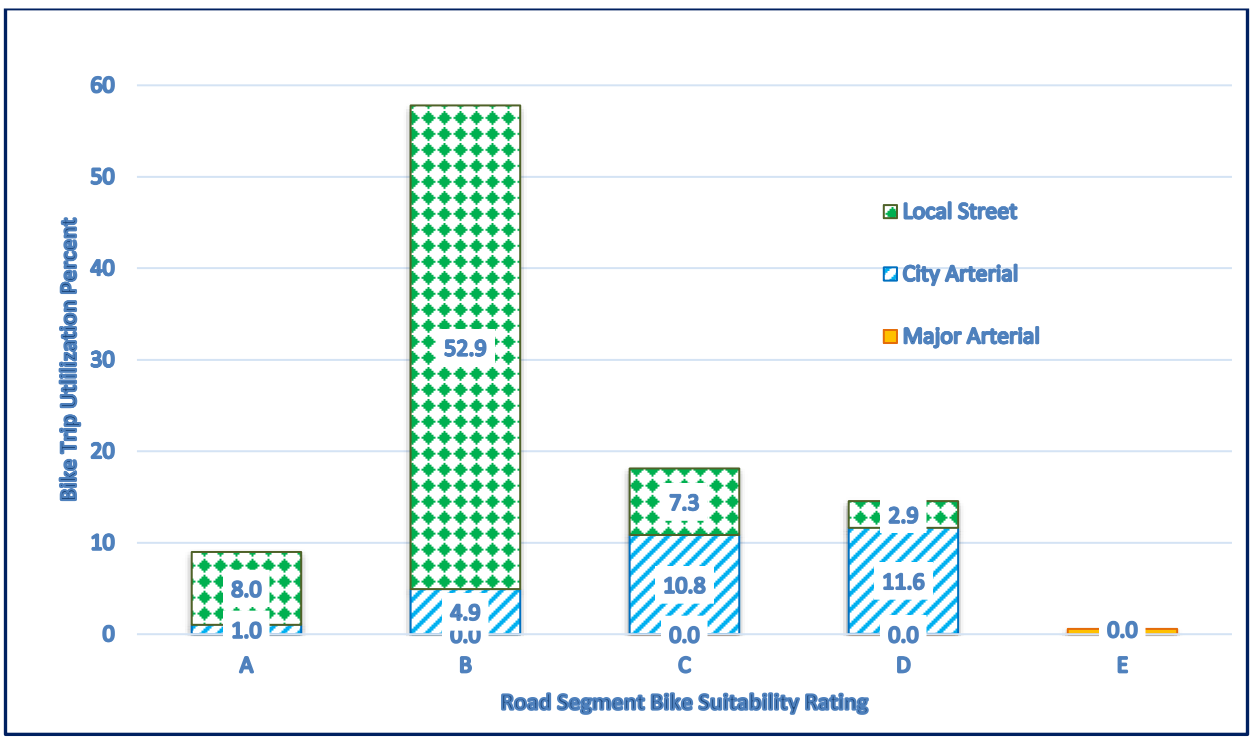


Figure 16 Bike Share Trip Combined Utilization (%) vs. Roadway Class & Bike Suitability Rating

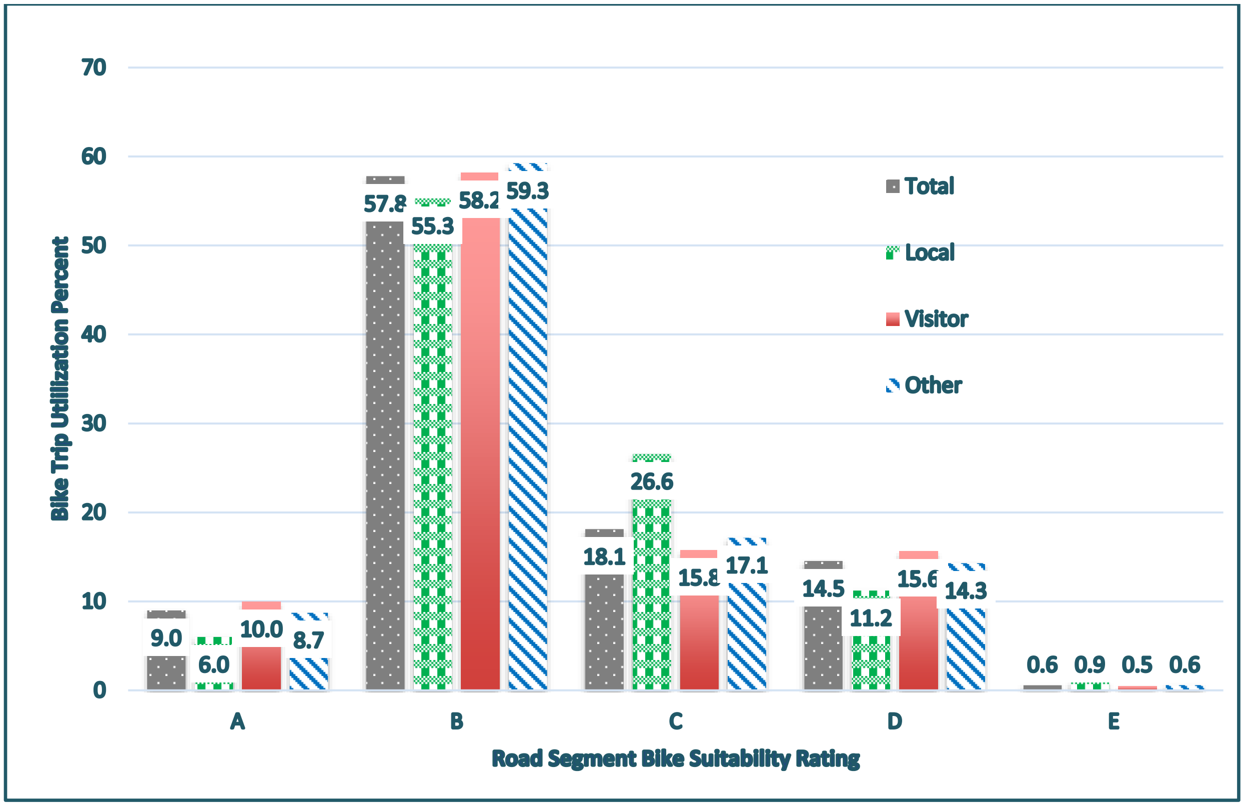


Figure 17 Bike Share Trip (%) vs. Ridership Type and Bike Suitability Rating

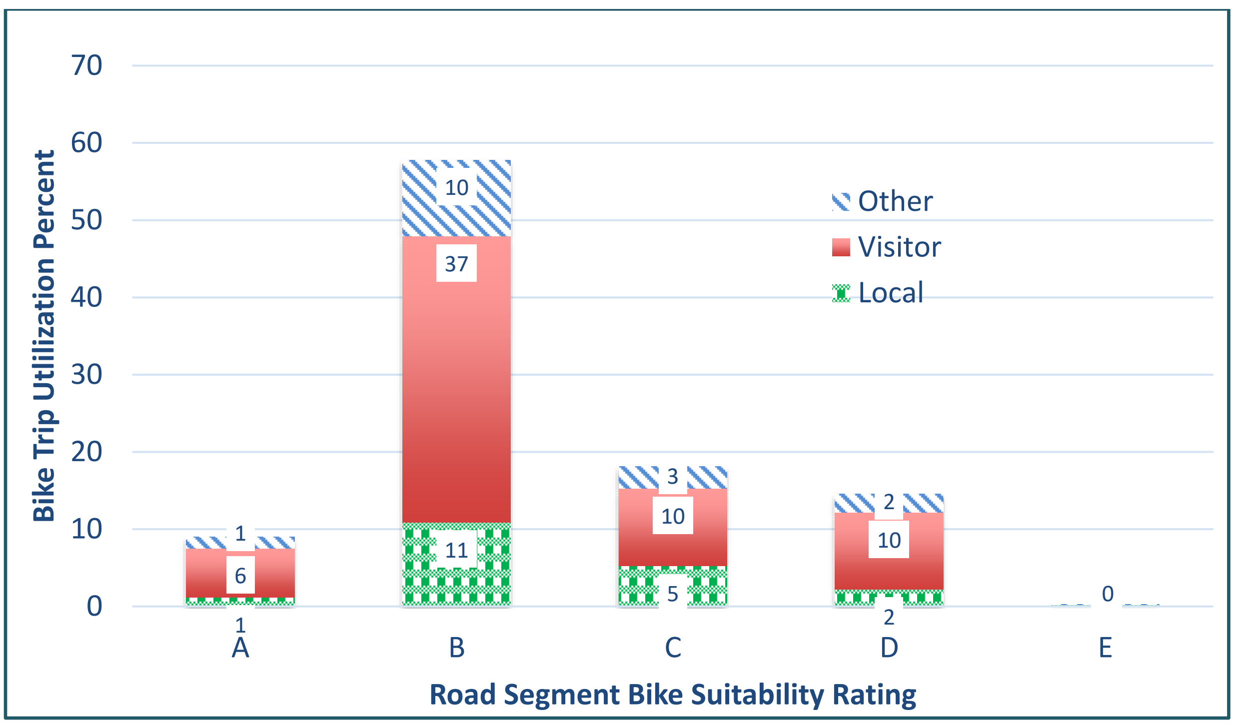


Figure 18 Bike Share Combined Trip (%) vs. Ridership Type and Bike Suitability Rating

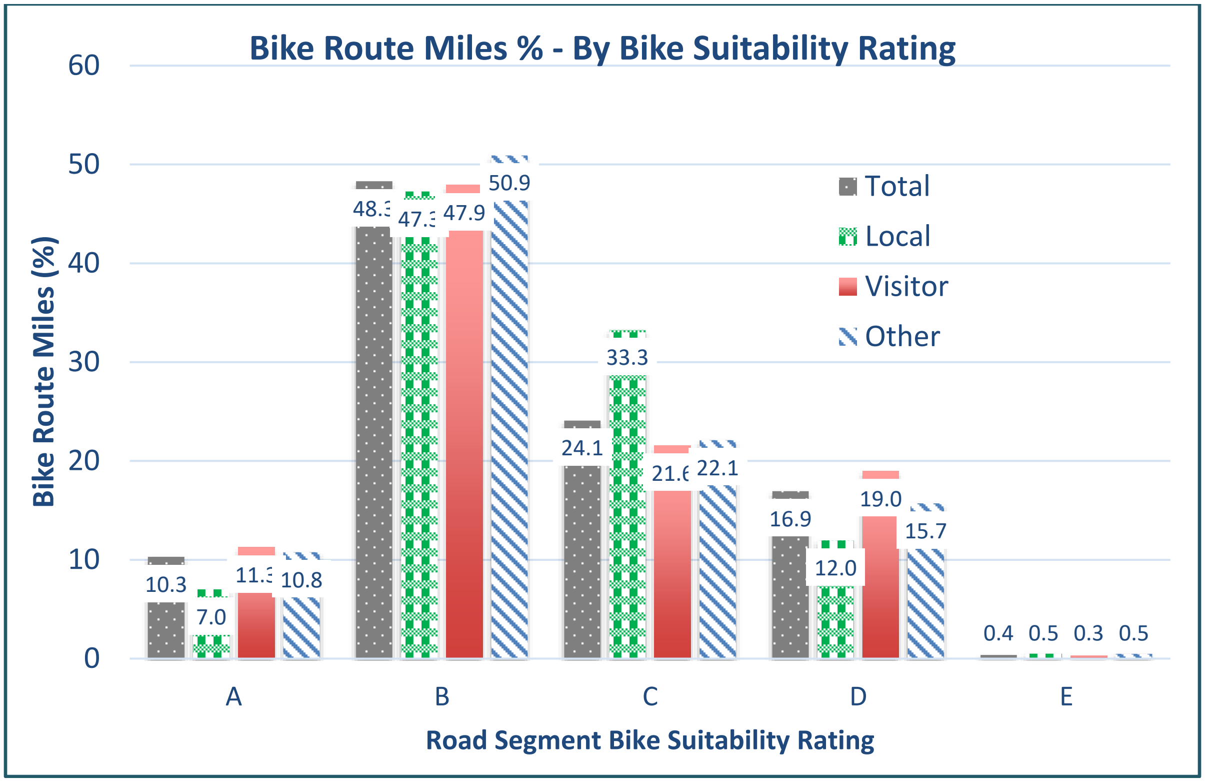


Figure 19 Bike Share Miles (%) vs. Bike Suitability Rating

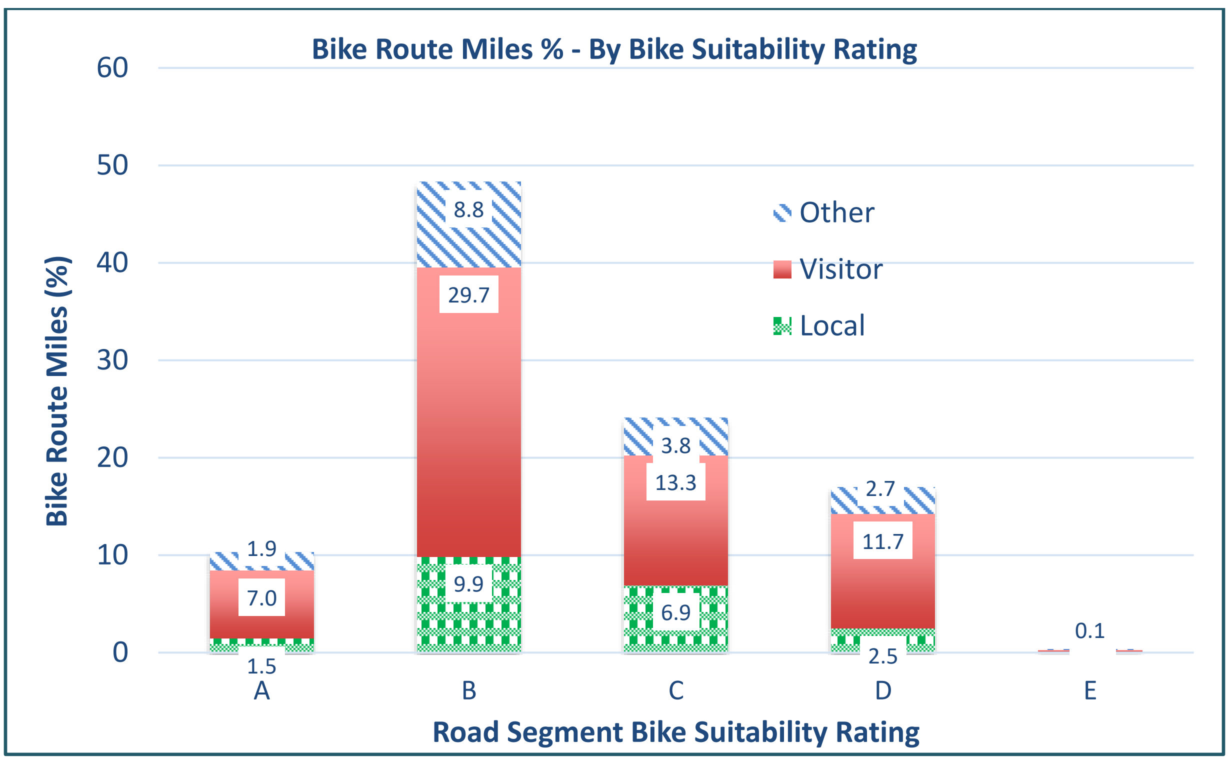


Figure 20 Bike Share Route Miles (%) vs. Bike Suitability Rating

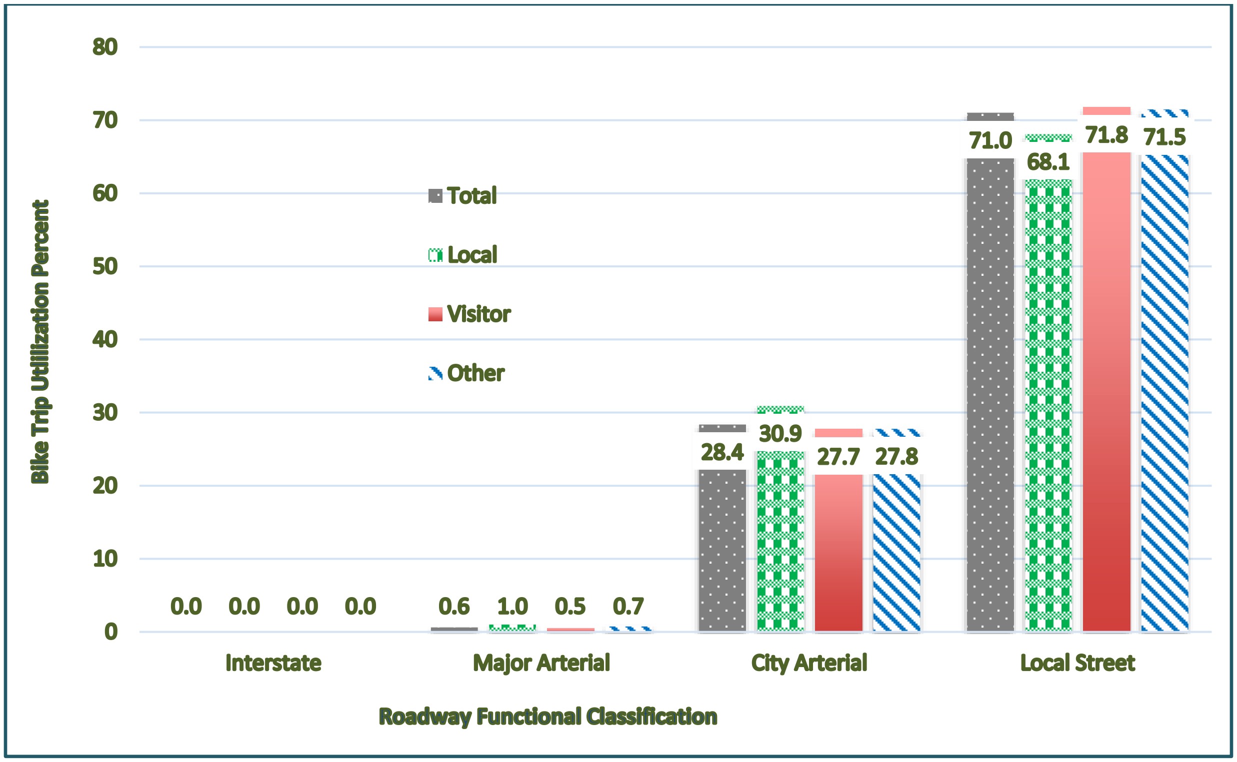


Figure 21 Bike Share Trip (%) vs. Roadway Functional Classification

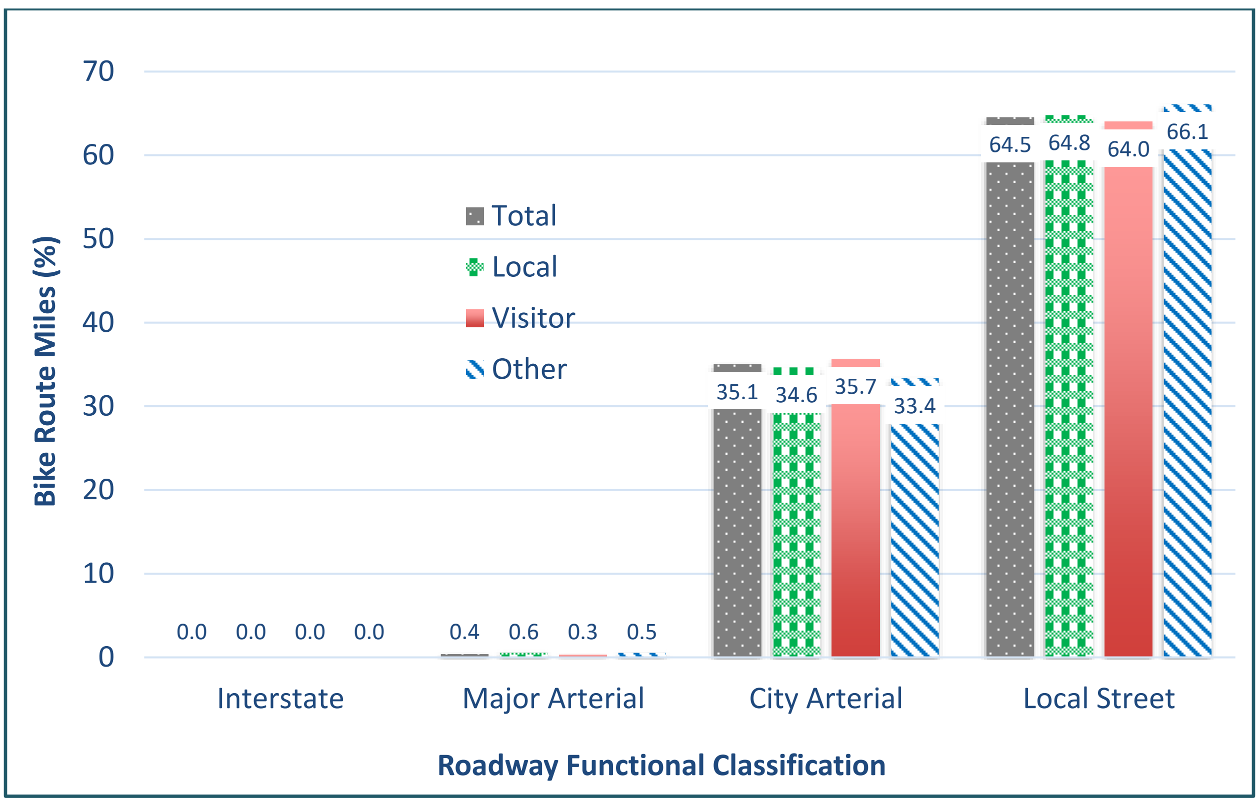


Figure 22 Bike Share Route Miles (%) vs. Roadway Functional Classification

As depicted in data aggregations shown in Figures 9-22, for Charleston initial Holy Spokes bike share system including 27-stations, 250-bicycle fleet, and 13,000-registered members, for which during the initial year of operation users logged 49,000-trips and 105,000-miles of travel within the downtown peninsula district, along 108.5-miles of existing surface street, the following sections provides a summary of GIS roadway and bicycle suitability LOS findings.

Summary of Bicycle Suitability LOS Findings

1. Over 12% of bike trips are on roads with LOS A and 54% of bike trips are on roads with LOS B
2. Approximately 89% of all miles ridden by bike are on roads with LOS B with 2% on LOS A
3. Over 9% of bike trips are on roads with Bike Suitability Rating of A and 58% of bike trips are on roads with Bike Suitability Rating of B
4. Approximately 48% of all miles ridden by bike are on roads with Bike Suitability LOS B, with 10% on roads with Bike Suitability LOS A.

Summary of Bicycle Functional Class Findings

1. Over 70% of bike trips are on local roads and 28% of bike trips are on roads city arterials
2. Approximately 95% of all miles ridden by bike are on local roads with approximately 5.5% on city arterials.
3. Over 70% of bike trips are on local roads and 27% of bike trips are on roads city arterials
4. Approximately 64% of all miles ridden by bike are on local roads with approximately 35% on city arterials

Summary of Bicycle Suitability Street Route Findings

1. Ranking of the most used roadways by rank have been created.
2. Most commonly used roadways
    a. Top 5 (Number of aggregated routes)
        i. E Bay St (27858)
        ii. King St (24304)
        iii. Meeting S (23304)
        iv. Ashley Ave (14102)
        v. Rutledge Ave (11406)

4.2.3. Qualitative Bike Score Assessment of Sample Street Segments

Table 5A provides a comparison of 22 representative road/street segments showing two different evaluation methods: Bike Suitability Level of Service and actual bike rider ratings using Bike Score 0-100 rating scale, previously summarized in Table 3.

Table 5A. Bike Level of Service and Bike Rater Scores for Select Road/Street Segments

Segment	Description	Segment Limits (from: to:)	Bike LOS	Rater 1 Score	Rater 2 Score
1	King St.	Huger St. to Spring St.	C	55	50
2	King St.	Spring St. to Hutson St.	B	80	50
3	King St.	Hutson St. to Calhoun St.	D	75	50
4	King St.	Calhoun St. to Hasell St.	C	80	30
5	King St.	Hasell St. to Fulton St.	C	80	30
6	King St.	Fulton St. to Board St.	C	82	45
7	King St.	Broad St. to Murray Blvd.	C	90	55
8	Murray Blvd.	Tradd St. to E. Battery St.	B	92	60
9	S. Battery St.	Tradd St. to E. Battery St.	B	89	70
10	Lockwood Blvd. multiuse path	Broad St. to Ashley Yachts /City Marina driveway	B	80	100
11	Calhoun St.	Courtenay Dr. to Smith St.	E	20	10
12	Calhoun St.	Smith St. to E. Bay St.	E	25	30
13	Broad St.	Lockwood Dr. to E. Bay St.	C	70	70
14	Meeting St.	Broad St. to S. Battery St.	B	90	50
15	E. Battery/E. Bay St.	Murray Blvd. to Broad St.	C	82	70
16	E. Bay St.	Broad St. to N. Market St.	E	60	30
17	E. Bay St.	N. Market St. to Calhoun St.	E	25	10
18	E. Bay St.	Calhoun St. to South St.	E	20	10
19	E. Bay St. multiuse path	South St. to Cooper St.	B	80	100
20	Cooper R. Bridge multiuse path	Cooper St. to mid-span Cooper River shipping channel	B	95	95
21	Morrison Dr. partial bike lane/sharrows	Grace Bridge St. to Huger St.	E	25	49
22	Huger St.	Morrison Dr. to President St.	C	35	50

Table 5B. Bike LOS, Rater Average Scores and Walkscore Bike Score Comparison for Riden Segments

Bike LOS	Rater 1 Average Score	Rater 2 Average Score	Rater 1 & 2 Average Score	Bike Score Comparison
B	86.6	75	80.6	70 – 89 (Very Bikeable - Biking is convenient for most trips)
C	71.8	50	60.9	50 – 69 (Bikeable - Some bike infrastructure)
D	75	50	62.5	50 – 69 (Bikeable - Some bike infrastructure)
E	29.2	23.2	26.2	0 – 49 (Somewhat Bikeable Minimal bike infrastructure)

Results from Table 5A suggest that the quantitative bike LOS is not well correlated with the qualitative bike scores. This is because the bike scores are subjective. They are dependent on a rider's judgment of whether such a route is suitable for commutes by bike or could be used to make errands. The time of day in which the evaluation was performed was likely to have an effect on the bike scores. That is, both raters felt safe during the entire ride due to the low traffic volume. Although both raters are experienced bicyclists, one is intimately familiar with the routes and has ridden them numerous times before. For the other rater, it was his first-time riding on these routes. The rater who has ridden the routes before took into account his previous experience on them when rating them. Thus, his scores reflect how safe/good the routes were compared to his previous rides. Familiarity with the routes is the primary reason for the discrepancy in the two raters' scores. Collectively, there is agreement between the two raters that a segment with a score below 50 would not be safe to travel during rush hours, and segments with a score of 80 or higher are perfectly suitable for commutes and errands.

However, further aggregation of the qualitative assessment in Table 5B provided more support for the Bike LOS categories (A, B, C, D, E, F) determined by the research team for the study areas, Charleston, SC than the disaggregate data did. There were no LOS A or F segments on the qualitative assessment route. Also, aside LOS D segments which had only one data point due to random sampling of routes the other LOS categories (B, C and E) had at least 5 segments. Although the individual ratings subjected and varied, they did not vary significantly within the ranges of the Walkscore Bike Score Service Levels. As shown in Table 6, even with only two bike raters with somewhat varying scores, the results of the qualitative determination of bike suitability for the segments support the quantitative results further validating the determined LOS categories for the project. Therefore, for the purpose of this research further qualitative assessment of the bike infrastructure was not deemed necessary.

4.3 Physical Activity Estimation, Greenway Usage, and Public Health Impacts.

4.3.1. Physical Activity Expenditure Calculation Results

A total of 34,551 bike rides were examined between January and December 2018. On average, the bike rides were 2.43 miles for a duration of about 40 minutes. The average calculated speed of the bike share rides were about 5 miles per hour. After completing the physical activity estimations, the average bike ride resulted in about 161 MET-minutes of energy expenditure. In addition to the overall sample of bike rides, we also examined this data by type of membership. Non-local riders were classified by one and two-day bike share passes, while membership types, like annual, student, and industry partner memberships, were categorized as 'local' rides. As expected, there were large differences between the local and non-local bike ride characteristics, including non-local riders using the bikes for a longer duration, further distance, and expending more energy. Local riders expended less overall energy, but they traveled at a faster speed, resulting in more vigorous energy expenditure during their bike rides.

Table 6. Holy Spokes Bike Ride Descriptive Data, 2018 (n= 34,551).

	Bike Rides		
	Total (n=34,551)	Local (n=16,902)	Non-Local (n=17,649)
Variables	Mean (S.D.) or %	Mean (S.D.) or %	Mean (S.D.) or %
Distance (miles)	2.43 (2.3)	1.42 (1.3)	3.39 (2.5)
Duration (minutes)	42.02 (52.6)	16.0 (21.1)	67.0 (61.0)
Miles per hour	5.1 (2.4)	6.5 (2.2)	3.8 (1.75)
MET minutes	161.7 (184.1)	75.1 (81.8)	244.6 (214.2)
METs (Metabolic Equivalent)			
3.5	58.0%	29.1%	85.7%
5.8	40.5%	68.1%	14.1%
6.8 or Above	1.5%	2.8%	0.2%
Day of Week			
Weekend	32.9%	16.8%	48.3%
Weekday	67.1%	83.2%	51.7%

4.3.2. Health Economic Assessment Tool (HEAT) Results

Health Economic Assessment Tool (HEAT) Too was used to evaluate the benefit of Increased physical activity that leads to reduced premature deaths per year. The Health Economic Assessment Tool (HEAT v5.0.6) provides a methodology that quantifies physical activity benefits from bicycling and walking for specific populations. Using 2018 data of 34,551 riders traveling for 2.6 miles at an average speed of 5-miles per hour, expanded for a one- year theoretical evaluation period, HEAT benefits included a range of 0.099-0.3 reduced premature deaths per year, estimated at a range of $551,00 to $1,700,000 economic impact per year.

4.3.3. Direct Observation & Intercept Surveys of Multiuse Paths in Charleston, SC

As shown in Table 7, a total of 3,681 individuals were observed using the three greenways in Charleston, SC, with similar number of users observed on the Ravenel Bridge Multiuse Path (42.1%) and Hampton Park Multiuse Path (41.0%), and fewer on the West Ashley Greenway (16.9%). Of all greenway users, a majority were adults (84.3%), male (54.3%), White (82.2%). Walking was the most prevalent activity type observed across all three greenways (47.0%). The same demographic and activity type patterns were generally observed for individuals at each space, with a few exceptions. There were more females (51.5%) than males (48.5%) observed using the Ravenel Bridge Multiuse Path (Table 1). In addition, more users on the West Ashley Greenway were observed biking (50.6%) compared to walking (30.2%) or running (19.2%).

Table 7. Sample Characteristics for Greenway Users Measured by Direct Observation, N=3,681

	Total Sample (n=3681)	Hampton Park Multiuse Path (n=1508, 41.0%)	Ravenel Bridge Multiuse Path (n=1549, 42.1%)	West Ashley Greenway (n=624, 16.9%)
Age				
Child/Teen	5.8%	5.6%	5.8%	8.2%
Adult	84.3%	88.4%	84.3%	78.4%
Older Adult	9.9%	6.0%	9.9%	13.4%
Gender				
Male	54.3%	61.1%	48.5%	52.4%
Female	45.7%	38.9%	51.5%	47.6%
Race/Ethnicity				
White	82.2%	78.6%	83.0%	89.1%
Non-White	17.8%	21.4%	17.0%	10.9%
Activity Type				
Biking	31.0%	38.0%	16.2%	50.6%
Walking	47.0%	36.8%	63.9%	30.2%
Running	22.0%	25.2%	19.9%	19.2%
Time of Day				
Morning	29.8%	25.4%	23.6%	51.7%
Noon	20.2%	21.6%	21.0%	18.5%
Afternoon	18.7%	21.0%	24.2%	14.2%
Evening	31.3%	32.0%	31.3%	30.7%

Notes:
Age categories were defined as: Child/Teen (0-20 years), Adult (21-59 years), and Older Adult (60 years and older)
Time of Day categories were defined as: Morning (7:30-8:30am), Noon (12-1pm), Afternoon (3:00-4:00pm) and Evening (6:30-7:30ps).

Results comparing PA types by greenway location are presented in Table 2. Individuals using the West Ashley Greenway (OR=5.50, 95% CI=4.41, 6.87) and the Hampton Park Multiuse Path (OR=2.95, 95% CI=2.46, 3.53) were significantly more likely to be observed biking than walking/running compared to those observed on the Ravenel Bridge Multiuse Path. Several associations were also detected in PA types by gender, race/ethnicity, and time of day (Table 2). Across all greenways, compared to females, males were significantly more likely to be observed biking than walking/running (OR=4.01, 95% CI=3.39, 4.74). Compared to Whites, racial/ethnic minority greenway users were significantly less likely to be observed biking than walking/running (OR=0.41, 95% CI=0.33, 0.52). Finally, compared to individuals observed during the evening time period, morning greenway users were less likely to be observed biking than walking/running (OR=0.51, 95% CI=0.41, 0.63). No significant differences were detected between biking and walking/running PA types by age (Table 8).

Table 8. Associations between Physical Activity, Greenway Location, and Demographic Characteristics in Charleston, SC

	Total Sample (n=3681) *Biking vs. Walking/Running* *(Odds Ratio, 95% Confidence Interval)*
Location	
Ravenel Bridge Multiuse Path	Reference
West Ashley Greenway	5.50 (4.41, 6.87)
Hampton Park Multiuse Path	2.95 (2.46, 3.53)
Age	
Older Adult	Reference
Adult	1.05 (0.80, 1.37)
Child/Teen	0.78 (0.51, 1.20)
Gender	
Female	Reference
Male	4.01 (3.39, 4.74)
Race/Ethnicity	
White	Reference
Non-White	0.41 (0.33, 0.52)
Time of Day	
Evening	Reference
Afternoon	1.15 (0.93, 1.43)
Noon	0.97 (0.79, 1.21)
Morning	0.51 (0.41, 0.63)

Notes:
Logistic regression was used with the outcome variable as biking vs. walking/running; all listed variables were covariates.
Age categories were defined as: Child/Teen (0-20 years), Adult (21-59 years), and Older Adult (60 years and Older)
Time of Day categories were defined as: Morning (7:30AM-8:30AM), Noon (12pm-1pm), Afternoon (3:00PM-4:00PM) and Evening (6:30PM-7:30PM)

Intercept Survey: A total of 148 intercept surveys were collected. As shown in Table 3, the average age of survey respondents was 45.2 (SD=16.7), and the majority were female (55.5%), White (89.1%), and had some college experience or a college degree (91.1%). Most respondents reported using the space for recreation only (85.8%), with a majority of respondents walking or running (76.3%) compared to biking (21.0%). Greenway users reported exercise/being active as the main motivation for use (4.76 on the 5-point scale), while safety and security was reported as the most important feature when using the greenways (4.53 on the 5-point scale).

Table 9. Demographic Characteristics and Reported Motivations and Features for Greenway Use for All Intercept Survey Participants (n=148)

Demographic Characteristics	**% or Mean (SD)**
Age (years)	45.2 (16.7)
Greenway Location	
Hampton Park Multiuse Path	26.4%
Ravenel Bridge Multiuse Path	35.1%
West Ashley Greenway	38.5%
Gender	
Male	44.5%
Female	55.5%
Race/ethnicity	
Non-White	10.9%
White	89.1%
Education	
High School Degree or Less	8.9%
Some College and College Degree	58.2%
Advanced Degree	32.9%
Physical Activity Mode	
Walking/running	76.3%
Biking	21.0%
Other (e.g., rollerblading, skateboarding)	2.7%
Motivations	
Exercising/being active	4.76 (0.52)
Resting and relaxing	3.90 (1.24)
Experiencing nature	3.87 (1.19)
Spending time family/friends	4.02 (1.30)
Getting to and from places	3.26 (1.56)
Importance of Features	
Safety and security	4.53 (0.76)
Condition and maintenance	4.22 (0.77)
Accessibility of space	4.39 (0.81)
Connections to attractions	3.45 (1.33)
Natural scenery	4.20 (0.95)

Note: Respondents were asked to rate the level of importance for all motivations and features on a 5-point Likert scale ranging from not at all important (value of 1) to extremely important (value of 5)

Several demographic differences in reported motivations and important features for greenway use were detected (Table 4). A positive association between gender and the motivation 'spending time with family and friends' was detected (b=0.65, p= 0.0035), indicating that females rated this motivation higher than males. Another positive association detected was race/ethnicity and the motivation 'getting to and from places', where non-White individuals ranked this motivation higher than White persons (b=1.07, p=0.015).

Differences were also observed in how greenway users rated the importance of features that influenced use (Table 4). Females rated the greenway feature of 'safety and security' and ‘natural scenery’ higher than males (*b*=0.28, p=0.03; *b*=0.38, p=0.025, respectively). Similarly, each 1-year increase in age was also positively associated with ranking ‘natural scenery’ as an important greenway features (*b*=0.01, p=0.027).

Table 10. Associations Between Motivations and Features for Using Greenway, Individual Demographic Characteristics, and Mode of Physical Activity (n=148)

	Motivations for Greenway Use				
	Exercise	Resting and Relaxing	Experiencing Nature	Time with Family and Friends	Getting to and from places
	Beta estimate (standard error)				
Age	0.005 (0.003)	-0.004 (0.01)	0.002 (0.01)	-0.02 (0.01)* *(p=0.023)*	-0.003 (0.01)
Gender (reference = male)					
Female	-0.02 (0.10)	0.02 (0.22)	0.14 (0.21)	0.65 (0.22)* *(p=0.003)*	0.49 (0.27)
Race/Ethnicity (reference = White)					
Non-White	-0.21 (0.16)	0.51 (0.35)	0.39 (0.34)	0.39 (0.35)	1.07 (0.43)* *(p=0.015)*
Education Level (reference = High school degree or less)					
Some college or coll. degree	0.17 (0.16)	0.05 (0.36)	0.50 (0.35)	-0.42 (0.36)	0.012 (0.45)
Advanced degree	0.20 (0.17)	-0.56 (0.38)	0.50 (0.37)	-0.01 (0.38)	-0.53 (0.47)
Physical Activity Mode (reference = walking/running)					
Biking	0.03 (0.12)	0.31 (0.26)	0.46 (0.25)	0.48 (0.26)	0.57 (0.32)
Other	-0.46 (0.32)	0.10 (0.72)	-0.09 (0.69)	-0.55 (0.72)	0.60 (0.89)
	Importance of Features for Greenway Use				
	Safety and Security	Condition and Maintenance	Accessibility	Connections	Natural Scenery
	Beta estimate (standard error)				
Age	-0.002 (0.004)	0.01 (0.004)	0.007 (0.004)	0.004 (0.01)	0.01 (0.01)* *(p=0.025)*
Gender (reference = male)					
Female	0.28 (0.13)* *(p=0.038)*	0.16 (0.13)	0.25 (0.15)	0.31 (0.24)	0.38 (0.17)* *(p=0.027)*
Race/Ethnicity (reference = White)					
Non-White	0.18 (0.21)	0.35 (0.21)	0.25 (0.23)	0.36 (0.39)	-0.05 (0.27)
Education Level (reference = High school degree or less)					
Some college or col. degree	-0.41 (0.22)	-0.22 (0.22)	-0.33 (0.24)	0.27 (0.40)	0.21 (0.28)
Advanced degree	-0.21 (0.23)	-0.22 (0.24)	-0.09 (0.26)	0.06 (0.42)	0.02 (0.29)
Physical Activity Mode (reference = walking/running)					
Biking	-0.09 (0.16)	0.09 (0.16)	0.12 (0.17)	0.20 (0.29)	-0.01 (0.20)
Other	-0.82 (0.44)	1.12 (0.44)* *(p=0.013)*	-0.32 (0.48)	0.11 (0.80)	-0.39 (0.55)

**p<0.05; specific p-values noted under the beta estimate.*
Note: Respondents were asked to rate the level of importance for all motivations and features on a 5-point Likert scale ranging from not at all important (value of 1) to extremely important (value of 5)

CHAPTER 5
Summary and Conclusions

Charleston's initial bike share system, Holy Spokes, launched in 2017, included 27 stations, a fleet of 250 bicycles, and registered 13,000 members in its first year. Over the initial year of operation, users completed 49,000 trips, traveling 105,000 miles primarily within the downtown peninsula, an area spanning 8 square miles or 5,120 acres. The research objectives of this evaluation focused on assessing physical activity benefits and identifying suitable bicycle travel routes within the existing 108.5-mile surface street network. The following sections summarize the findings of this evaluation of Charleston's initial Holy Spokes bike share system.

5.1 GIS data Analysis of Charleston Holy City Bike Share Trips.

The GIS analysis offered detailed insights into ridership patterns across Charleston's downtown area. For April 2018, selected as a representative month, 5,655 bike trips were recorded, accounting for 10% of the annual total (54,761 trips in 2018). The average trip length was 2.6 miles with an average duration of 39 minutes. Analysis highlighted distinct patterns between local users and visitors, with locals favoring business districts and visitors concentrating on attractions. High-use routes included Vendue Range (2,685 trips, LOS A), East Bay Street (1,559 trips, LOS A), and Ashley Avenue (1,507 trips, LOS A). Conversely, low-use, problematic routes included Spring Street (79 trips, LOS E) and Calhoun Street (345 trips, LOS E). The GIS route analysis for this study leveraged analytical tools and displays from previous research and system dashboards. However, the specific segment by segment analysis of bike rides using GPS points and routes is unique to this research to the best of the knowledge of the research team.

5.2 Quantitative Roadway Suitability of Bike Share Trips.

Creating a spatial representation of the Bike Level of Service (BLOS) for the Charleston, SC network was a critical step in assessing bike suitability for roadways in the project area. This step not only provided visual patterns of the road network suitability for biking but also enabled aggregation of bike trips and further quantitative analysis of the data. Data from April 2018 Charleston Holy Spokes bike share trips (n=5,655), average length of 2.6-miles, average duration of 39 minutes, and total of 14,846 trip miles, were used to evaluate bike share system trips use of existing streets and roadways within Charleston's downtown peninsula district. Assessment of roadway suitability indicated that 82.7 percent of bike share tips are made on accommodating BLOS A through C roadways (accommodating bikes), while 17.3 percent of bike share trips are made on unaccommodating BLOS D and E roadways. No bike share trips were made on BLOS F roadways. The primary concerns to be addressed as a result of this study are bike trips that occur on the LOS D and LOS E sections. Transportation planning, safety and operation officials in the city could potentially use this research to strategically prioritize the improvement to LOS D and LOS E sections what are heavily used by bikers. Alternatively, information could be provided the public, especially visitors, on which routes would be the safest to ride on if no immediate significant improvements can be made to the low bike suitability segments.

5.3 Qualitative Bike Score Assessment of Sample Route Segments.

Qualitative Bike Score assessment of a sample of 22 roadway segments by two bike route raters who each rode bicycles along the segment routes located within the study are on the city of Charleston peninsula. Qualitative Bike Score ratings ranged from a high of 100 to a low of 20. A comparison with quantitative roadway suitability LOS indicated that bike score ratings seemed uncorrelated, however, the variability between rider perceptions and difficulty in assessing bike suitability across a range of bike riders was verified through these direct comparisons and rider experiences. Also, further aggregation of qualitative ride data supported the quantitative groupings for Bike LOS

5.4 Physical Activity Benefits of Bike Share Trips.

For assessment of physical activity benefits 2018 total Charleston Holy Spokes bike share trips (n=34,551), average trip distance of 2.43-miles, average duration of 40-minutes, and average speed of five (5) miles per hour, were used to calculate physical activity for an average bike ride as 161 MET-minutes of energy expenditure. Using the average calculated speed of the bike share rides of 5 miles per hour and determining physical activity estimations, an average bike ride resulted in 161 MET-minutes of energy expenditure. In addition to an overall sample of bike rides, membership type was we also examined. Non-local riders were classified by one and two-day bike share passes, while membership types, like annual, student, and industry partner memberships, were categorized as 'local' rides. As expected, there were large differences between local and non-local bike ride characteristics, including non-local riders using bike share bikes for a longer duration, further distance, and expending more energy. Local riders expended less overall energy, but traveled at a faster speed, resulting in more vigorous energy expenditure during their bike rides.

5.5 Direct Observations of Multi-use Trails in City of Charleston.

Direct Observations using System for Observing Play and Recreation in Communities (SOPARC) at three high use multi-use trails, popular with bike riders, in the City of Charleston including: West Ashely Greenway, Hampton Park Multiuse Path and Ravenel Bridge Multi Use Path. 3,681 individuals were observed distributed as follows for the three locations: Ravenel Bridge Multiuse Path (42.1%), Hampton Park Multiuse Path (41.0%), West Ashley Greenway (16.9%). Of all greenway users, a majority were adults (84.3%), male (54.3%), White (82.2%). Walking was the most prevalent activity type observed across all three greenways (47.0%). The same demographic and activity type patterns were generally observed for individuals at each location, with a few exceptions. There were more females (51.5%) than males (48.5%) observed using the Ravenel Bridge Multiuse Path. In addition, more users on the West Ashley Greenway were observed biking (50.6%) compared to walking (30.2%) or running (19.2%). Odds ratio evaluation was used to compare user physical activity and demographics across the three data collection locations.

5.6 Intercept Surveys of Multi-Use Trails in City of Charleston.

User Intercept surveys were administered at the same three high use multi-use trials, popular with bikes, in the City of Charleston. A total of 148 intercept surveys were collected with the average age of survey respondents of 45.2 (SD=16.7), of which the majority were female (55.5%), White (89.1%), and indicated college experience or college degree (91.1%). Most respondents reported using the space for recreation only (85.8%), with a majority of respondents walking or running (76.3%) compared to biking (21.0%). Greenway users reported exercise/being active as the main motivation for use (4.76 on the 5-point scale), while safety and security was reported as the most important feature when using the greenways (4.53 on the 5-point scale). Additional associations were indicated for motivations and facility features preferences.

5.7 Health Economic Assessment Tool (HEAT).

Health Economic Assessment Tool (HEAT) was used to evaluate the benefit of Increased physical activity that leads to reduced premature deaths per year. The Health Economic Assessment Tool (HEAT v5.0.6) provides a methodology that quantifies physical activity benefits from bicycling and walking for specific populations. Using 2018 data of 34,551 riders traveling for 2.6 miles at an average speed of 5-miles per hour, expanded for a one- year theoretical evaluation period, HEAT benefits included a range of 0.099-0.3 reduced premature deaths per year, estimated at a range of $551,00 to $1,700,000 economic impact per year.

5.8 Enhancing Accessibility and Inclusion

Access to Charleston's bike share system presents a unique opportunity to foster greater inclusivity. While the system has demonstrated significant benefits for urban mobility and public health, certain communities face barriers that limit their ability to fully participate. These challenges include limited station placement in historically underserved neighborhoods, membership costs that may be prohibitive for low-income residents, and outreach efforts that have not yet fully engaged non-English-speaking populations or individuals with disabilities. Expanding the reach of the bike share system requires a thoughtful and positive approach that acknowledges these barriers while embracing solutions to overcome them. Strategically increasing the placement of bike share stations in areas that have been underserved can make the system more accessible to a wider audience and foster greater connectivity across Charleston. Financial accessibility is another area with great potential for improvement. Offering subsidized memberships can open doors for residents who might otherwise find the service unaffordable. Partnerships with local businesses and government grants could provide the necessary funding to support these initiatives, ensuring that economic barriers are addressed without compromising the system's sustainability. Equally important is the role of community outreach and education. Developing multilingual marketing campaigns and hosting workshops on safe biking practices can engage more diverse populations and build trust within communities. Collecting data on station usage, membership demographics, and user feedback can provide valuable insights and guide adjustments to policies and programs over time. By maintaining a commitment to equity and inclusion, Charleston's bike share system can serve as a model for other cities, demonstrating how transportation systems can be both effective and inclusive for all residents.

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