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Evaluation of Transportation Network, Route Conditions, and Use Characteristics of E-Bike Share and E-Scooter Share

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16. Abstract - Individual MaaS rideshare systems are proliferating across U.S. cities in response to unmet demand for convenient mobility in short distance (3-mile, or less) urban trip making and first-mile/last-mile options for public transit travel. GPS tracking data and transportation network conditions were used to conduct a comparative Geographic Information System (GIS) evaluation focusing on the following objectives: 1.) evaluate differences between traditional bike share, e-bike, and escooter share micro-mobility systems with respect to trip making, operation, and user characteristics, and 2.) evaluate differences between traditional bike share, e-bike share, and escooter systems in achieving beneficial levels of physical activity and public health outcomes. GPS tracking was used to evaluate MaaS travel modes and examine differences between e-bike share, and e-scooters systems by analyzing trip characteristics and transportation network conditions. GPS data of e-bike and e-scooter trips in Birmingham and Mobile, Alabama, from MaaS systems operated by Gotcha Powered by Bolt were evaluated using six months of data collected during 2021. ArcGIS Pro and ModelBuilder were used to examine route conditions including posted speed limits, bike lanes, and traffic counts determined a Level of Traffic Stress (LTS) measuring comfort level experienced by users along the roadway network. Differences in energy expenditure, perceptions of difficulty, and acceleration between regular bikes and e-bikes in a bike share system were evaluated. Initially, study participants (n=15) underwent a bicycle maximal fitness test, and body composition was assessed. In associated study, two-hour steady-state bicycle rides were conducted at a local park, once on a regular bike and once on an e-bike. Continuous measurements of heart rate and speed were recorded with a heart rate monitor during each ride. Participants reported perceived exertion at four intervals within each ride, along with perceived enjoyment, difficulty, and tiredness at the ride's conclusion. e-bike share rides resulted in lower energy expenditure than regular bike share rides, both falling into the moderate-intensity physical activity category, contributing to meeting national physical activity guidelines. E-bikes in bike share systems may be appealing for integrating physical activity into daily routines due to reported lower difficulty and increased enjoyment.

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ABSTRACT

An emerging trend in U.S. cities is wide-scale availability of Mobility as a Service (MaaS) trip making options for a variety of trip purposes. MaaS is revolutionizing urban trip making and is credited with travel that is more convenient, more sustainable, more tech-savvy and more customer-service oriented. MaaS includes rapidly expanding bike share, electric powered bike (e-bike), and electric powered scooters (e-scooters) systems. Individual MaaS rideshare systems are proliferating across U.S. cities in response to unmet demand for convenient mobility in short distance (3-mile, or less) urban trip making and first-mile/last-mile options for public transit travel. GPS tracking data and transportation network conditions were used to conduct a comparative Geographic Information System (GIS) evaluation focusing on the following objectives: 1.) evaluate differences between traditional bike share, e-bike, and e-scooter share micro-mobility systems with respect to trip making, operation, and user characteristics, and 2.) evaluate differences between traditional bike share, e-bike share, and e-scooter systems in achieving beneficial levels of physical activity and public health outcomes.

GPS tracking was used to evaluate MaaS travel modes and examine differences between e-bike share, and e-scooters systems by analyzing trip characteristics and transportation network conditions. GPS data of e-bike and e-scooter trips in Birmingham and Mobile, Alabama, from MaaS systems operated by Gotcha Powered by Bolt were *evaluated* using six months of data collected during 2021. ArcGIS Pro and ModelBuilder were used to examine route conditions including posted speed limits, bike lanes, and traffic counts determined a Level of Traffic Stress (LTS) measuring comfort level experienced by users along the roadway network.

Differences in energy expenditure, perceptions of difficulty, and acceleration between regular bikes and e-bikes in a bike share system were evaluated. Initially, study participants (n=15) underwent a bicycle maximal fitness test, and body composition was assessed. In associated study, two-hour steady-state bicycle rides were conducted at a local park, once on a regular bike and once on an e-bike. Continuous measurements of heart rate and speed were recorded with a heart rate monitor during each ride. Participants reported perceived exertion at four intervals within each ride, along with perceived enjoyment, difficulty, and tiredness at the ride's conclusion. e-bike share rides resulted in lower energy expenditure than regular bike share rides, both falling into the moderate-intensity physical activity category, contributing to meeting national physical activity guidelines. E-bikes in bike share systems may be appealing for integrating physical activity into daily routines due to reported lower difficulty and increased enjoyment.

Keywords:
bike share, e-bikes, e-scooters

EXECUTIVE SUMMARY

E-bikes and E-scooters systems were compared within urban environments using GPS data in Birmingham and Mobile, Alabama, for Mobility as a Service (MaaS) systems operated by Gotcha, Powered by Bolt. The research findings determined that MaaS users tend to prefer local roads providing bicycle infrastructure for trip routes, reflecting lower Level of Traffic Stress (LTS). However, some MaaS bike/e-bike share system users exhibited a tendency to opt for routes that include major roadways, prompting questions about route making decision factors influencing these trip choices, whether by preference, familiarity, or necessity. Findings emphasized the need for improved infrastructure to alleviate Level of Traffic Stress (LTS) for users navigating e-bikes and e-scooters on transportation roadway/street networks, as cities adopt policies, regulations, and investments supporting more sustainable micro-mobility infrastructure and principles. As e-bikes and e-scooters transition from recreational vehicles to practical first and last-mile urban mobility options, it becomes imperative for cities to regulate and design infrastructure needed to accommodate these evolving modes of urban mobility, which hold considerable promise for meeting short duration urban trip making demand. The study used Level of Traffic Stress (LTS) as a measure for identifying locations where infrastructure enhancements can further promote the implementation of micro-mobility systems. Through examination of E-Bike share and E-Scooter share MaaS micromobility systems operated in Birmingham and Mobile, AL, research findings served to improve understanding of micro-mobility systems to meet urban travel demand. From July-Dec. 2021, MaaS micromobility systems in these cities were determined to remove short trip travel demand (3-miles, or less) from traditional network travel modes, commonly single occupancy automobiles, totaling: 1.) Birmingham, 7,347-trips, 7,583-mile; and 2.) Mobile, 41,997-trips, 28,646-miles. Factors unique to this study and these site locations may not be as transferable to other cities as initially intended in conducting this research.

Additionally, when examining differences in energy expenditure, perceptions of difficulty, and acceleration between regular bikes and e-bikes in a bike share system, e-bike share rides resulted in lower energy expenditure than regular bike share rides, both falling into the moderate-intensity physical activity category, contributing positively towards meeting established national physical activity guidelines. During field studies, participants on E-Bikes exhibite 87% heart rate intensity versus traditional bikes (n=15), with both equating to a moderate-intensity physical activity category, contributing towards users meeting adopted national physical activity guidelines for measuring as established by U.S. National Physical Activity Guidelines, who recommend 150-300 min. of moderate aerobic physical activity/week. E-bikes in bike share systems appear to be more appealing to the public for integrating physical activity into daily routines, as this MaaS mode is perceived as offering lower levels of user difficulty and increased rider enjoyment.

1.0 INTRODUCTION

U.S. cities are witnessing expansive growth of individual ridesharing Mobility as a Service (MaaS) options that frequently include bike share, electric-powered pedal-assist bikes (e-bikes), and electric powered scooters (e-scooters) systems. These travel modes appear to have potential in accommodating a portion of short distance (3-mile, or less) urban travel demand in a more efficient manner than alternative travel by private vehicle. A number of potential benefits associated with these types of MaaS ridesharing systems include: less air pollution, less fossil fuel consumption, greater sustainability, reduced demand on parking, reduced demand on network capacity, traffic congestion mitigation, increased physical activity, and improved public health outcomes. GPS tracking of individual routes using these modes, and GIS aggregation of travel data, provides a means for better understanding the potential of these modes to accommodate short distance urban trips, provides insight into how these modes differ, and offers insight as to what modifications need to be made to transportation network infrastructure to better accommodate these types of MaaS travel options. Through partnerships with MaaS private mobility providers, trip making comparisons and GPS route data will be compared for bike share, electric-powered pedal-assist bikes (e-bikes), and electric powered scooters (e-scooters) systems. Results will be useful in better understanding the differences between these types of MaaS vehicles in their potential for providing efficient travel options and meeting urban travel demand needs.

1.1 Research Objectives

The project literature review, data collection, analysis, evaluation, results and recommendations were conducted within the framework of addressing the following two primary research objectives:

1. Evaluate differences between e-bike, and e-scooter share micro-mobility systems with respect to trip making and network characteristics; and assess potential to accommodate demand of short distance (3-miles, or less) urban trips using comparable GPS tracks and GIS analysis techniques.
2. Evaluate differences between traditional bike share and e-bike share systems in achieving beneficial levels of physical activity and public health outcomes.

1.2 Project Scope

Tasks conduced for this project align with two primary research objectives and were supported by site specific data sharing agreements with mobility as a service (MaaS) micromobility service provides for systems located in targeted case study urban areas.

Data Sharing with MaaS Micromobility Systems: The research team established a collaborative partnership with Gotcha Powered by Bolt, a private, expanding mobility as a service (MaaS) company previously headquartered in Charleston, South Carolina.

Current products offered by Gotcha Mobility include traditional bike share, e-bike share, e-scooters, electric ride share, and an electric trike. As of 2021, Gotcha implemented approximately 50 rideshare systems with various mode options at each location. Many systems are operated in the southeastern U.S. The ongoing partnership between the academic team and Gotcha Mobility resulted in a data sharing cooperation in which the research team request and access data collected on ride sharing systems operated by Gotcha. Each mobility product the company offers are equipped with a GPS system that tracks each ride initiated by a user. This data is used internally by the company to improve their system and services; however, the perspective, capabilities, and skills of the academic team has already demonstrated utility to the company. For the purpose of this project, Gotcha Mobility agreed to share data for case study locations including Birmingham, AL, and Mobile, AL.

Research Objective 1: Evaluate differences between e-bike share and e-scooter share systems with respect to trip making and user characteristics and assess potential to accommodate demand of short distance (3-miles, or less) urban trips.

Case Study Approach: Two complementary case studies (one per city) will be conducted in this study. For each ride initiated using e-bike, or e-scooter, a GPS route-tracking capability is enabled, and location is captured in one-second intervals. The following methodological and analytical steps will be taken in order to compare differences between e-bike and e-scooter trip characteristics.

Constructing a Geospatial Database and Study Measures: Geospatial databases will be created to evaluate transportation infrastructure and MaaS micromobility system operation using the following steps:

1. Construct geospatial database containing: 1.) Roadway network characteristics, Departments of Transportation; 2.) Bike share travel routes (Gotcha mobility), and 3.) Bicycle Level of Service or Level of Traffic Stress (LTS) ratings.
2. Extract and clean data from the Gotcha Mobility system, including representative samples of e-bicycle and e-scooter MaaS system trips.
3. Merge data sources to develop an integrated geospatial database for analysis.

Analytical Approach: The methodology will be accomplished using the following steps:

1. Comparative analysis of trip distance, trip patterns, and trip characteristics between the e-bikes and e-scooters in one study setting using database summary and cross-tab statistics in Microsoft Excess and Access.
2. Comparative analysis trip distance, trip patterns, and trip characteristics of the e-bikes between the two study settings using database summary and cross-tab statistics in Microsoft Excess and Access.

3. Examination and comparative analysis of the prevalence of routes used, including specific street characteristics (i.e., lanes, lane width, speed limit, traffic, sidewalks, and bike infrastructure). Route analysis will be done using bike trips generated from GPS tracking points in ArcGIS. The bike trip paths will be aggregated by roadway segment hence providing a basis to identify prevalent routes by roadway segment.
4. Identification of transportation infrastructure network deficiencies. A bike/e-bicycle and e-scooter Level of Service (LOS) (*Bike Share in the US, 2017*) or Level of Traffic Stress (LTS) will be determined for the transportation network using network characteristics such as lanes, lane width, speed limit, and daily traffic volumes.

Research Objective 2: Evaluate differences between traditional bike share and e-bike share systems in achieving beneficial levels of physical activity and attaining desirable public health outcomes.

Physical activity and health estimation. There are numerous direct and indirect ways to measure, and estimate, physical activity levels. Most direct measures are time-intensive and have small sample sizes due to the measurement procedures (e.g., capturing oxygen consumption during activity) (Grøntved, 2016). Larger, population-based studies often rely on other valid estimation methods to quantify physical activity (Bourne, 2018). In this study, physical activity and energy expenditure will be estimated using the metabolic equivalent, or 'MET' value. One 'MET' is equal to the energy expenditure while resting, while walking at a moderate, 3.0 miles per hour paces is equivalent to 3.5 METs (Ainsworth, 2011). The updated, 2018 federal Physical Activity Guidelines recommends between 150-300 minutes of moderate-to-vigorous physical activity per week, which is equal to 500-1,000 MET-minutes (Piercy, 2018). The Compendium of Physical Activities (2011) is a scientifically developed classification system that standardizes the MET intensities of physical activities uses in population-based, epidemiological studies (Ainsworth, 2011). To determine the number of MET-minutes per bike ride, the duration of each ride and distance of each ride will be used to calculate the average speed (miles per hour) per bike ride. Using the average speed, MET-values will be assigned based on the Compendium of Physical Activities. For example, Compendium of Physical Activities assigns the following MET-values for biking based on speed: 3.5 METs for 5.5mph biking or below, 5.8 METs for 5.6 to 9.4mph biking, and 6.8 METs for 9.5 to 11.9mph biking (Ainsworth, 2011). The MET value that corresponds with the average speed will be multiplied by the duration of the ride to estimate the total number of MET-minutes per bike ride. This procedure for measuring physical activity levels and energy expenditure will be completed for both the traditional and e-bike sharing method. Estimates of physical activity will be focused on population-level characteristics from a GPS based analysis, rather than individual measurement of physical activity (e.g., physical activity diaries, oxygen uptake). Measurement methods will integrate bike-specific characteristics into our MET calculation to better calibrate valuations.

Analytical Approach: To analyze the overall differences in physical activity levels between traditional bike and e-bike sharing rides, researchers will compare data from approximately 3 months from both types of systems. To provide the most accurate comparison, data from the same months of traditional and e-bike share use will be compared. Researchers will account for the type of ride share user membership, time of day, and day of use in analyses. Also, the effect of grade change on energy expenditure by users will be accounted for using roadway grade information from directional terrain models in ArcGIS for the study locations. A second analysis will also be conducted that focuses on users that have a local bike share membership. Each user in the data system has a unique ID. Local users that have complete at least one ride per month will be identified and selected from the dataset. Then, data will be extracted for their bike rides and the physical activity levels of the traditional and e-bike rides will be compared for these identified repeat users. After completing these comparative analyses, the research team will also be able to create measurements of physical activity benefits if there would be an increase in bike share ridership. Additionally, the Health Economic Assessment Tools (HEAT) for walking and for cycling will be used to estimate the value of reduced mortality resulting from increased walking or cycling, as supported though better infrastructure networks and micro-mobility system implementation (Langford, 2017).

2.0 LITERATURE REVIEW

The literature review for this research project was conducted and organized under two technical concentrations including: 1.) micromobility system applications, and 2.) physical activity and health benefits. Although several crosscutting citations are identified between these technical fields, each literate review and summary of publications are presented individually in the following subsections.

2.1 Micromobility System Applications

Traditionally, transportation planning in the U.S. has been automobile-focused, resulting in marginalization of healthy and active modes of transportation like cycling and walking. Environmentally, this has contributed to air pollution; economically, this has contributed to an increased dependence on fossil fuels and automobile-oriented forms of development; and socially, this has contributed to an increased social segregation and reduced social contacts as well as to an increase in obesity rates, heart disease and asthma among both adults and children (Sallis, 2004). According to the 2004 National Household Travel Survey (NHTS), 41% of all personal trips are three miles or less, a distance that can reasonably be biked (Litman, 2004). Still, only about 1% of all trips made in the U.S. are by bike (AASHTO, 2012), while the vast majority of trips are made by driving a motor vehicle. Planning agencies have come to recognize the importance of bicycling as an active mode of transportation that can be incorporated in sustainable transportation planning. Many agencies agree that the fuel savings and health-care benefits from increased cycling activity can potentially outweigh monetary investments required for interventions aimed at increasing cycling (Gotschi, 2011). One of the nine societal sectors of the National Physical Activity Plan (NAPA) is Transportation, Land Use, and Community Design. Bike share systems, in particular, support physical activity and health through active transportation, aligning with NAPA goals of improving health, preventing disease and disability, and enhancing quality of life. Indeed, National Association of City Transportation Officials (NACTO) reported that the number of accessible bike share bikes in the US doubled from 2016 to 2017 from 42,500 to 100,000, along with an increase in the number of bike share companies (NACTO, 2018).

The use and growth of bike share systems in the U.S. has also spurred two additional, innovative modes of mobility: electric-powered pedal-assist bicycles (e-bikes) and electric scooters (e-scooters). E-bikes function as a regular bicycle but have an added electric battery and motor components to augment the human power used to propel the bicycle. Similarly, e-scooters have and use a battery and motor to propel a standing rider on the scooter (Fishman and Cherry, 2015). NACTO reported that the number of e-scooter trips surpassed the number of bike share trips in 2018 (38.5 million v. 36.5 million), with more than twice as many micro-mobility trips by both of these modes taken in 2018 compared to 2017. Given these upward trends in usage patterns, shared e-bike and e-scooter rideshare systems have the potential to increase active transportation trips in urban settings. With planning and accommodation of these ride sharing modes of transportation, cities could see a decrease in traffic congestion and improved health outcomes by increasing physical activity and decreasing harmful environmental exposures. (Fishman, 2015).

Early studies with e-bikes have shown promise as a mode of active transportation by helping individuals overcome some of the reported barriers to biking for transportation while also promoting advantageous environmental, physical activity, and health outcomes (Fishman and Cherry, 2015). Indeed, two recent studies have shown that when comparing health benefits between walking, traditional biking, and e-biking, persons using the e-bike still achieve moderate, or health-promoting, levels of physical activity (Langford, 2017; Bernsten, 2017). Importantly, evidence has also indicated that the persons using e-bikes travel further distances than with a traditional bike and report higher enjoyment when using e-bikes. E-bicycles have shown promise in encouraging more diverse users than traditional biking, such as older adults and less physically fit individuals, while concerns still remain a prominent individual and public policy issue (Fishman and Cherry, 2015). As e-bike share systems become more widely available in cities across the U.S., collaborative efforts between researchers, city officials, and key stakeholders can help maximize multimodal transportation systems to reduce traffic congestion and promote health.

Over 85,000 e-scooters were available for use in approximately 100 cities at the end of 2018 and the two main reasons that people report using e-scooters are getting to and from work and for recreation and exercise (NACTO, 2018). However, little empirical evidence has yet to demonstrate the characteristics of trip patterns for e-scooters compared to other modes of mobility sharing options. A recent (2019) study of spatial patterns of e-scooters and bike share systems in Washington, D.C., showed considerable different trip patterns between the two transportation modes (McKenzie, 2019). The average duration of e-scooter trips was about 5 minutes and the peak usage time for weekdays and weekend days was about midday (noon). In the same study, the highest proportion of rides occurred in recreational land use (40.6%), followed by commercial (36.3%) and residential (23.1%), with a clustering of e-scooter trips initiated in the core city center of Washington, D.C (*9*). In contrast, bike share rides were observed during more typical commute times (McKenzie, 2019*)*. This is one of the few studies that has examined the spatial patterns; therefore, more research is needed to explore the trip characteristics of e-scooters and how they differ from other ride sharing systems in order to inform best practice for co-existing MaaS systems.

Shared micro-mobility has grown during the last decade to position e-bikes and e-scooters in the new age of transportation. Although research on these modes has examined how they are used and how they interact with each other and with other modes, more in-depth work is needed to look into how ridership and user choice are influenced by infrastructure. The literature examined external factors such as traffic, the built environment, weather conditions and geography to determine how they influence demand for shared mobility services such as e-bikes and e-scooters.

Numerous sources of literature have examined the impact of user type and behavior on shared mobility. However, few articles looked at the socio-economic factors affecting e-bike and e-scooter sharing (Guidon, 2019). Previous research found a difference in use between members and non-members of e-bike and e-scooter services who use ride-sharing more casually. Non-members who partake in casual trips tend to go slower, aim for longer distances and time periods, as well as cluster in specific areas (Wergin, 2017). Among members and non-members of mobility sharing services, six user groups have been identified through cluster analysis (Yang, 2019): (1) commuters; (2) utility users; (3) leisure users; (4) infrequent commuters, (5) weekday visitors; and (6) weekend visitors.

External factors, such as dedicated infrastructure, traffic, and meteorological conditions, influence the choice to ride e-bikes. Members and non-members alike avoid roads without bike infrastructure. The literature shows that long term users look for bike lanes, cycle tracks, trails, and other bicycle infrastructure; however, in Washington DC as an example, only 7.6% of roadway mileage are equipped with bike facilities (Wergin, 2017). As an example of how this impacts usage, riders have expressed willingness to cycle for one mile on roads with bicycle infrastructure as opposed to being willing to cycle for 0.5 miles on roads with no bicycle infrastructure (Hood, 2011; Broach, 2012). Cyclists also tend to opt for longer distances to avoid a high number of turns per mile (Broach, 2012). Regarding e-bikes specifically, He, (2019) found e-bike sharing has an average travel distance of about five miles, which is much longer than regular bike sharing.

Regarding scooters, this mode is increasingly used for both recreational and transportation trips (Puczkowskyj, 2020). The increase in e-scooter usage is at least partly attributable to replacing walking trips, although the impact on public transit trips is still under debate (Laa, 2020; Sellaouti, 2020; Ziedan, 2021; City of Calgary, 2020). Furthermore, e-scooter users tend to prefer this mode for the ease of parking it offers (Hardt, 2019) but may be deterred because of safety, weather and baggage restrictions (Hardt, 2019).

Studies have shown that e-scooter use is chosen less for commuting as the daily usage is higher during weekends and holidays (Mathew, 2019; McKenzie, 2019; Noland, 2019). Even though the majority of e-scooter trips are likely recreational (Bai and Jiao, 2020; Mathew, 2019; McKenzie, 2019), e-scooters are mainly found in residential, commercial, and industrial areas with high employment rates and available bicycle infrastructure (Zou, 2020; Buck and Buehler, 2012; Buehler and Dill, 2016; El-Assi, 2017; Faghih-Imani, 2014; Faghih-Imani and Eluru, 2015; Fishman, 2016; Heinen, 2010; Li, 2018; Lin, 2018; Mateo-Babiano, 2016; Sun, 2018; Wang, 2018, 2016; Zhang, 2017; Zou, 2020)**.** Finally, studies suggest that daily users, male riders, and users closer to city centers are more likely to use e-scooters for commuting purposes (Puczkowskyj, 2020; Denver Public Works, 2019; San Francisco Municipal Transportation Agency, 2019; Laa and Leth, 2020), due to the availability of e-scooters and the presence of land uses that provide demand and density necessary for this mode (Nikiforiadis, 2019). Similar to e-bikes, mode choice and usage of e-scooters can be affected by the lack of a viable infrastructure (Nikiforiadis, 2019). E-scooter users have expressed concern regarding poor infrastructure as a reason for making less trips using e-scooters (Nikiforiadis, 2019). The adjacency of transit stops and traffic conditions factor into the users' mode choice for e-scooters (Zou, 2020) as well as trip origins and destinations (Zuniga-Garcia, 2020; Zou, 2020).

Although the literature widely looks into external factors to explain e-bike and e-scooter ridership, internal factors, such as user socio-demographics should be further investigated to understand how these factors influence user choice and use of either mode within urban settings. The literature has employed both surveys and GPS data to determine mode and infrastructure characteristics, but still lacks in depth information on the socio-economic aspects related to these particular modes.

Additionally, research looking into e-bike and e-scooter routes at the street link levels is still new. Our project is one of the first to examine GPS points created by ride share vehicles and calculate routes to understand user choice of routes based on infrastructure conditions. In this case, we use travel patterns of riders in Birmingham and Mobile, AL at the street link level and link the date to the availability of infrastructure through Level of Traffic Stress (LTS) to understand why ridership patterns.

With the expansion of e-scooter systems, one major concern expressed about this technology is safety. The mayor of Nashville proposed a temporary ban to all scooters following the death of a local resident due to a e-scooter accident. News outlets report elected officials adopted legislation to address safety concerns, including reducing the size of e-scooter fleets, creating no ride areas and slow zones, and signage that e-scooters are not allowed to be driven on sidewalks. Better understanding the patterns of use and trip characteristics, including the types of infrastructure that e-scooter riders are utilizing most can help inform and shape the policies created to regulate this new ride share system.

2.2 Physical Activity and Health Benefits

Physical activity (PA) is important for many dimensions of human well-being including cardiovascular fitness and mental health (Luepker, 1996). The U.S. National Physical Activity Guidelines and the American College of Sports Medicine (ACSM) recommends that adults engage in 150 to 300 minutes of moderate aerobic physical activity per week, yet over half of American adults do not meet this guideline (U.S. Department of Health and Human Services, 2018). This lack of activity is a growing concern as health care costs increase and general American well-being declines (U.S. Department of Health and Human Services, 2018). However, the 2018 federal Physical Activity Guidelines report that inactive individuals can improve their overall health by replacing sedentary habits with light-to-moderate intensity PA throughout their daily lives (U.S. Department of Health and Human Servies, 2018). Furthermore, the National Physical Activity Plan recommends active recreation and commute travel as two ways to integrate PA into regular routines (Sommer, 2021). For example, replacing short car trips with a more active option, such as biking or walking to public transit stops, (De La Iglesia, 2018) is a key approach to promote increased PA and improve overall health (Bopp, 2012; Gordon Larsen, 2009). As Grøntved (2016) concluded, commuting by bicycle to work increased physical activity and was associated with cardiovascular risk factor prevention (Grøntved, 2016). Bike share programs or systems are one way cities have encouraged more opportunities for active commuting and recreation via bicycles (Fishman, 2016).

Bike share programs have emerged in cities around the world and in the United States. According to the National Association of City Transportation Officials (NACTO, 2022). In 2017, the number of bike share bicycles in the United States more than doubled, from 42,500 bikes at the end of 2016 to 100,000 bikes at the end of 2017 (NACTO, 2017). More recently, people took 40 million trips on bike share systems in 2019 (pedal & electric-assist pedal bikes) compared to 35 million trips taken in 2017 (NACTO, 2019). While the COVID-19 pandemic created significant challenges for this industry, data point to the number of bike share systems and trips rebounded in 2021 (Hu, 2021). Many bike share systems provide docking stations throughout a city, encouraging active commuting and recreation transportation by renting and returning bikes for convenient use. In recent years, such programs are innovating by offering electric assist pedal bikes (e-bikes) in addition to traditional pedal bikes. This assist feature aids the cyclist's effort while using the bicycle. Specifically, as the user pedals, the engine works to increase the pedaling intensity, allowing the cyclist to potentially travel farther and faster.[4] By making the biking process more comfortable and less vigorous, research indicates that e-bikes broaden the potential user population to include older, less physically fit, and/or less able bodied individuals (MacArthur, 2014). Although e-bikes are easier to use, they are still physically engaging, and therefore still provide cardiovascular health benefits (Langford, 2017).

Multiple studies have begun to document the PA and health benefits of e-bikes. Previous literature, including a systematic review of the health benefits of e-bikes, has indicated that riders expend less energy on e-bikes than on regular bikes but still achieve moderate level PA (Langford, 2017; Bourne, 2018; Gojanovic, 2011; Simons, 2009). Specifically, one study explored heart rate and human power output among three active transportation modalities (i.e., walking, conventional bicycle, e-bike) along a fixed route including flat, downhill, and uphill segments. Using metabolic equivalent of task (MET) averages, they found e-bikes provide moderate PA on flat and downhill terrain, and vigorous PA on uphill segments, concluding that e-bikes used as active transportation can contribute to meeting PA guidelines (Langford, 2017). Although riding an e-bike requires more frequent and longer rides to provide comparable health benefits as conventional bicycles, substituting sedentary travel modes, such as car transportation, with e-bikes would result in positive PA outcomes (Bourne, 2018). Some evidence shows e-cycling alone can increase cardiorespiratory fitness and, with public health initiatives to promote e-biking, whole populations can experience improved health (Bourne, 2018).

Despite growing evidence comparing the energy expenditure between regular bikes and e-bikes, additional research can further strengthen the evidence base regarding e-bikes. In current literature, some studies have focused on populations with their own personal e-bike, with few studies utilizing bike share bikes in their comparison (Bourne, 2018). In the U.S., bike share systems are one of the primary means to access e-bikes outside of personal purchasing, so it is important to include these bicycles in research trials. Further, in at least two of the studies comparing the activity levels between regular bicycles and e-bikes, researchers set a specific path for the riders to follow, which was a limited distance. No studies to our knowledge have held a steady state ride, where participants ride at a pace that is comfortable to them for a specific period of time, rather than a set distance. Similarly, no regular and e-bike comparison studies have integrated starts and stops during the trial to investigate differences in acceleration and energy expenditure throughout an extended ride of about an hour. As a bike share user rides throughout a city, intersections with a traffic signal or a stop sign generate unavoidable stops and accelerations. E-bikes, with the engagement of a pedal motor-assist, would ideally make the act of accelerating easier and more comfortable. Finally, while some studies have captured both objective physical measurements and subjective perception data for using e-bikes compared to conventional bicycles or walking, (Langford, 2017; Sperlich, 2012) more data is needed to fully support these conclusions. Expanding e-bike research to quantify the health benefits and human perceptions is critical for improving these programs and making empirical recommendations for cities, municipalities, and companies.

3.0 RESEARCH OBJECTIVE 1: Comparative Analysis of E-Bike and E-Scooter Trips in Birmingham and Mobile, Alabama

This project evaluated individual ridesharing Mobility as a Service (MaaS) options ranging from bike share to electric-powered pedal-assist bikes (e-bikes) and electric scooters (e-scooters), emerged as potential solutions to address short-distance (3 miles or less) urban travel demands more efficiently than private vehicles. The project aimed to explore benefits associated MaaS ridesharing systems. Micro-mobility systems were evaluated in Birmingham and Mobile, Alabama and an array of factors describing MaaS trip making characteristics were identified through this research study. A summary of MaaS case study locations and micromobility system parameters for Birmingham, AL and Mobile, AL are summarized in Table 1 and Table 2.

TABLE 1. BIRMINGHAM, AL AND MOBILE, AL, STUDY LOCATIONS, 2021

Category		Birmingham, AL	Mobile, AL
2021 city population		197,575	187,041
2021 MSA population		1,115,289	661,964
Population Density		1,397 pop/sq. mi.	1,341 pop/sq. mi.
Area:	**City**	151.9 acres	180.0 acres
	Land	149.9 acres	139.5 acres
	Water	2.0 acres	40.5 acres
Elevation:	**Downtown**	643-ft.	10-ft.
	Max. Elev.	1,552-ft.	211-ft.
	Min. Elev.	275-ft.	3-ft.
Terrain		Rolling hills, ridge & valley	Coastal plain
Climate		humid subtropical	mild subtropical
Precipitation		56-inches/year	66-inches/year
Temps:	**Low**	47-days/yr. below freezing	19-days/yr. below freezing
	High	51-days/yr. above 90-deg.	57-days/yr. above 90-deg.
Universities		Univ. of Alabama, Birmingham Birmingham Southern Univ. Samford Univ.	Univ. of South Alabama Spring Hill College Univ. of Mobile
Tourism		3,600,000 visitors per year	3,300,000 visitors per year

TABLE 2. BIRMINGHAM, AL AND MOBILE, AL, E-BIKE, MAAS SYSTEMS, 2021

Parameter	Birmingham, AL	Mobile, AL
MaaS system studied	Gotcha, Powered by Bolt	Gotcha, Powered by Bolt
Service launch	July 22, 2021	Dec. 29, 2019
E-bikes, E-scooters	50 e-bikes, 100 e-scooters	25 e-bikes, 200 e-scooters
Corrals/Bike Hubs	95	58
Study period	July 25 to Dec. 7, 2021	July 25 to Dec. 7, 2021
Service cost	$1 to unlock, $0.35 per min.	$1 to unlock, $0.42 per min.
Current status	in operation, Sept. 21, 2022	service ended Aug. 14, 2022
Competing MaaS system	Veo/Zyp, 400-bicycles, 40-docking stations	n/a

3.1 Introduction, Research Objective 1

Shared micro-mobility appeared for the first time in 1975 in the Netherlands, however shared e-bikes and e-scooters did not become popular until Bird launched their fleet in Santa Monica in 2017 ("The Three Eras of Micromobility | Micromobility Europe," 2019). Micro-mobility startups emerged around the world and users slowly became accustomed to e-bikes and e-scooters as a part of the urban landscape. Around the world, e-bikes and e-scooters are deployed as links within modal share networks. Their presence as a first and last mile option and a recreational mode of transportation placed them among the most preferred means of travel, especially in cities that provide appropriate and safe infrastructure. In the United States, where single occupancy vehicle trips remain as the predominant mode of travel in many cities, shared micro-mobility is making positive strides. Since 2010, shared micro-mobility ridership grew from 321K to 136M in 2019 ("Shared Micromobility in the U.S.: 2019 | National Assoc. of City Transportation Officials" 2019).

E-bikes and e-scooters in US cities are provided by micro-mobility services through mobile applications. MaaS providers including Lime, Bird, and Gotcha Powered by Bolt, Figure 1, have launched vehicles across the United States where users can rent e-bikes and e-scooters by the minute. Service models for these vehicles depend on the provider. Three service models include: docked, dockless and hybrid (Shaheen, 2021). Docked vehicles, as the name indicates, can be checked out at unattended stations, and have to be returned to a station once the trip is over. Dockless vehicles can be found parked on sidewalks after users are through using them and can be activated anywhere through a mobile application. As for hybrid vehicles, they are a combination of docked and dockless that allow users to check out a vehicle at a station or a sidewalk and return it to a station or leave it on a sidewalk after the trip is over (Shaheen, 2021).

FIGURE 1: E-BIKES AND E-SCOOTERS PROVIDE BY GOTCHA POWERED BY BOLT

A survey conducted by the National Association of City Transportation Officials (NACTO, 2019) showed that these travel modes have caused a mode shift in the United States ("Shared Micromobility in the U.S.: 2019 | National Association of City Transportation Officials" 2019). Figure 2 shows that 45% of shared micro-mobility was a replacement for personal and ride hailing vehicles, 28% for walking trips, and 9% for trips taken by transit. This shift has prompted cities to accept e-bikes and e-scooters as alternative modes that need to be incorporated into policy and planning documents.

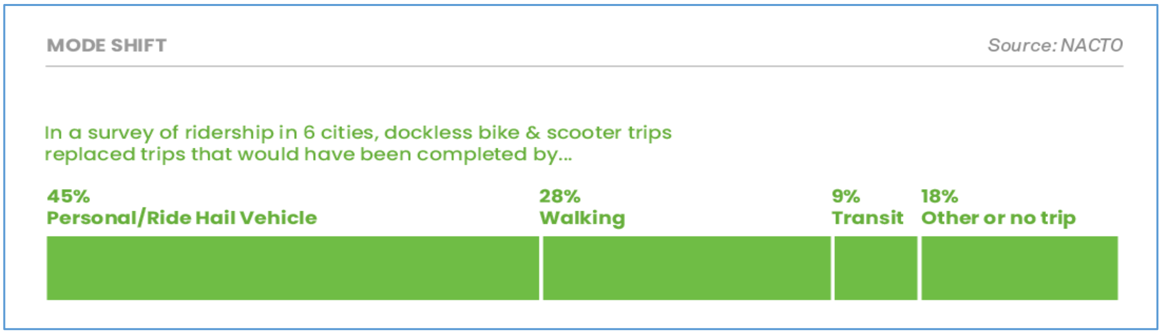

FIGURE 2: MODE SHIFT CAUSE BY SHARED MICRO-MOBILITY IN UNITED STATES. SOURCE: NACTO 2019

For cities that have yet to take a step towards regulating shared micro-mobility, NACTO has published the "Guidelines for Regulating Shared Micromobility" ("Guidelines for Regulating Shared Micromobility Section 1 Guidelines for Regulating Shared Micromobility," 2019). Birmingham, AL adopted "shared mobility ordinances" that establish guidelines and operational rules regarding how shared micro-mobility are to be implemented and managed ("History of Shared Micromobility « The Official Website for the City of Birmingham, Alabama" n.d.).

This analysis specifically investigates the relationship between infrastructure (bike lanes and e-bike/e-scooter separation of vehicular traffic) and user behavior towards e-bikes and e-scooters. This study aims to address two primary questions: 1.) How does the roadway infrastructure influence mode choice between e-bikes and e-scooters? 2.) How does roadway infrastructure impact route choice and distances traveled?

Gotcha Powered by Bolt is a Mobility as a Service (MaaS) company owned by Bolt Mobility. As indicated in Figure 3, vehicles provided by the company span across twenty-three states in 2022. This research examines how infrastructure impacts micro-mobility mode choice, trip distribution and length using e-bikes and e-scooters in Birmingham and Mobile, AL. The data used spanned between July 25 and December 7, 2021.

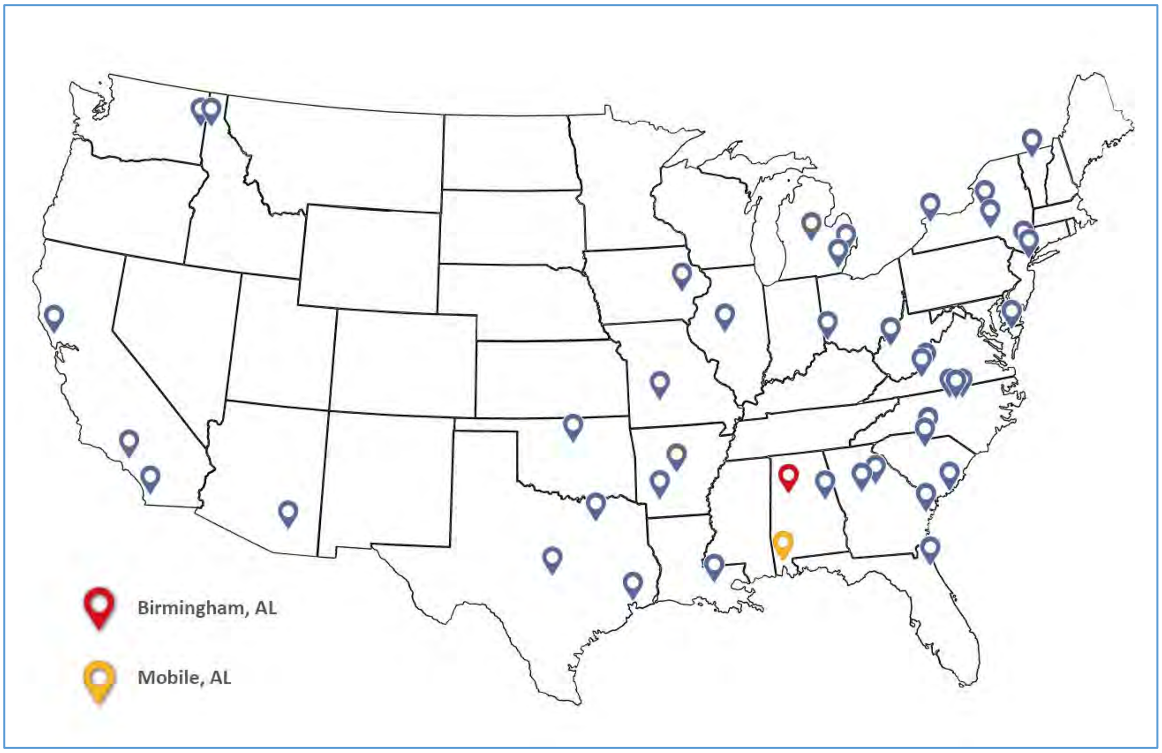

FIGURE 3: LOCATIONS OF GOTCHA POWERED BY BOLT SERVICES ACROSS THE UNITED STATES, 2021

Availability of both e-bikes and e-scooters in Birmingham and Mobile, AL cemented the choice of these cities as case studies. It allowed the comparison of the two modes under different conditions. The availability of both modes also allowed comparison of how trips are distributed in each city, as well as how roadway infrastructure affected mode choice and trip length. Birmingham and Mobile launched e-bikes and e-scooters across both cities in 2021, in partnership with Gotcha, to increase accessibility and encourage people to opt for cleaner travel modes. During the span of this study, Gotcha deployed 863 vehicles in Birmingham, and 918 vehicles in Mobile. In both cities, e-bikes and e-scooters can be found in repurposed parking spaces called micro-mobility corrals. The vehicles can only be unlocked using the Gotcha Mobility App. It costs riders $1 to unlock a Gotcha vehicle and 35¢ per minute to use the vehicle afterwards. Table 3 provides a summary of 2021 monthly trips for e-bikes and e-scooters, over six-month study period.

TABLE 3. BIRMINGHAM, AL AND MOBILE, AL, E-BIKE, E-SCOOTER MONTHLY TRIPS, 2021

Month, 2021	Birmingham, AL	Mobile, AL
July	427 (6%)	10,276 (24%)
Aug.	1,596 (22%)	7,173 (17%)
Sept.	1,985 (27%)	7,246 (17%)
Oct.	1,929 (26%)	6,346 (15%)
Nov.	714 (10%)	5,004 (12%)
Dec.	696 (9%)	5,952 (14%)
Total	**7,347**	**41,997**

Figure 4 is a map provided by Gotcha Powered by Bolt to indicate hub locations to users in Birmingham. The static map is reproduced in their mobile application with an interactive option to show vehicle type, price, and the availability of parking options. Although there is not a similar static map of hub locations in Mobile, the mobile application offers the same information on vehicles and locations for the city.

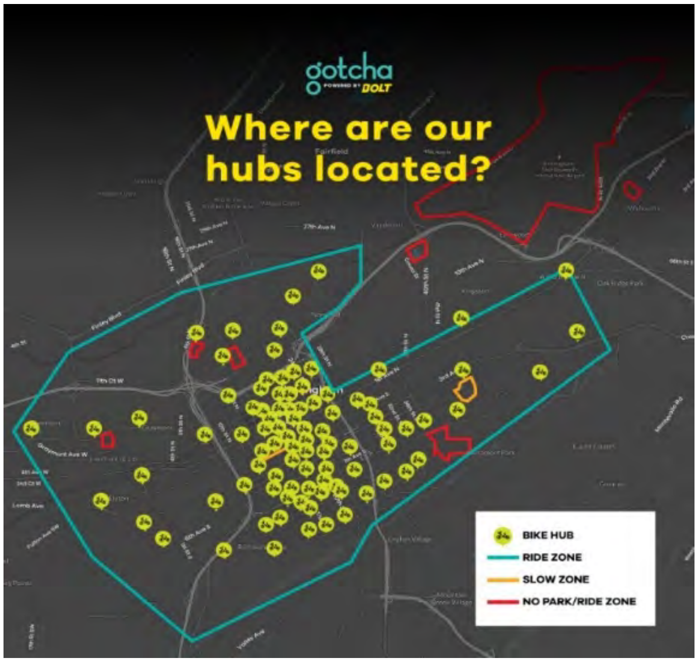

FIGURE 4: E-BIKE AND E-SCOOTER HUBS IN BIRMINGHAM, AL. SOURCE: CITY OF BIRMINGHAM

3.2 Methodology, Research Objective 1

This study explores differences between E-bike and E-scooter sharing through trip making characteristics influenced by the available infrastructure. For this, the study used data retrieved from Gotcha Powered by Bolt who provided GPS points for e-bike and e-scooter trips in Birmingham and Mobile, Alabama. The data is generated by e-bike and e-scooter users in both locations, where every ride is recorded with a corresponding user ID, start and end times, and trip lengths that were calculated from latitudes and longitudes of the GPS points. In processing GPS trip data, it should be noted that both cities have municipal ordinances prohibiting operation of e-bikes and e-scooters on sidewalks, however, gps tracking data indicate that both trip types frequently involve operational along sidewalks. Although not optimal, separation of sidewalk portions of trips from the data was not possible and the effort was not able to disaggregate data to extract this pervasive trip tendency. An overview of the methodology used to evaluate micro mobility trips is outlined in Table 4.

TABLE 4. METHODOLOGY TO EVALUATE MICROMOBILITY TRIPS

Sequence of Analysis Procedures
1. E-bike, E-Scooter, **GPS** route points (1-second intervals)
2. User ID, **start/end times** of each trip
3. Calculated **trip lengths** from latitude/longitude
4. Assigned trips to **road network** segments
5. Calculated **Level of Traffic Stress** (LTS) for road segments
6. Evaluated micromobility system operational **patterns**
7. Evaluated roadway network use and identified **LTS problems**
8. Identified **differences** in E-Bike and E-Scooter trip characteristics

To evaluate the differences in use between e-bikes and e-scooters in both cities, GPS data collected by Gotcha was used to capture e-bike and e-scooter locations in one-second intervals. Figures 6 and 7 show the distribution of GPS points (trips) retrieved from Gotcha. Mapping these points in ArcGIS Pro provided an initial indication of the urban coverage and extent of e-bike and e-scooter use across the roadway network. As micro-mobility services remain close to downtown areas in both cities, it was important to draw a limit around the GPS points in order to evaluate road infrastructure as it relates to routes involving e-bike and e-scooter use. To do so, block groups where trips were made were identified and served to comprise the study area for each city.

To examine trip characteristics in more depth, ArcGIS Pro and ModelBuilder were used to analyze the generated routes for each mode under current road infrastructure. Furthermore, metrics like posted speed limits, existence of bike lanes, and traffic counts were applied to investigate transportation infrastructure network deficiencies through e-bike and e-scooter Level of Traffic Stress (LTS) analysis. This analysis is used to evaluate the bicycle infrastructure network connectivity (Abad, 2019) and identify the most bikeable segments of the road infrastructure in both cities by looking at which roads are most frequented by users. Figure 5 represents the levels of stress corresponding to the degree of separation between users and vehicular traffic. The levels of traffic stress go from LTS 1 to LTS 4 depending on what kind of protection users have from traffic. The less protection there is, the less regular users can commit to micro-mobility modes such as e-bikes and e-scooters (Transportation Institute, 2012). As the figure shows, it becomes increasingly difficult for regular users (8 to 80 years old) to ride bicycles safely as bicycle infrastructure is minimized and cyclists and scooter-users must increasingly travel in with car traffic. As delineated by the Mineta Transportation Institute of Geoinformatics, the four levels of LTS ratings are categorized as Level 1 – very low stress, equivalent to neighborhood streets, cycle tracks, trails; Level 2 – low stress, suitable for 60 percent of population, equivalent to low-volume, low-speed roads; Level 3 – moderate stress suitable for 10 percent of population, equivalent to bicycling on four-lane roadways with bike lanes; Level 4 – high stress, suitable for one percent of the population, equivalent to bicycling in traffic on 40+ mph roads. Given that riders levels of stress increase with unavailable bicycle infrastructure and traffic separation, data on roadway network characteristics, bicycle and sidewalk infrastructure, traffic numbers and posted speed limits was collected in Birmingham and Mobile, AL. The collected data was then used to calculate LTS for all roadways within the study areas. LTS analysis was developed to reflect bicycle operational issues, which are different than e-scooters.

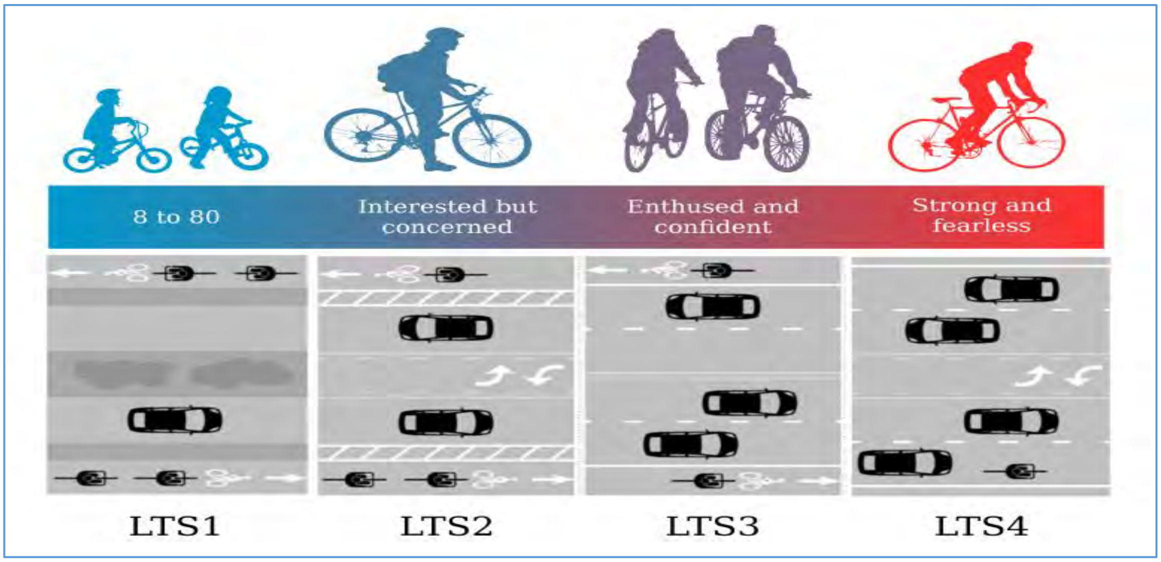

FIGURE 5: LEVEL OF TRAFFIC STRESS BY BICYCLE FACILITY. SOURCE: INST. FOR GEOINFORMATICS 2019

3.3 Results and Discussion: Research Objective 1

ArcGIS pro was used to map e-bike and e-scooter GPS trip coordinates. Figures 6 and 7 show the distribution of trips in Birmingham and Mobile, AL. Given e-bike and e-scooter fleets were newly introduced to both cities, trips were concentrated in limited areas. To account for this, the study identified block groups where GPS data was collected to ensure all trips within the study timeframe were accounted in the data analysis.

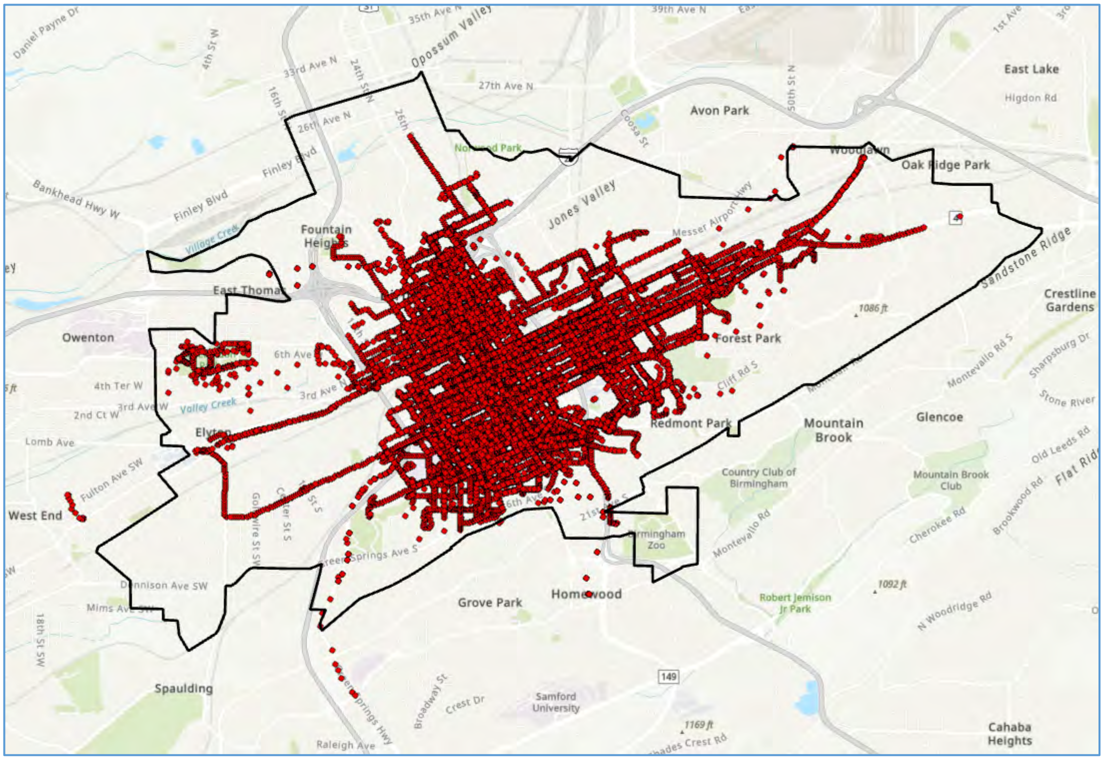

FIGURE 6: GPS POINTS RETRIEVED FROM GOTCHA IN BIRMINGHAM, AL

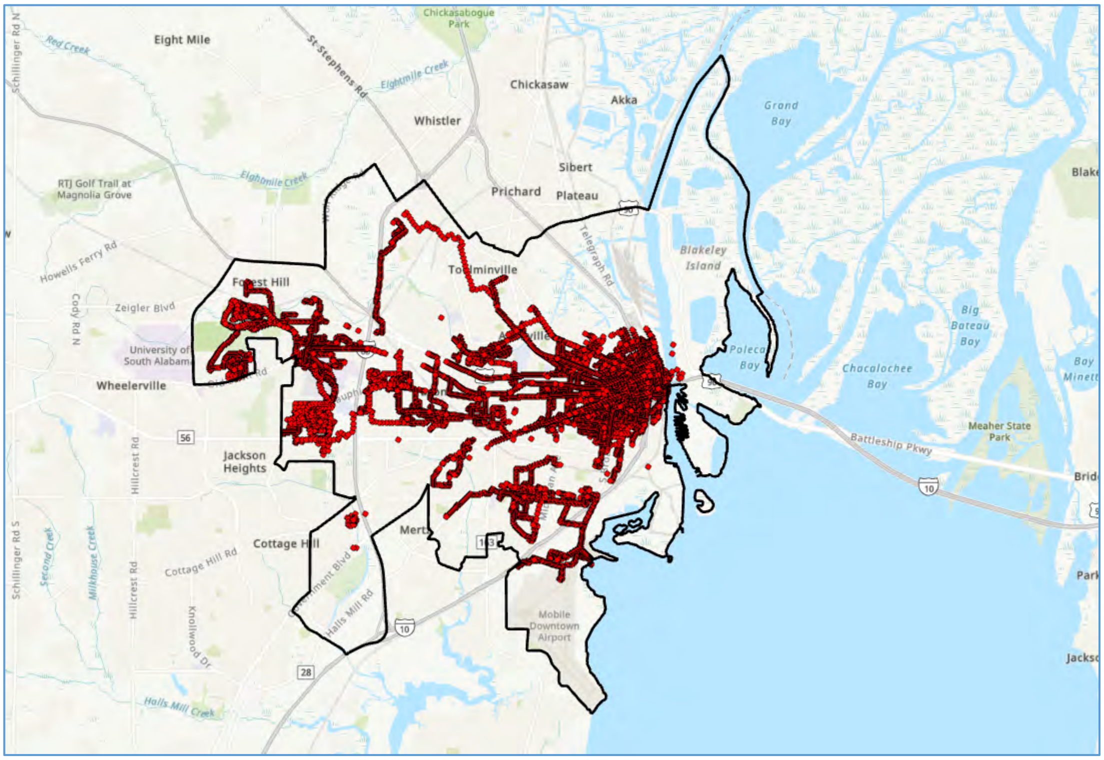

FIGURE 7: GPS POINTS RETRIEVED FROM GOTCHA IN MOBILE, AL

Between July 25,2021 and December 7, 2021, the deployment and use of fleets varied in Birmingham and Mobile, AL. Figures 8 and 9 show the differences in vehicle deployment during the span of this research in both cities. Although the figures show much higher numbers of deployed vehicles in Mobile, AL, both cities show similar seemingly random fluctuations in these numbers during the study period.

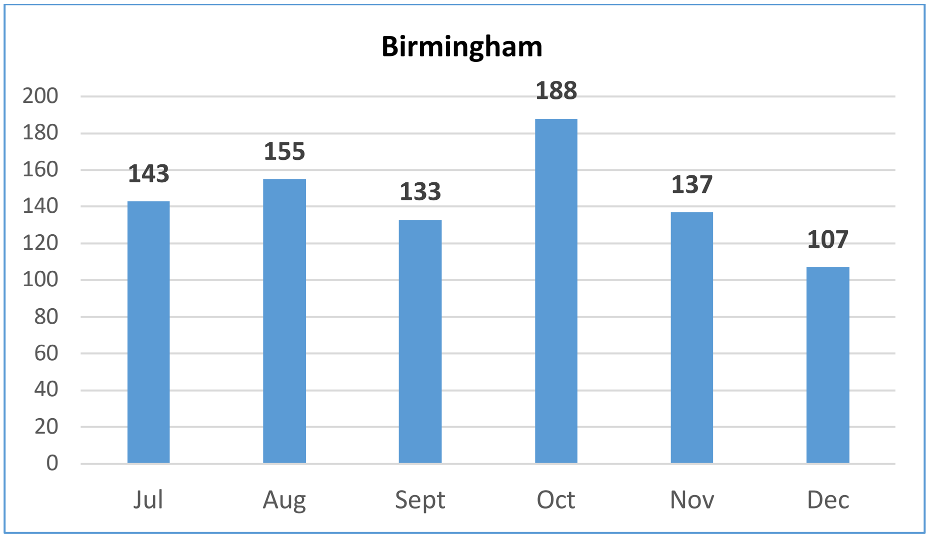

FIGURE 8: MONTHLY DEPLOYED VEHICLES IN BIRMINGHAM, AL

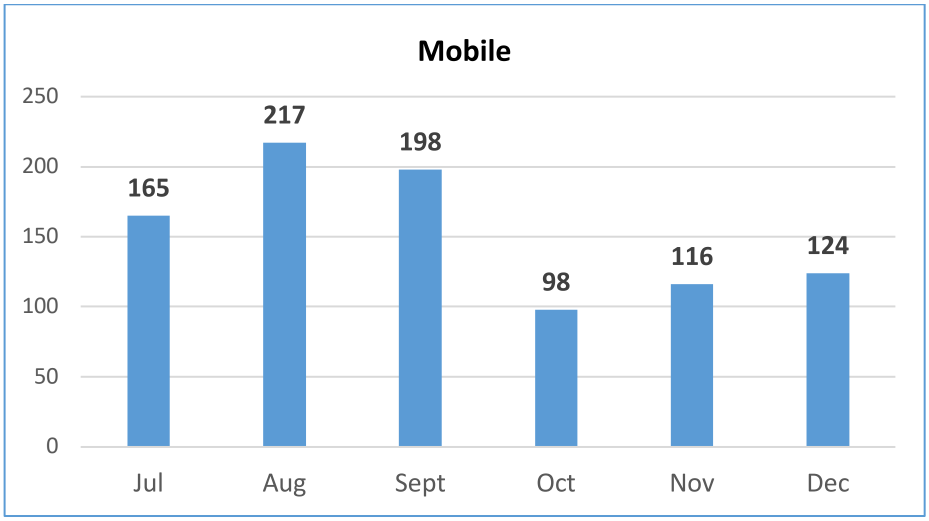

FIGURE 9: MONTHLY DEPLOYED VEHICLES IN MOBILE, AL

In Birmingham, Figure 8 shows that deployed vehicle numbers have oscillated around an average of 144 vehicles per month, counting e-bikes and e-scooters. A peak can be observed in vehicle deployment in August and October with 155 and 188 vehicles, respectively. Throughout the study period, Mobile deployed an average of 153 vehicles per month. Figure 9 shows that unlike Birmingham, peaks in deployment took place during the months of August (217 vehicles) and September (198 vehicles), while October registered the least number of deployed vehicles with ninety-eight vehicles only.

Although vehicles deployed were similar, the number of users was substantially higher in Mobile. Number of users in Birmingham increased from 217 users after launching, as shown in Figure 10, to peak at 759 users in September. August, September, and October registered high numbers of users with 666, 759, and 680, respectively. As the weather moves to colder months, user numbers declined to register 302 users in November and 287 in December. Similarly, Mobile registered a fluctuation in e-bike and e-scooter users albeit with different peaks and declines. Figure 11 shows that user numbers peaked in July, right after vehicles were launched. Although numbers declined by more than 1,000 users in August, ridership remained relatively high with the lowest number of users registered in November at 1,614 users.

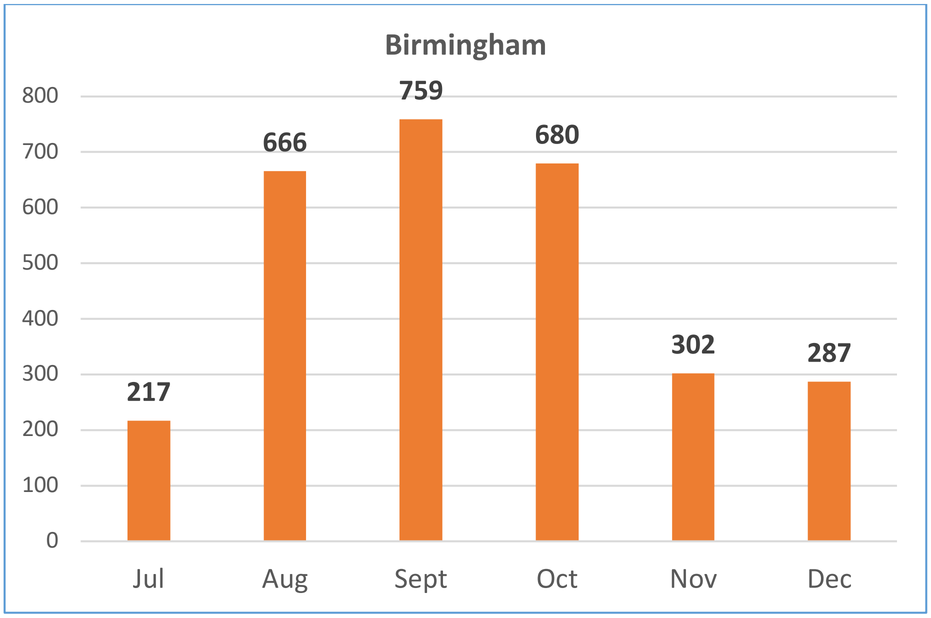

FIGURE 10: MONTHLY NUMBER OF USERS IN BIRMINGHAM, AL

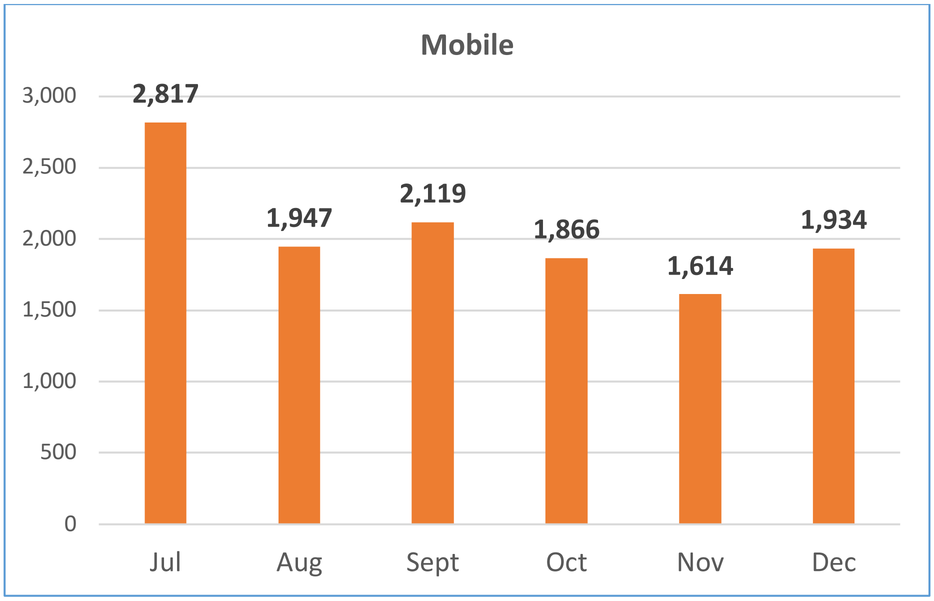

FIGURE 11: MONTHLY NUMBER OF USERS MOBILE, AL

The number of rides, shown in Figures 12 and 13, represent the frequency in which riders use e-bikes and e-scooters. In Birmingham, Figure 12, the number of rides took off in August, going from 427 rides in July to 1,596 rides in August. The numbers kept climbing throughout September and October to reach 1,985 rides and 1,929 rides, respectively. The number of rides registered a steep decline in November and December as weather conditions become colder. In Mobile, Figure 13, on the other hand, rides were substantially higher than in Birmingham and the number of rides registered a steady decline all through the study period. In July, 10,276 riders used e-bikes and e-scooters. In December, 58% of those rides were lost.

In the absence of data on driving and transit ridership, it is difficult to link the observed fluctuations in numbers of rides and riders to travel patterns relating to other modes. However, this research is able to answer the question of the effect of infrastructure, or the lack thereof, has on route choice and distances traveled.

Collected GPS points were used to map routes at the street link level in Birmingham and Mobile, AL to determine which roadways supported trips made by e-bikes and e-scooters. In these roadways, the study gathered data about the availability of bicycle lanes, posted speed limits, and AADT to determine the relationship between route choice and the levels of stress users feel while using e-bikes and e-scooters.

Mapping the routes on the street link level shows the location and frequency of trips in the study areas. Figure 14 represents e-bike and e-scooter routes in Birmingham. The maps show that trips are being made in the downtown area, Five-Points South, and North Avondale to the east. This distribution of trips follows the locations of bike and scooter hubs in the city, previously shown in Figure 4.

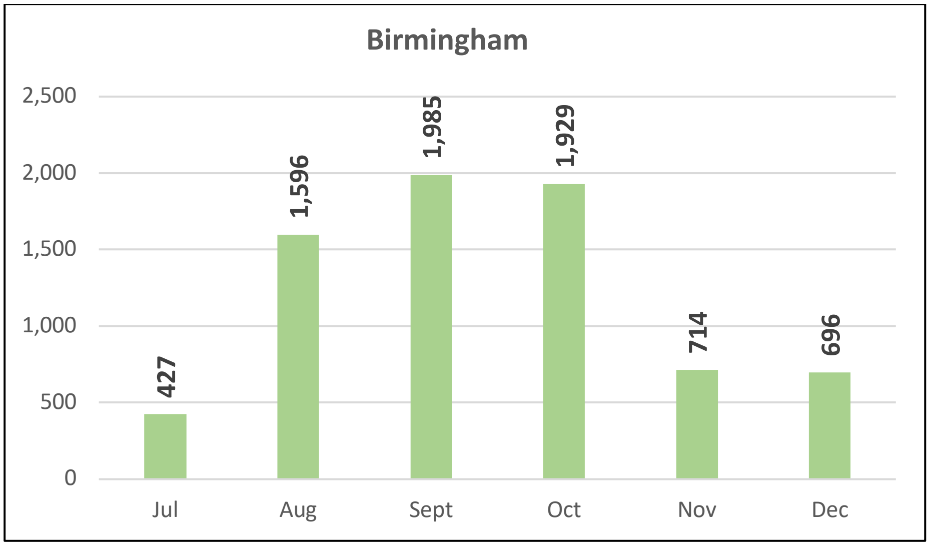

FIGURE 12: MONTHLY NUMBER OF RIDES IN BIRMINGHAM, AL

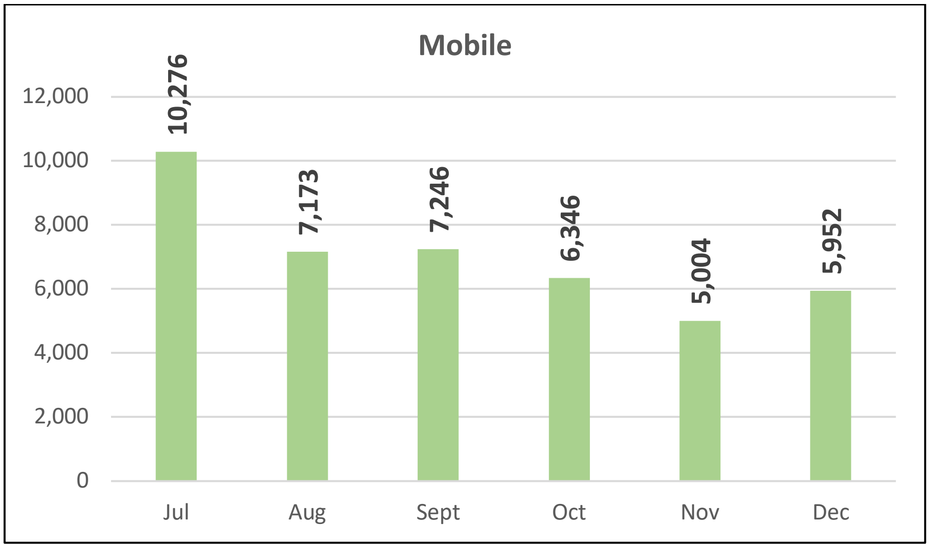

FIGURE 13: MONTHLY NUMBER OF RIDES IN MOBILE, AL

Figures 15 and 16 look more deeply into roadway type and user route choice. Figure 15 is a map of roadways within the study area with their corresponding LTS scores. As the map shows, downtown Birmingham, where the majority of trips are made, is populated with orange and red lines that represent LTS 3 and 4 roads. According to the Level of traffic stress by bicycle facility chart, previously shown in Figure 5, these scores are indicative of roads with medium to high traffic counts, posted speed limits between 35 and 40mph, and a drop/absence of bike lanes. These numbers indicate that only a limited number of riders may be able to use the infrastructure safely.

As shown in Figure 16, graphics indicate that 78.35% of users prefer using e-bikes on roads of LTS 1, while 16.35% of users opt for e-scooters under the same conditions.

Conversely, over 85% of users opt for e-scooters across streets with LTS 3 and 4. These numbers confirm that the absence of bike lanes, the existence of high posted speed limits, and busy streets deter users from riding e-bikes on major and principal roads, while e-scooter users are not deterred by such limitations in the infrastructure.

Looking at e-bike and e-scooter use by road class confirms these findings. Figure 17 shows the distribution of trips across minor, major, and principal roads. The majority of trips made by e-bikes (61.8%) were recorded on minor roads, while major roads see 60.31% of trips made by e-scooters. These numbers could be explained by the availability of bicycle infrastructure that makes trips not only easier but also gives users a sense of safety and security while using the vehicles. While not all minor roads at Birmingham may be equipped with bike lanes, it is far easier and safer for bicyclists to use unequipped minor roads than it is to hazard unequipped and busy major and principal roads. As for e-scooters, the high number of trips registered on major roadways can be explained by the fact that, unlike e-bikes, e-scooters often coexist on sidewalks along pedestrians even if this may cause disturbances to pedestrian mobility.

Regarding trips made on principal roadways, e-bikes and e-scooters register non negligeable numbers of use with 14.27% and 16.15% respectively. Although this might insinuate the presence of fearless riders committed to e-bikes and e-scooters as a mode of transportation regardless of infrastructure, it also raises concerns on how coherent and continuous the infrastructure is. For users depending on these modes to make trips, having to cross highways and interstates to travel on an e-bike or an e-scooter is often hazardous. These findings can be employed to ensure that a safe infrastructure, or at least one that is not in a direct interaction with intense vehicular traffic, is available to users who desire to travel using Gotcha vehicles.

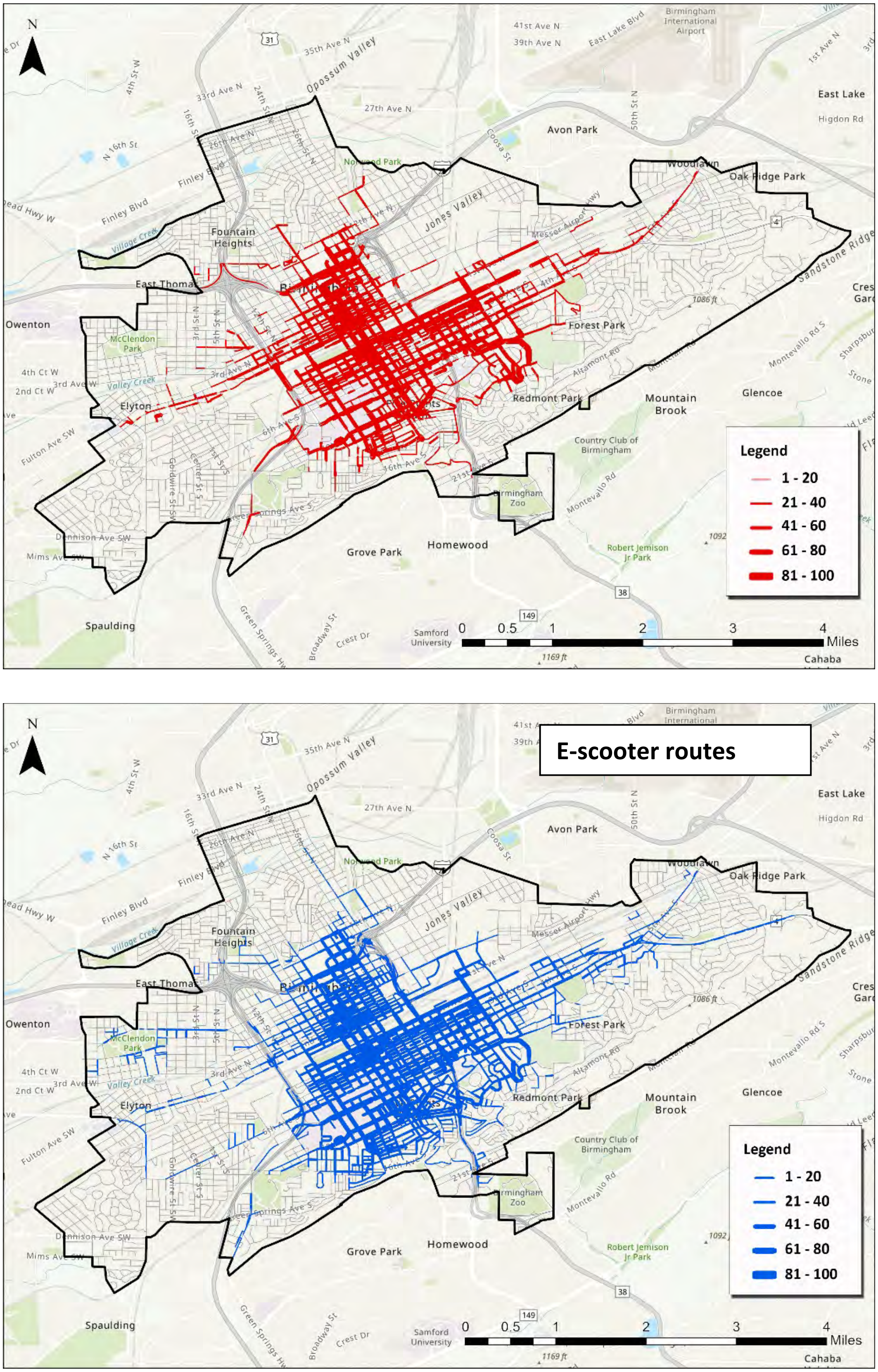

FIGURE 14: E-BIKE AND E-SCOOTER TRIPS MADE IN BIRMINGHAM, AL FROM JULY 25 TO DEC. 7, 2021

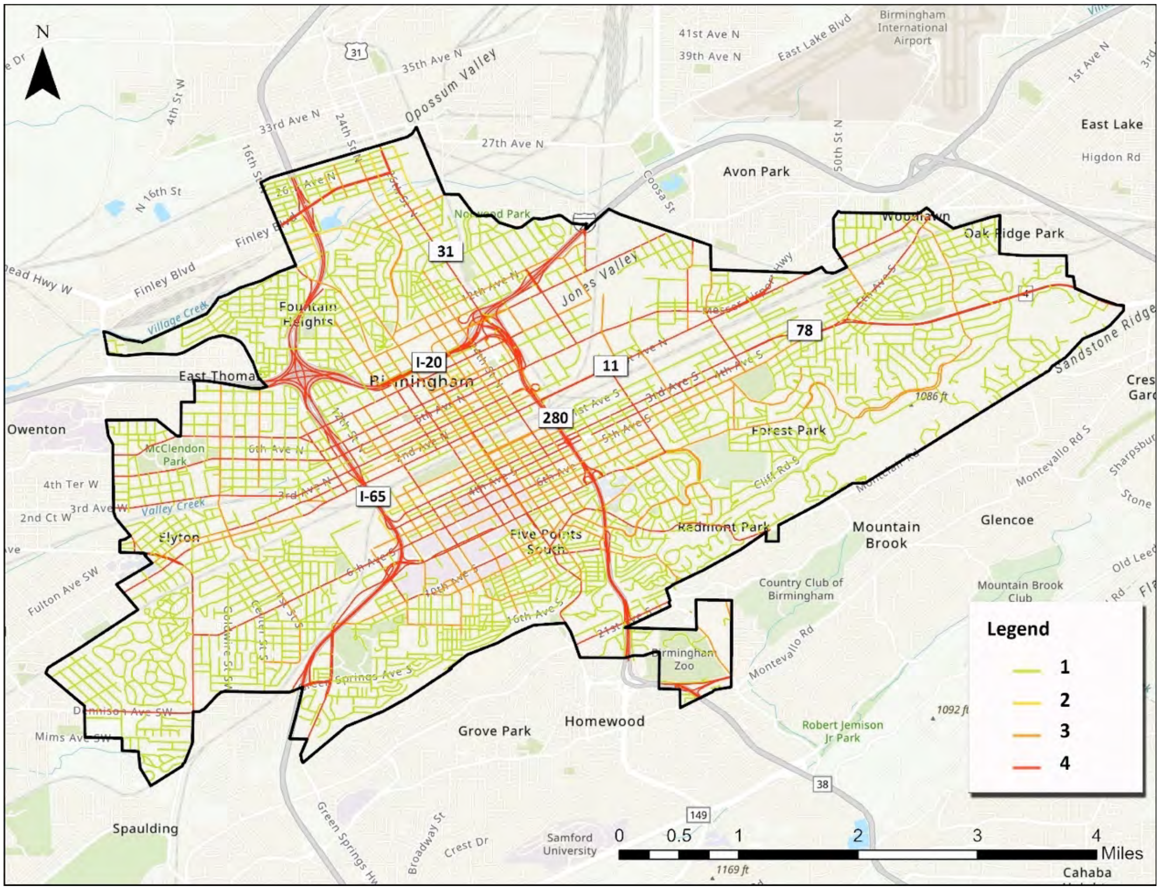

FIGURE 15: LEVEL OF TRAFFIC STRESS (LTS) BY ROADWAY TYPE IN BIRMINGHAM, AL

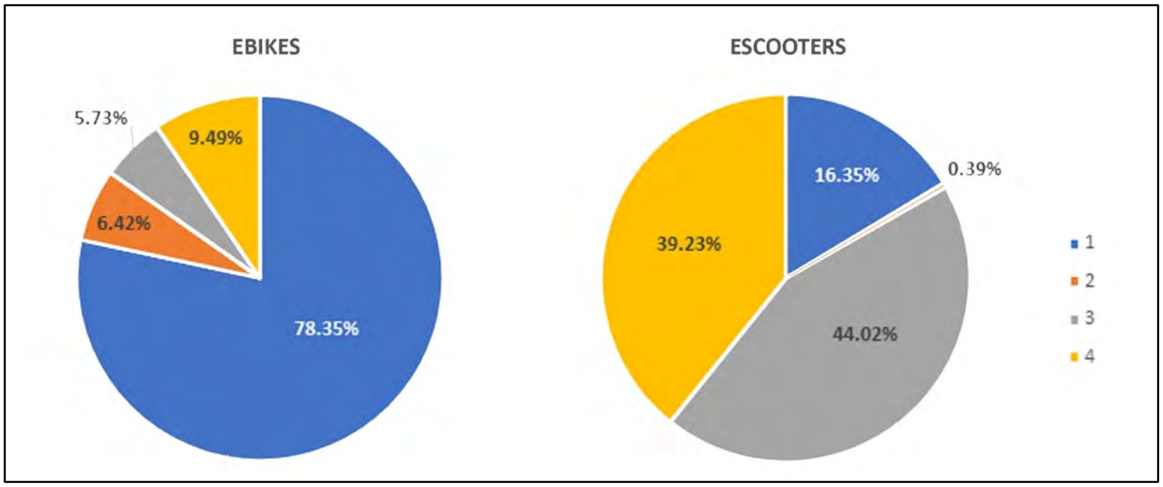

FIGURE 16: E-BIKE AND E-SCOOTER TRIPS BY LEVEL OF TRAFFIC STRESS (LTS) IN BIRMINGHAM, AL

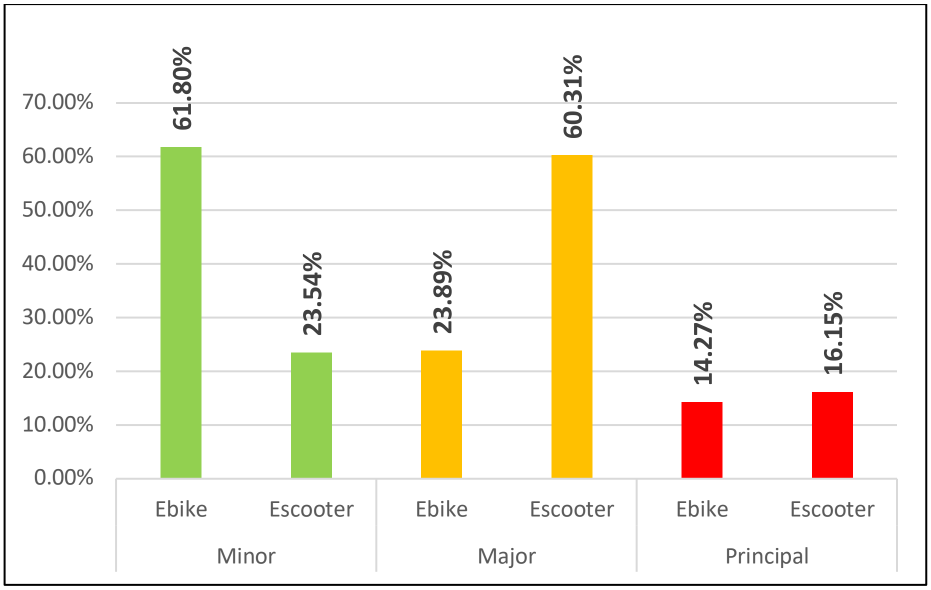

FIGURE 17: E-BIKE AND E-SCOOTER TRIPS PER FUNCTIONAL ROAD CLASS IN BIRMINGHAM, AL

These findings also raise the question of how far users are willing to travel on e-bikes and e-scooters when the majority of roads receiving trips are scored LTS 3 and 4. Figure 18 and Table 5 provide comparisons of e-bike and e-scooter trip lengths in Birmingham. The graphic shows that 44.7% of e-bikes are used for trips less than 0.5 miles compared to 37.4% of e-scooters for the same trip length. For trips between 0.5 miles and 2 miles, the data show that e-scooters are more widely used than e-bikes. E-scooters take 50.2% of trips in this category, while e-bikes register 45.2%.

Furthermore, the graphic shows a significant decrease in e-bike and e-scooter use in trip lengths between 2 and 5 miles. For these trip lengths, e-bikes and e-scooters register 9.2% and 9.4% of trips, respectively. As trip lengths increase, the number of trips decrease for both modes. Only 1% of users opt for e-bikes for trips extending beyond the 5-mile mark, while 2.2% choose e-scooters for the same trip lengths. According to these results, users seem to opt for e-scooters for all types of trip lengths, while e-bikes are preferred for shorter distances. This can be explained, once more, by the ability of e-scooter to share sidewalks with pedestrians when e-bikes users cannot.

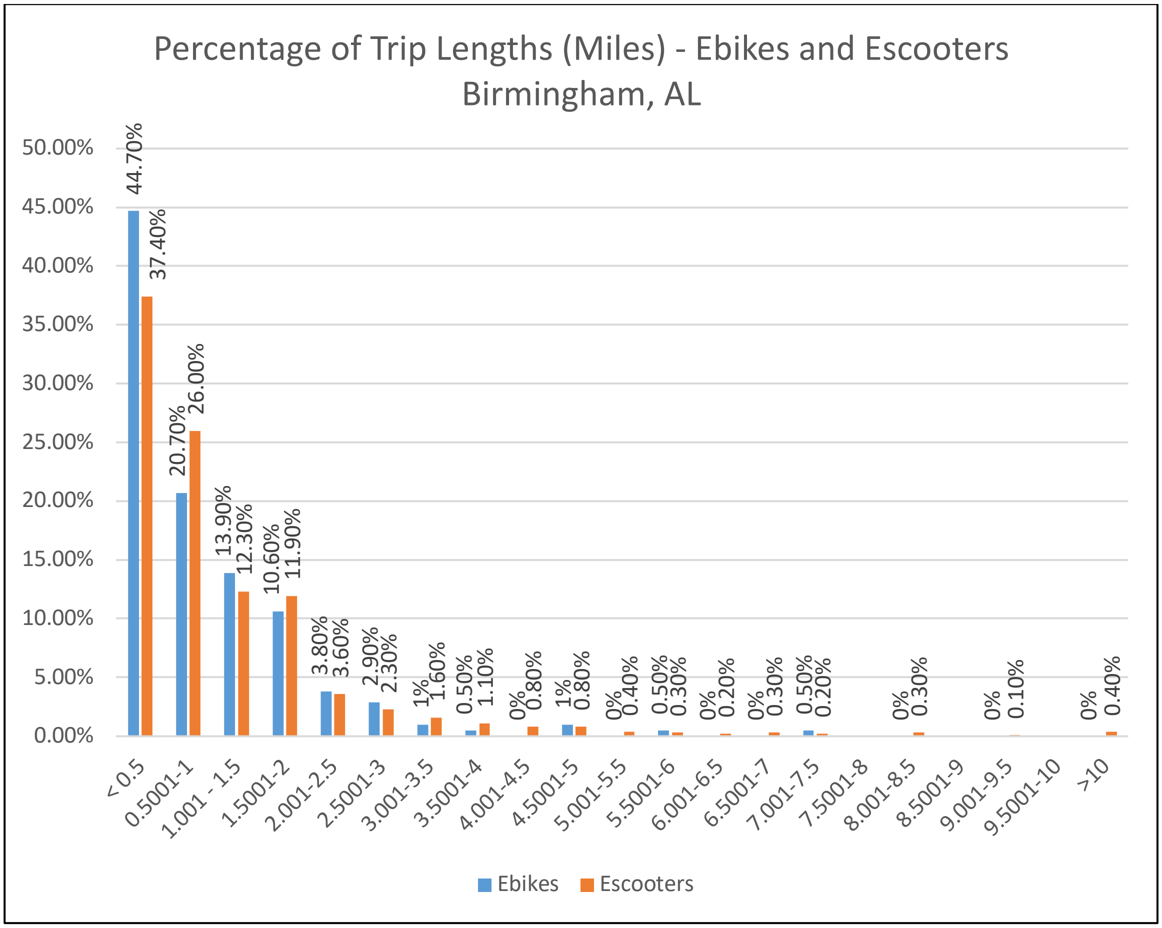

FIGURE 18: PERCENTAGE OF TRIP LENGTHS (MILES) – E-BIKES AND E-SCOOTERS IN BIRMINGHAM, AL

TABLE 5. BIRMINGHAM, AL: E-BIKE, E-SCOOTER TRIP SUMMARY, 2021

Trips	**E-Bikes**	**E-Scooters**
Less than 0.5 mi.	583	2,260
0.5-2 mi.	590	3,033
2-3 mi.	87	357
over 3 mi.	44	393
Total Trips	**1,305**	**6,042**
Miles		
Less than 0.5 mi.	145.8	565.0
0.5-2 mi.	671.2	3,365.6
2-3 mi.	215.6	871.6
over 3 mi.	177.4	1,571.0
Total Miles	**1,210.0**	**6,373.2**
Avg. mi./trip	**0.93**	**1.05**

In Mobile, the difference between e-bike and e-scooter trip distributions is stark. The maps in Figure 20 show that trips made by e-bikes are concentrated in the downtown area, while e-scooter trips are more widely distributed. The study area was drawn based on block groups where GPS data was collected to ensure that every trip within the study timeframe was accounted for. The differences in distribution between e-bike and e-scooter trips can be explained by the fact that e-scooters are more available to riders than e-bikes are. Figure 19 is a screenshot taken from the Gotcha Mobility app used to rent e-bikes and e-scooters in Mobile. The screenshot shows that e-scooters are more widely available than e-bikes are in Mobile, which explains the high number and distribution of e-scooter use.

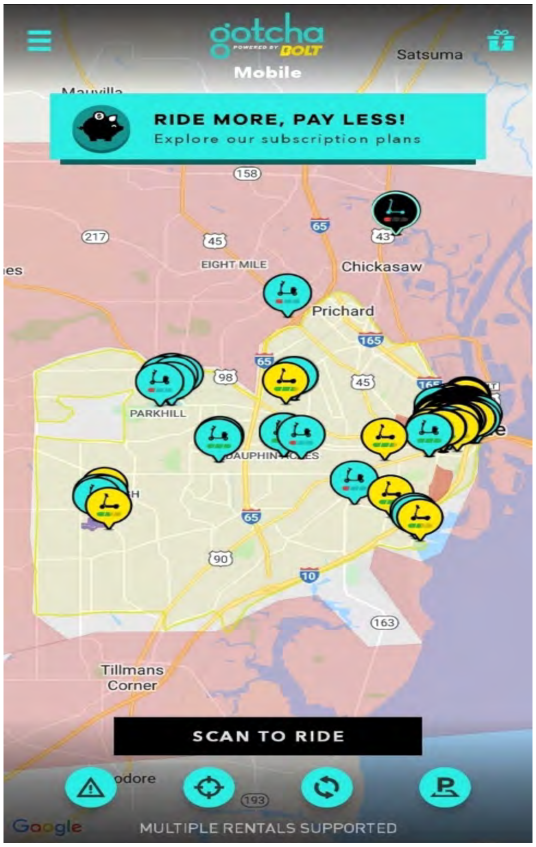

FIGURE 19: SCREENSHOT FROM THE GOTCHA APP 2022 IN MOBILE, AL

Another explanation to the limited number of e-bike trips is an equally limited bicycle infrastructure in Mobile, AL. To look into this possibility, the study used Level of Traffic Stress to score roadways in Mobile in order to determine the conditions under which trips were being made. Figure 21 shows that the majority of roads in Mobile are scored LTS 1 with a number of LTS 2, 3, and 4 roads that are receiving a non-negligeable number of trips according to figure 20. Taking a closer look at these figures, it becomes apparent that e-bike trips are made within the downtown area of Mobile where LTS 1 roads are predominant, with few trips outside of that immediate area.

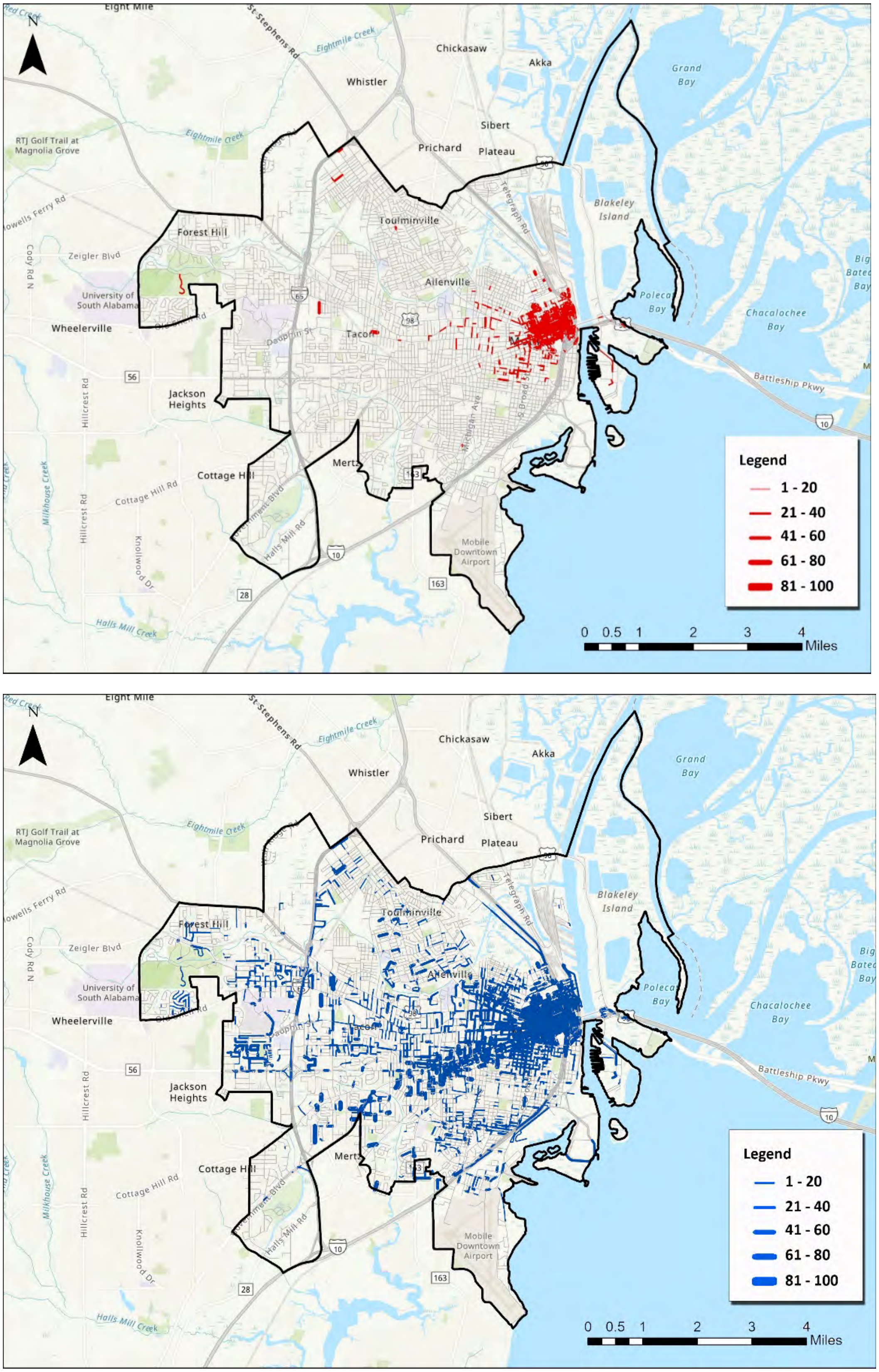

FIGURE 20: E-BIKE AND E-SCOOTER TRIPS MADE IN MOBILE, AL FROM JULY 25 TO DEC. 7, 2021

These findings raise again the question of how far and under which circumstances users of e-bikes and e-scooters are willing to travel using Gotcha vehicles.

Figure 22 shows e-bike and e-scooter trips by Level of Traffic Stress. According to the graphics, a high majority of rides, for both modes, have been registered in LTS 1 streets with 72.3% and 78.7% for e-bikes and e-scooters, respectively. Furthermore, the graphics show that a small percentage of e-bike users choose to make trips on LTS 2 roads (7.5%) while 20.1% of them ride on LTS 3 and 4 roads. To determine these tabulations, individual trips were divided into segments reflecting LTS analysis.

These findings are not surprising considering the predominance of LTS 1 roads within the study area. However, the high numbers of trips made in LTS 3 and 4 roads once again raises concerns of the safety and reliability of infrastructure if users are forced to use Gotcha vehicles on principal roads to travel.

In the absence of demographic data and reasons for travel, it is hard to deduce why users undertake principal roads and how other modes like driving and transit interact with e-scooters during travel.

Based on the GPS and roadway infrastructure data, this study looked into distances traveled using both modes to gauge how mode choice relates to trip length in Mobile in comparison to Birmingham.

Figure 23 and Table 6 show that mode choice by trip length in Mobile differs from that observed in Birmingham and indicates that users prefer e-scooters to e-bikes for trips shorter than 0.5 miles. For these types of trips, 56% of users opt for e-scooters versus 42.8% of e-bikes users.

Additionally, the data shows that for trip lengths between 0.5 and 2 miles, user mode choice shifts in favor of e-bikes. An aggregate of 57.2% of users choose e-bikes, while 40.9% of users opt for e-scooters. The number of trips decrease at the 2-mile mark. The graphic shows that e-bike use stops completely beyond this point, while e-scooter use does not exceed 3.1%.

Although e-scooter trips benefit from a wider distribution than e-bikes, the two modes are competing for short trips. As trip length reaches the two-mile mark, e-scooter completely takes over, albeit for a reduced number of trips. Once more, the wide availability of e-scooters and the benefit of sharing sidewalks with pedestrian give e-scooters an edge over e-bikes in Mobile.

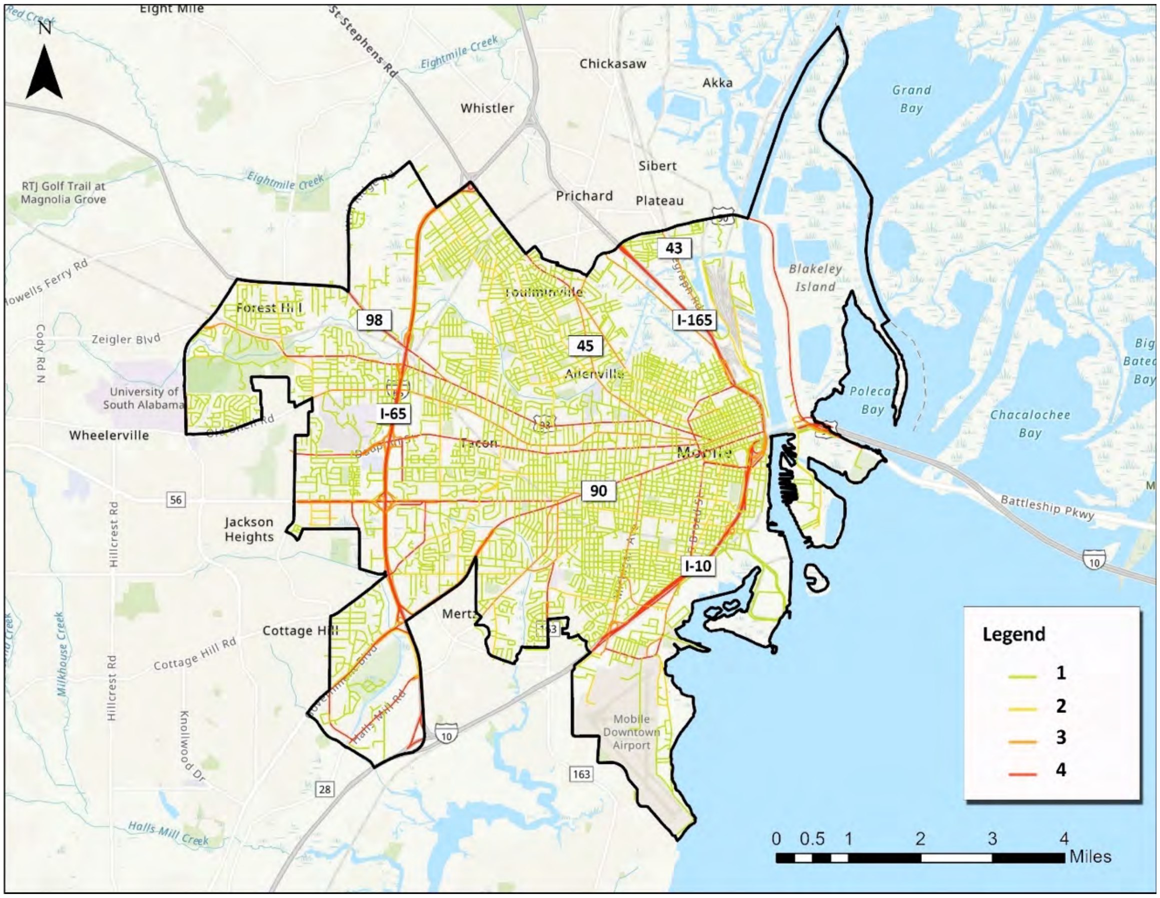

FIGURE 21: LEVEL OF TRAFFIC STRESS (LTS) BY ROADWAY TYPE IN MOBILE, AL

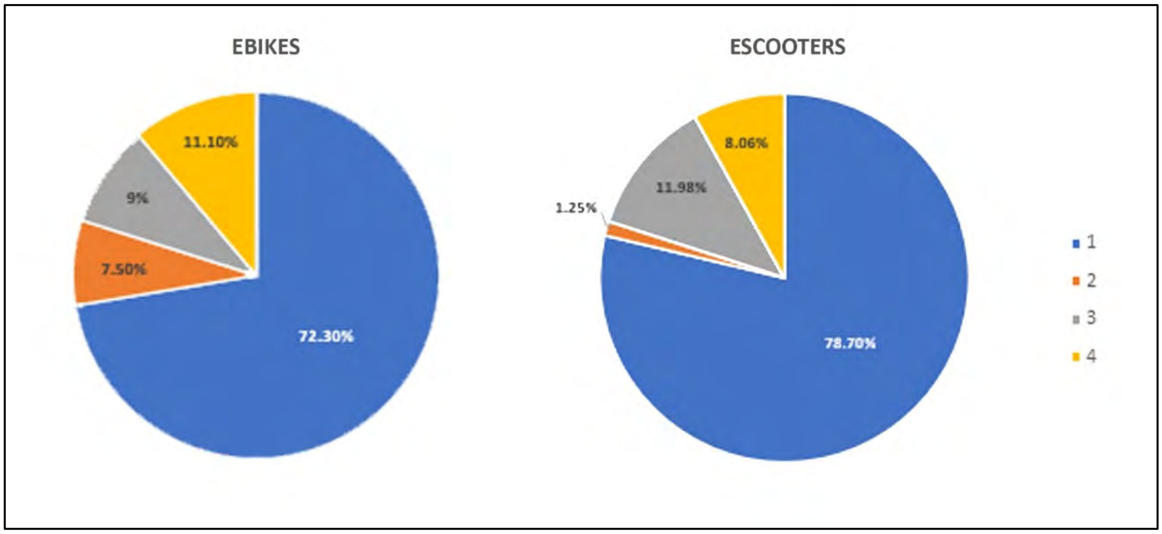

FIGURE 22: E-BIKE AND E-SCOOTER TRIPS BY LEVEL OF TRAFFIC STRESS (LTS) IN MOBILE, AL

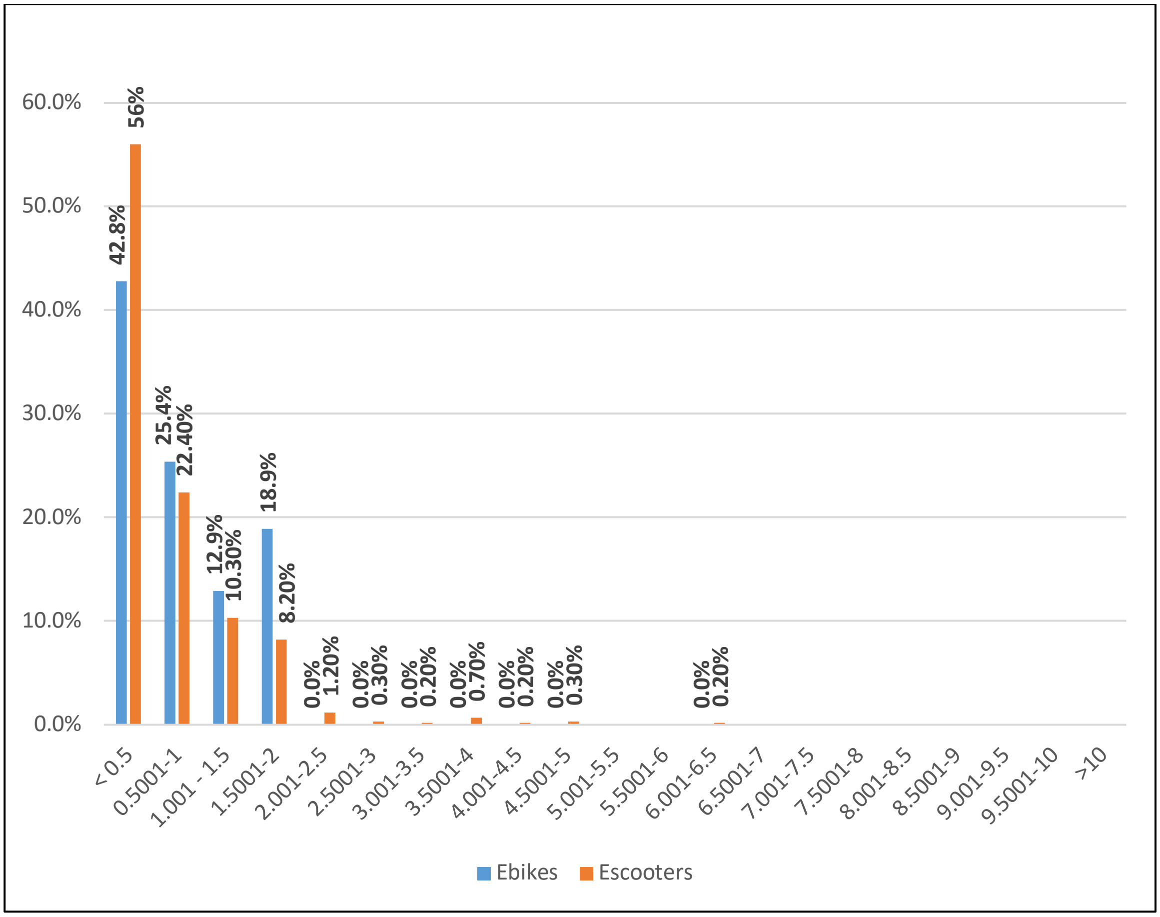

Figure 23: Percentage of Trip Lengths (Miles) – E-Bikes and E-Scooters in Mobile, AL

Table 6. Mobile, AL: E-Bike, E-Scooter trip summary, 2021

Trips	**E-Bikes**	**E-Scooters**
Less than 0.5 mi.	426	22,961
0.5-2 mi.	569	16,770
2-3 mi.	0	615
over 3 mi.	0	656
Total Trips	**995**	**41,002**
Miles		
Less than 0.5 mi.	106.4	5,740.3
0.5-2 mi.	679.0	18,051.2
2-3 mi.	0	1,445.3
over 3 mi.	0	2,624.1
Total Miles	**785.4**	**27,861.0**
Avg. mi./trip	**0.79**	**0.68**

3.4 Conclusion: Research Objective 1

This research investigated how e-bikes and e-scooters micro-mobility systems are being used within an urban environment through a comparison of ase study locations in Birmingham, AL, and Mobile, AL. MaaS systems were comprised of average number of combined deployed vehicles of 144 per month in Birmingham and 155 per month in Mobile. Differences were noted in combined MaaS system use, with a high of 759 monthly users and 1,985 rides in September 2021 in Birmingham and high of 2,817 monthly users and 10,276 rides in July 2021 in Mobile.

Level of Traffic Stress (LTS) analysis results indicate that most users tend to use local roads where transportation network infrastructure offers more compatible traveling conditions, some users are still making trips on major and principal roadways. In Mobile, AL, 20-percent of e-bike and e-scooter MaaS trips occurred on Level of Stress LTS 3-4 roads, whereas in Birmingham, AL, 83-percent of MaaS trips occurred on Level of Stress 3-4 roads. These comparisons between case study locations points to important MaaS issues of route choice, trip purpose, local knowledge, and availability of desired road conditions. It is true that a certain caliber of MaaS user are capable of effectively navigating roads among heavy and busy vehicular traffic, however many MaaS users tend towards avoiding problematic conditions, when possible.

As cities increasingly implement micro-mobility, it becomes more apparent that modes like e-bikes and e-scooters are evolving rapidly from recreational vehicles to first and last-mile options (Puczkowskyj, 2020). Accordingly, it is important to regulate and design infrastructure to accommodate not only single-occupancy vehicles and transit, but also e-bikes and e-scooters as viable alternative means of transportation. In this regard, Level of Traffic Stress (LTS) is a good measure that can allow policy- and decision-makers to identify locations where infrastructure needs to be fortified in order to encourage micro-mobility to thrive.

These conclusions collectively provide a step in the direction of establishing a broader understanding of the complicated relationship between transportation network conditions and MaaS user trip making characteristics.

4.0 RESEARCH OBJECTIVE 2: Quantifying Physical Activity Levels of a Bike Share System in Charleston, South Carolina

Differences in energy expenditure, perceptions of difficulty, and acceleration between regular bikes and e-bikes in a bike share system were evaluated. Initially, participants underwent a bicycle maximal fitness test, and body composition was assessed. Two-hour steady-state bicycle rides were conducted at a local park, once on a regular bike and once on an e-bike. Continuous measurements of heart rate and speed were recorded with a heart rate monitor during each ride. Participants reported perceived exertion at four intervals within each ride, along with perceived enjoyment, difficulty, and tiredness at the ride's conclusion.

4.1 Introduction: Research Objective 2

Objectives of this research analysis were to 1) Quantify energy expenditure, 2) Compare the trip characteristics (i.e., speed, distance, and acceleration) and 3) Examine differences in perceptions of difficulty, enjoyment, and comfort/safety between regular bikes and e-bikes. We hypothesized that 1) E-bikes would result in about 25% less energy expenditure than conventional bikes, but users will still reach heart rates in target zones for moderate activity, and 2) Individuals would report that e-bikes are easier to use.

This study was conducted in the City of Charleston, South Carolina (2019 population: 137,566) (U.S. Census Bureau, 2021). Participants were recruited from the City of Charleston, including the College of Charleston, a public liberal arts and sciences university with about 11,000 undergraduate and graduate students. This project was done in partnership with Gotcha Powered by Bolt, the company who managed the Charleston bike share (Holy Spokes) program in 2021. The Holy Spokes bike share program began operations in Charleston in 2017 and currently operates 250 bikes throughout the city (2021).

4.2 Methodology: Research Objective 2

Overview: Study participants included Fifteen (n=15) participants who were recruited via word of mouth, social media posts, and emails geared towards the City of Charleston and College of Charleston community. All participants were between 18 and 40 years old, had no underlying health conditions that would prevent them from exercising vigorously, and reported meeting the National PA guidelines of at least 150 minutes of moderate physical activity per week (U.S. Department of Health and Human Services). Participants received a water bottle and $25 for participating in the study. This study was approved by the Institutional Review Board at the College of Charleston. An overview of the methodology used to evaluate micro mobility trips is outlined in Table 7.

TABLE 7. METHODOLOGY OVERVIEW TO EVALUATE BIKE VS. E-BIKE PHYSICAL ACTIVITY PARAMETERS

Sequence of Data Collection and Analysis Procedures
1. Bike vs. E-bike, **participant study** was conducted in Charleston, SC
2. **15** participants, 18-40 years of age, no underlying health conditions
3. Participant body mass index (**BMI**) & est. body fat % were measured
4. **Fitness** level assessed via cycle ergometer max. oxygen uptake (VO2max)
5. Data collection: Lab & Field Measurements (**1-mi. test track** in local park)
6. 15-participants rode instrumented Bike and E-Bike cycles for **1-hour**
7. Study **comparisons** in travel, heart rate, and participant perceptions

Data collection consisted of three separate visits for each participant. The first visit included baseline fitness test and body composition assessment in College of Charleston’s Exercise Science laboratory. The second/third visits consisted of 60-min. steady state bicycle ride, once on a regular bike share bicycle and once on an e-bike.

Laboratory Visit #1: First, research assistants reviewed the informed consent with all participants, including study procedures. The participant’s height and weight were measured using a standardized stadiometer and the participant’s body mass index and estimated body fat percentage were measured using a handheld bioelectrical impedance analyzer (BIA) (Omron HBF-306), accounting for height, weight, age, and sex (Fahs, 2020). After body composition, fitness level was assessed via a cycle ergometer maximal oxygen uptake (VO2 max) test using the COSMED Quark RMR metabolic cart. Instruments were calibrated prior to the first research visit of the day. Before the test, each participant adjusted the cycle ergometer’s seat height to a comfortable position, secured a Polar H7 heart rate sensor strap around their chest, and fit a silicone face mask with headgear snugly over their nose, mouth, and head. Once comfortable on the bicycle, participants rested for two minutes followed by a five-minute warm up, where the participant was instructed to keep their revolutions per minute (RPM) between 50 and 60. The test began as the first resistance was added (0.5kg for women, 1.0kg for men) (Beam, 2019). Every two minutes, the same resistance was added, and research assistants recorded the participant's rate of perceived exertion. The test continued until volitional exhaustion occurred. Finally, participants pedaled resistance-free for at least three minutes to cool down.

Field Bicycle Measurement: Visits two and three consisted of a 60-minute steady state cycling test at Hampton Park (one-mile loop). One bike ride occurred on a regular pedal bicycle (29 inches wheel size, 45 pounds), and the second bike ride occurred on an electric-assist pedal bicycle (26 inches wheel size, 68 pounds, Lithium Ion 14Ah battery, 350 watt motor capacity, 17 mile per hour maximum); both bicycles were provided by the bike share company. About half of participants began with the regular bicycle, while the other half began with the e-bike; the order was randomly assigned. Participants also completed both of their tests at the same time of day (morning or afternoon), with two exceptions for scheduling conflicts. For both bike rides, participants were instructed to ride at a leisurely pace that was comfortable to them (Beam, 2019). To begin each field visit, the participant adjusted the bike seat height, put on a helmet, and secured a heart rate monitor strap on their chest. Heart rate was continuously monitored at 1-second intervals using a Polar H7 heart rate monitor paired to the Polar Beat app on a smartphone, which was mounted to the bicycle. Specific participant data (age, height, weight, sex, and age-predicted heart rate maximum) was input into the mobile app to individualize the output data. To imitate a bike ride that would occur on city streets and to mimic behavior at a stop sign or red signal, the participant was instructed to come to a stop every 15-minutes, pause, report their perceived exertion, and then start again. At the 60-minute mark (fourth stop), participants filled out a brief, 7-question survey about their bike ride.

Measures: Through the lab data collection procedures, measures of body composition and fitness were calculated. Body mass index (BMI) was calculated as body mass measured in kilograms divided by height measured in square meters. BMI values range from underweight (below 18.5), normal weight (18.5 to 24.9), overweight (25.0 to 29.9), and obese (30.0 and above). The bioelectrical impedance analyzer (BIA) allowed us to estimate body fat percentage, ranging from “very lean” to “very poor” depending on age and sex. Although BIA is an inexpensive and reliable tool to measure body fat percentage, some factors can affect BIA results (i.e., hydration status) causing a 4-8% margin of error (Medicine Libre Texts, 2019). Furthermore, the VO2max test measures one’s aerobic fitness and cardiorespiratory endurance, where larger values are associated with greater fitness (UC Davis Sports Medicine, 2020). Males typically have larger VO2max values than females since, on average, males have more muscle mass than females. For males aged 20-29, a “good” VO2max ranges from 36.5 to 42.4 ml/kg/min, whereas for females of the same age group, “good” ranges from 29.0 to 32.9 ml/kg/min.

Two key dependent variables, energy expenditure and perception of exertion, were collected during the field bicycle rides. Energy expenditure was measured as a percentage of maximal heart rate. This percentage was calculated as the average heart rate from the steady state bicycle ride (either regular or e-bike) divided by the individual’s maximum heart rate achieved in the VO2 max test. Perceived exertion was measured using the Borg scale; (Borg, 1982) this was used during the laboratory and field research visits. On the numeric scale of six to twenty, lesser values correspond with an easier workload (i.e., 6 as “very, very light,” 11 as “fairly light''), and greater values imply a more vigorous workload (i.e., 15 as “hard,” 19 as “very, very hard). Speed and distance were two additional measures captured by the heart rate monitor and GPS unit during the bicycle rides. Average speed was expressed in kilometers per hour and total distance was expressed in kilometers traveled. Acceleration was also calculated as speed divided by time. This was done using the polar H7 speed data over the 20 second interval a participant began biking after an instructed stop to when they reached a steady state speed again on the respective bike type.

Several perceptual measures were captured on the surveys during the field data collection. Six questions assessed the difficulty, enjoyment, safety, comfort, and tiredness (2 items) using a five-point Likert scale (1=strongly disagree to 5=strongly agree) (Langford, 2017). The final open-ended question asked participants to elaborate on how they felt physically during ride. After the fourth stop at the final visit (visit #3), an additional three questions were asked comparing the two bike types, including which bike type would be preferred during leisure use and which during transportation use.

4.3 Results: Research Objective 2

Data Analysis: Descriptive statistics were calculated to document the study sample characteristics (e.g., average body mass index). A paired t-test was used to examine whether there were differences between e-bikes and regular bikes for energy expenditure, speed, distance, and perceptual measures. A paired t-test was also used to examine differences in acceleration between each segment (i.e., segment 1 from regular bike compared to segment 1 from e-bike). All statistical analyses were completed using the IBM SPSS program, version 27. All significance was determined using a p-value of 0.05 and 95% confidence interval level.

Results: A total of 15 participants completed the study. Two-thirds of the sample were female while one-third was male. On average, participants were about 27 years of age with a body mass index of 23.2. A summary of participant characteristics are presented in Table 8.

TABLE 8. SUMMARY OF PARTICIPANT CHARACTERISTICS (N=15)

Participant Variable	Mean (SD), or Percentage
Male	33.3%
Female	66.6%
Age (years)	27.07 (6.42)
Body Mass Index	22.93 (3.25)
Body Fat %	20.06 (3.46)
VO2max (ml/kg/min)	36.35 (3.69)

Table 9 displays the differences in dependent variables between the regular bike and e-bike. On average, participants rode at significantly greater speed on the e-bike (mean=20.91km/h±1.09) compared to the regular bike (mean=14.63±2.05; p=0.000), and traveled a significantly further distance on the e-bike (mean=21.67km±1.68) than on the regular bike (mean=15.23±2.29; p=0.000) in the same time interval (60-minutes). Participants' energy exertion from their individually achieved maximal heart rate was significantly lower on the e-bike (mean=61.46%±11.24) compared to the regular bike (mean=69.59%±7.73; p=0.008), respectively. Perceived exertion (BORG) was, on average, greater on the regular bike (mean=11.95±1.88) than on the e-bike (mean=9.62±1.82, p=0.000). Participants reported significantly more difficulty and tiredness on the regular bike (mean=3.07.00±0.96, 3.73±0.70, respectively) compared to the e-bike ride (mean=2.00±0.85; p=0.000, 2.40±0.99; p=0.000, respectively). Participants also reported significantly greater enjoyment on the e-bike (mean=4.60±0.63) than the regular bike (mean=3.80+0.94; p=0.009). Participants reported no difference on safety and comfort between the e-bike and regular bike.

TABLE 9. PHYSICAL ACTIVITY/ENERGY EXPENDITURE AND PERCEPTIONS BETWEEN E-BIKE, REGULAR BIKE

	Electric assist pedal bike (e-bike) *Mean (SD)*	Regular bike *Mean (SD)*	Difference between e-bike and regular bike
Objective Measures			
Average Speed (kilometers per hr.)	20.91 (1.09)	14.63 (2.05)	6.27***
Distance (kilometers)	21.67 (1.68)	15.23 (2.29)	6.45***
Average Heart Rate (beats per minute)	112.53 (19.22)	128.13 (17.72)	-15.6**
% Heart Rate Max (from their VO2 test)	61.46 (11.24)	69.59 (7.73)	-8.13**
Perceptual Measures			
Rate of Perceived Exertion (Borg Scale)	9.62 (1.82)	11.95 (1.88)	2.33***
Difficulty^	2.00 (0.85)	3.07 (0.96)	1.07***
Tiredness^	2.40 (0.99)	3.73 (0.70)	1.33***
Enjoyment^	4.60 (0.63)	3.80 (0.94)	-0.8**
Safety & Comfort^	4.60 (0.63)	4.60 (0.51)	0.0
Commute Travel Preference (%)	93.3	6.7	-------
Recreational Travel Preference (%)	53.3	46.7	--------

*p<0.05, **p<0.01, ***p<0.001
^=Measured with a five-point Likert scale (1=strongly disagree to 5=strongly agree)

Table 10 summarizes descriptive data from participants' average segmental data for each 15-minute interval instructed stop. Percentage of heart rate maximum increased by 0.34% on the e-bike throughout the four 15-minute segments during the 1-hour ride, whereas the percentage of heart rate maximum increased 4.06% on the regular bike. Similarly, from segment 1 (first 15 minutes) to segment 4 (last 15 minutes), average RPE values increased by 3.07 and 1.93 on the regular bike and e-bike, respectively. Additionally, as participants began pedaling after each stop, acceleration was calculated and averaged among participants. E-bike accelerations were significantly faster than regular bike accelerations after Segment 2, Segment 3, and Segment 4 (mean=-0.07m/s^2±0.05; p=0.00, -0.09±0.05; p=0.00, -0.08±0.04; p=0.000, respectively). Figure 24 displays this acceleration relationship between regular bicycles and e-bikes, with significant differences for segments 2, 3, and 4.

TABLE 10. ENERGY EXPENDITURE, PERCEIVED EXERTION, AND ACCELERATION BETWEEN THE E-BIKE AND REGULAR BIKE BY 15-MINUTE SEGMENTS, N=15

	Segment 1	**Segment 2**	**Segment 3**	**Segment 4**
E-bike HR (bpm); *Mean (SD)*	112.5 (18.0)	114.4 (21.7)	112.3 (19.0)	113.4 (20.2)
Regular bike HR (bpm); *Mean (SD)*	125.6 (16.8)	129.9 (18.7)	130.1 (18.4)	133.4 (21.4)
E-bike (%HRmax); *Mean (SD)*	61.52 (11.15)	62.51 (12.30)	61.25 (10.63)	61.86 (11.14)
Regular bike (%HRmax); *Mean (SD)*	68.27 (7.60)	70.54 (8.25)	70.66 (8.23)	72.33 (9.15)
E-bike Rate of Perceived Exertion	8.40	9.47	10.27	10.33
Regular bike Rate of Perceived Exertion	10.40	11.73	12.20	13.47
E-bike Acceleration (m/s^2)	0.13	0.22	0.21	0.21
Regular Bike Acceleration (m/s^2)	0.09	0.15	0.13	0.14

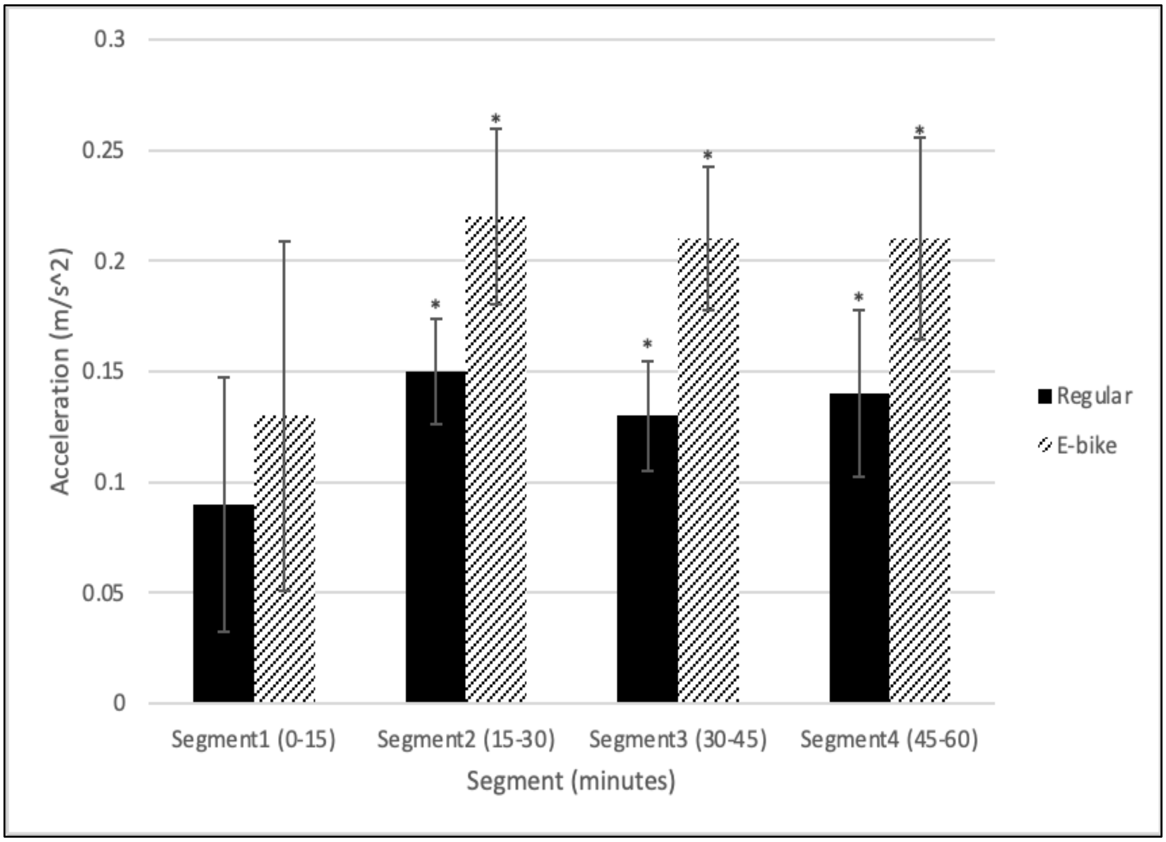

FIGURE 24: AVERAGE SEGMENT ACCELERATION CALCULATED AFTER INSTRUCTED STOPS (TO MIMIC THAT OF A STOP SIGN OR TRAFFIC LIGHT) FOR E-BIKE AND REGULAR BIKE-SHARE BICYCLES

4.4 Conclusion: Research Objective 2

Bike share systems have increased options for active recreation and transportation, with many programs now offering e-bikes. Previous literature suggests that e-bikes may be appealing to a broader population to promote bicycling, and physical activity and energy expenditure can be one of the potential health benefits of e-bike use (Fishman, 2016). This study compared regular bikes and e-bikes, with specific investigation in differences for energy expenditure, trip characteristics (i.e., speed, distance), acceleration, and perceptual differences. Results indicated participants expended lower quantities of energy, as a percentage of relative maximum heart rate, while also reporting higher levels of enjoyment and lower levels of difficulty, perhaps due to the increased speed and acceleration experienced on the e-bikes. Participants reported preference for e-bikes when commuting from one place to another, suggesting that this mode has potential to increase active transportation patterns.

As hypothesized, the regular bike share bicycles resulted in higher energy expenditure compared to the e-bike share bicycles. For the regular bike ride, participants averaged about 70% (±6.17%) of their maximal heart rate, while on e-bikes, participants averaged about 62% (±0.54%) of their maximal heart rate (as determined by the fitness test conducted in the laboratory). A difference in energy expenditure was hypothesized given the motor assist that engaged while bicyclists pedal the e-bike; however, the exact difference had not been quantified for a steady state ride. Despite a 13.1 percent change in energy expenditure between the regular bike and e-bike share bicycles, both bicycle rides were classified as moderate intensity based on the average percentage of heart rate maximum between 50-70% (American heart Association, 2022). The moderate intensity physical activity for e-bikes is similar to previous studies that used controlled trial parameters testing the differences between regular bicycles and e-bikes (Langford, 2017; Bernsten, 2017; Sundør and Fyhri, 2017). For example, Berntsen and colleagues had 8 participants complete a regular and e-bike ride for both a flat and hilly course; results indicated that across both bike modes, most time (92-99%) was spent in at least moderate intensity physical activity (Bernsten, 2017). Given that the majority of adults do not meet physical activity recommendations of at least 150 minutes of moderate intensity physical activity, (U.S. Department of Health and Human Servies, 2016). approaches that are enjoyable and can be integrated into daily routines are recommended (Sommar, 2021). Therefore, incorporating e-bikes into bike share programs is one way to encourage active commute and recreation travel while offering physical activity and health benefits with an engaging and assistive motor.

On this 60-minute, steady state bike ride, participants on the e-bike rode at a significantly greater speed (6.27 kph faster) and traveled a greater distance (6.45 km further) compared to the regular bike rides. At least one other study also found that e-bikes completed a predetermined route faster than on a regular bicycle; (Langford, 2017) however, no studies had tested differences in distance traveled throughout a 1-hour steady state ride. This may be an encouraging factor specific to active transportation since individuals are often seeking to travel directly to their destination as directly and quickly as possible (Bernsten, 2017). However, when considering the implications of less energy expenditure for e-bike rides, the original mode of transportation and regular activity patterns must be measured in future studies (Bauman, 2017). For example, if an individual changes mode from regular bicycle ride for commuting to an e-bike ride, and no other behaviors change, this will likely result in a net reduction in energy expenditure. Alternatively, if an individual changes their trip from a single occupancy vehicle, there would be net positive energy expenditure and physical activity benefits. As bike share companies move towards e-bike usage, researchers should consider whether this mode ultimately results in a greater proportion of active transportation users or whether current users are replacing their mode (Bauman, 2017).

Compared to a regular bicycle trip, e-bikes may facilitate a more convenient trip for those considering active transportation or recreation. In addition to greater speed and distance completed on the e-bike compared to the regular bike, participants accelerated significantly faster on the e-bike than on the regular bicycle, and reported more ease overall (lower rate of perceived exertion, lower Likert scale response for difficulty and tiredness, and higher rate of enjoyment). Combined with data that shows that participants' percentage of their heart rate max increased more on the regular bike (4.06%) than for the e-bike (0.34%) from segment 1 (first 15 minutes) to segment 4 (last 15 minutes), multiple study findings support an overall greater ease on the e-bike trip compared to the regular bike trip. Previous literature has also indicated perceptual differences, with lower difficulty reported for the e-bike (Langford, 2017; Ling, 2017; Torrisi, 2021). For inner-city bicycle travel, stop signs and traffic signals create inevitable stops along routes, causing the need to accelerate. This acceleration difference is important to riders for commuting purposes as the goal is to get from one place to another quickly and efficiently. This implies e-bikes would be favorable for commute travel purposes, which the majority of participants (93%) reported preferring the e-bike for recreation, compared to about 50% that reported preferring the e-bike for recreation or exercise (Ling, 2017; Lopez, 2017). Since e-bikes can provide moderate-intensity physical activity with high levels of enjoyment, promoting the usage of e-bikes has promise for a successful community health approach for active living.

While this study confirmed similar findings from previous literature using a different bicycle route in the methodology, future research should seek to further strengthen e-bike and physical activity research. This study was conducted with 15 healthy individuals that had not been diagnosed with any chronic health conditions, which is a small sample that does not reflect complexities of larger populations. To understand whether these findings focused on energy expenditure differences are generalizable, future research should expand participants characteristics to include a broader age and health status. Additionally, future research could expand to include different variables of interest, potentially integrating data from bike share companies to observe actual user populations (i.e., commuters, tourists, students). Key indicators of interest include how often they are using the bike share program and how the bike share contributes to their overall physical activity patterns (Bauman, 2017). Researchers can partner with bike share companies to potentially identify regular bike share users from which they can glean more in-depth data and patterns related to utilization of the program. This would assist in gathering information for more real-world bike share trips. Like other studies, participants were in a fairly controlled environment via a bike-lane around a large park where traffic volume is low and when present, at low speeds. This is likely not to be the type of infrastructure that bike share users in many cities will experience when trying to get to different destinations within a city. Therefore, it is important to gather more realistic data on perceptions of safety and riding in city streets to understand the viability for this type of community intervention for physical activity.

5.0 CONCLUSION

Bike share, e-bike, and e-scooter share micro-mobility systems were evaluated using comparable GPS tracks and GIS analysis techniques with respect to trip making, operation, and user characteristics, and assessed for potential to accommodate demand of short distance (3-miles, or less) urban trips. Differences in energy expenditure, perceptions of difficulty, and acceleration between regular bikes and e-bikes in a bike share system were evaluated through participant bicycle and e-bike rides while monitoring heart rate and speed to evaluate beneficial levels of physical activity and public health outcomes. Conclusions regarding both primary research objectives are summarized in the following sections

5.1 Conclusion: Research Objective 1

GPS tracking was used to evaluate MaaS travel modes and examine differences between bike share systems, e-pedal-assist bike share, and e-scooters by analyzing trip characteristics, transportation network conditions, and traffic operations. GPS data of e-bike and e-scooter trips in Birmingham and Mobile, Alabama, from Gotcha Powered by Bolt was evaluated. Transportation network characteristics were collected in Mobile and Birmingham, providing base map for analysis. ArcGIS Pro and ModelBuilder were used to examine route conditions including posted speed limits, bike lanes, and traffic counts determined a Level of Traffic Stress (LTS) measuring comfort level experienced by users along the roadway network.

Using ArcGIS Pro and ModelBuilder to examine routes for e-bike and e-scooter trips in Birmingham and Mobile, Alabama for trip characteristics and Level of Traffic Stress (LTS) ratings, findings from this research are summarized as follows:

1. E-Bike share and E-Scooter share MaaS micromobility systems operated in Birmingham and Mobile, AL, were determined to remove short trip travel demand (3-miles, or less) from traditional network travel modes, commonly single occupancy automobiles (although other possible modes include walking and public transit) totaling:

Birmingham	7,347-trips	7,583-miles (July-Dec. 2021)
Mobile	41,997-trips	28,646-miles (July-Dec. 2021)

2. E-Bike share and E-Scooter share MaaS micromobility systems operated in Birmingham and Mobile, AL, were determined to help meet short distance travel demand, based on the following combined trip distance distribution:

45% of trips	less than 0.5 miles
48% of trips	0.5-2.0 miles
7% of trips	over 2.0 miles

3. E-Bike share and E-Scooter share MaaS micromobility systems operated in Birmingham and Mobile, AL, were determined to exhibit the following range of moderate to high stress Level of Traffic Stress (LTS) ratings:

Birmingham	83% of trips on Level of Stress (LTS) 3-4 roads
Mobile	20% of trips on Level of Stress (LTS) 3-4 roads

It should be noted the percentage of moderate to high stress ratings are much higher for Birmingham, AL, which is likely related to the downtown, central business district, transportation network being primarily comprised of higher volume and higher speed roadways, which cannot be avoided in using the E-Bike share and E-Scooter share Maas micro mobility systems. Furthermore a large railyard extends east-west through the CBD between the commercial districts and University of Alabama, Birmingham campus, where connection between these adjacent areas is provided by a limited number of viaducts that are aligned with higher volume and higher speed roadways.

4. E-Bike share and E-Scooter share MaaS micromobility systems operated in Birmingham and Mobile, AL, were determined to exhibit the following range of average trip distances in miles :

Birmingham	E-bikes, 0.93 mi. (n=1,305)	E-Scooter, 1.05-mi. (n=6,042)
Mobile	E-bikes, 0.79 mi. (n=995)	E-Scooter, 0.68-mi. (n=41,002)

5. Lessons and insights from case study location comparisons include:
    - For Birmingham MaaS system, a much larger demand for e-scooters was evident with e-scooters comprising 82 percent of total trips during 6-month period.
    - For Mobile MaaS system, a much larger demand for e-scooters was evident with e-scooters comprising 98 percent of total trips during 6-month period.
    - Number of MaaS trips can produce surprising totals, 41,997 trips in Mobile during a 6-month period.
    - E-bike MaaS system users experience difficulty avoiding busy roadways in downtown areas with a combined 38 percent of trips occurring on major or principal function class roads in Birmingham over 6-month period.
    - E-scooter MaaS system users experience difficulty avoiding busy roadways in downtown with a combined 76 percent of trips occurring on major or principal function class roads in Birmingham over 6-month period.

5.2 Conclusion: Research Objective 2

Differences in energy expenditure, perceptions of difficulty, and acceleration between regular bikes and e-bikes in a bike share system were evaluated. Initially, participants (n=15) underwent a bicycle maximal fitness test, and body composition was assessed. Two-hour steady-state bicycle rides were conducted at a local park, once on a regular bike and once on an e-bike. Continuous measurements of heart rate and speed were recorded with a heart rate monitor during each ride. Participants reported perceived exertion at four intervals within each ride, along with perceived enjoyment, difficulty, and tiredness at the ride's conclusion. e-bike share rides resulted in lower energy expenditure than regular bike share rides, both falling into the moderate-intensity physical activity category, contributing to meeting national physical activity guidelines. E-bikes in bike share systems may be appealing for integrating physical activity into daily routines due to reported lower difficulty and increased enjoyment.

Using user data and perceptions collected from lab and field measurements, findings from this research are summarized as follows:

1. Paired t-tests revealed that study participants exerted more energy at a greater percentage of their maximum heart rate on the regular bike (mean=69.6%) compared to the e-bike (mean=61.5%, p=0.006) during test rides.
2. Study participant test rides on E-Bikes provided 87% heart rate intensity vs. traditional bikes (n=15), with both equating to a moderate-intensity physical activity category, contributing towards users meeting adopted national physical activity guidelines.
3. Study participant test rides on E-bikes traveled 6.3 km/h (43%) faster than bikes for 60-min (level terrain)
4. Study participant test rides on E-bikes traveled 6.4 km (42%) further than bikes, for 60-min (level terrain)
5. Study participants rated riding enjoyment as higher on the e-bike (mean=4.6) than the regular bike (mean=3.8; p=0.009; 5-point Likert scale).
6. Study participants preferred E-Bikes 93.7% vs. traditional bikes

Overall, as bike share companies introduce e-bikes, users can travel faster, further, with less energy expenditure, and with less perceived difficulty than regular bicycles. E-bikes may be more preferable for commute travel than regular bikes, whereas the active population may still prefer conventional bikes for recreation travel (i.e., leisure or physical activity). This study provides supportive evidence for advocating for increased promotion of bike share systems, including the integration of e-bikes with regular bicycles.

5.3 Broader Impacts of Research

Broader impacts of collecting this data, preforming research analysis and identifying findings are summarized in the following lists of short-term and long-term impacts.

Short-Term Impacts

- **Increased Awareness:** Research findings will serve to raise awareness regarding the potential of individual ridesharing Mobility as a Service (MaaS) micromobility options, especially the potential benefits of bike, e-bike, and e-scooter share systems for short-distance urban travel, 3-miles or less.
- **Policy Considerations:** Data collected and analyzed can serve to inform adoption of local transportation policies and decision-making criteria, as results are informative to city authorities, who are charged with implementing changes in infrastructure or regulations to better accommodate micro-mobility systems and enhance the overall transportation network efficiency and sustainability.

Long-Term Impacts

- **Transportation Infrastructure Improvement/Development:** Research methods, conclusions and findings serve to quantify Mobility as a Service (MaaS) micromobility system operation metrics useful in long-term transportation infrastructure planning and land use zoning initiatives. Municipal, regional, and state governments require data derived insights for decision making in developing and enhancing bicycle lanes, sidewalk infrastructure, and overall traffic operations, for the purpose of creating more supportive environments for supporting and implementing successful micromobility systems.
- **Policy Revisions:** Research methods, conclusions and findings provide useful input for adoption of forward learning and equitable urban transportation policies. Regulatory frameworks are expected to evolve to better integrate MaaS options into urban planning, considering factors such as traffic stress, user preferences and network improvements to provide the traveling public with viable mobility options for urban areas.
- **Public Health Benefits:** A better understanding of physical activity benefits of bike share and e-bike share use provides useful comparisons for quantifying larger scale public health benefits. The integration of MaaS micromobility system options into daily routines contributes to sustained physical activity levels, leading to improved overarching public health outcomes.
- **Societal Shifts**: Adoption of bike, e-bikes and other MaaS micromobility system options provides the traveling public with more sustainable, environmentally friendly travel choices, this can server to inform broader societal shift towards embracing more active transportation, efficient urban mobility, and livable communities; with beneficial implications on equitable mobility, positive urban culture, healthier lifestyles, energy consumption, and environmental awareness.

6.0 RECOMMENDATIONS

Through completion of this project, collaboration with stakeholders, coordination with other intuitions, collection of mobility data, application of research methodologies, and identification of conclusions, the following findings and recommendations were identified:

- Expansive growth is occurring in Mobility as a Service (Maas) micromobility travel modes including: 1.) bike share systems; 2.) electric-powered pedal-assist bikes (e-bikes); and 3.) electric powered scooters (e-scooters). All of these services provide potential to accommodate short distance trips (3-mile, or less) to meet urban travel demand.
- Benefits of MaaS microbobility systems when used to displace short distance trips by single occupancy automobile include: 1.) less air pollution, 2.) less fossil fuel consumption, 3.) greater sustainability, 4.) reduced parking demand, 5.) better use of network capacity, 6.) traffic congestion mitigation, 7.) increased physical activity, 8.) improved public health outcomes.
- The use of GPS route tracking and GIS aggregation of MaaS micro mobility travel modes provides a useful means to evaluate 1.) potential of MaaS modes to accommodate short distance trips; 2.) insight into MaaS travel mode differences; 3.) identification of needed transportation network compatibility through application of rating criteria such as Level of Traffic Stress (LTS) roadway evaluation methodologies.
- Physical activity (PA) is important for human well-being, cardiovascular fitness, and mental health. A standard for measuring has been established by U.S. National Physical Activity Guidelines who recommend 150-300 min. of moderate aerobic physical activity/week, yet over half adults do not meet. Lack of physical activity is a growing concern as health care costs rise and general American well-being declines. Replacing short distance automobile trips with active travel modes is a key approach to promote increased periodic physical activity (PA) and improve overall public health outcomes.
- Commuting by bicycle, bike share, or e-bike share increases physical activity for users and is associated with cardiovascular risk factor prevention.
- Use of E-bike share systems broaden potential user populations to include older, less physically fit, and/or less able-bodied individuals. E-bikes share systems are easier to use, however are physically engaging, and provide cardiovascular health benefits.
- Use of E-bikes require more frequent and longer rides to provide comparable health benefits as conventional bicycles, however, substituting sedentary travel modes, with E-bikes use will result in positive physical activity (PA) and public health outcomes.
- Through examination of E-Bike share and E-Scooter share MaaS micromobility systems operated in Birmingham and Mobile, AL, research findings served to improve understanding of the role of micro-mobility systems and potential for better accommodating evolving MaaS travel options.

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8.0 APPENDICES

8.1 Appendix A – Acronyms, abbreviations, etc.

AASHTO	American Association of State Highway and Transportation Officials
ALbD	Active Living by Design
APHA	American Public Health Association
ArcGIS	Mapping and Analytics Software and Services
BIA	Bioelectrical Impedance Analyzer
BMI	Boddy Mass Index
CDC	Centers for Disease Control and Prevention
FHWA	Federal highway Administration
GIS	Geographic Information System
GPS	Global Positioning System
HIA	Health Impact Assessment
HR	Heart Rate
ITE	Institute of Transportation Engineers
Likert	psychometric scale used in multiple choice surveys and questionnaires
LTS	Level of Traffic Stress
LTS1	Level of Traffic Stress, Level 1, very low stress
LTS2	Level of Traffic Stress, Level 2, low stress
LTS3	Level of Traffic Stress, Level 3, moderate stress
LTS4	Level of Traffic Stress, Level 4, high stress
MAAS	Mobility as a Service
MET	Metabolic Equivalent of Task
MPH	Masters of Public Health
MSA	Mean Statistical Area
NCI	National Cancer Institute
NACTO	National Association of City Transportation Officials
NHTS	National Household Travel Survey
NIH	National Institutes of Health
NIEHS	National Institute of Environmental Health Sciences
PA	Physical Activity
PBIC	Pedestrian & Bicycle Information Center
SD	Standard Deviation
SPSS	Statistical Package for the Social Sciences
STRIDE	Southeast Transportation Research, Innovation, Development & Education
USDOT	United States Department of Transportation
UTC	University Transportation Center
V02max	Maximal Oxygen Consumption
WHO	World Health Organization

8.2 Appendix B – Summary of Accomplishments

Date	Type of Accomplishment	Detailed Description
9/21/2022	Other	A webinar with title "Transportation Infrastructure, Safety, and Travel Route Characteristics of Bike Share, e-Pedal-Assist Bike Share, and e-Scooter System Operation" was offered on September 21, 2022 by William J. Davis and Kweku Brown from The Citadel. Forty-eight professionals attended the webinar live. The webinar is now available at YouTube at: https://www.youtube.com/watch?v=0bu53qJ8QuQ The YouTube video had 65 views as of Sept. 12, 2023.
12/29/2022	Publication	Hughey, S.M., Sella, J., Adams, J.D., Porto, S.C., Bornstein, D., Brown, K., Amahrir, S., Michalaka, D., Watkins, K., Davis, J. (in press) It's Electric! Measuring Energy Expenditure and Perceptual Differences Between Bicycles and Electric-assist Bicycles. Journal of Transport & Health. https://www.sciencedirect.com/science/article/abs/pii/S2214140522001955?via%3Dihub
5/29/2023	Conference Presentation	Michalaka, D. (Presenter), Davis, W. J., Brown, K. , Watkins, K., Hughey, M., 9th Annual International Conference on Transportation, "Evaluation of Transportation Network Infrastructure, Safety, and Travel Route Characteristics of Bike Share, Electric-Powered Pedal-Assist Bike Share, and Electric Scooter System Operation," ATINER, 9 Chalkokondili Street, 10677 Athens, Greece, Athens, Greece.