Exploring Micromobility Services in Florida

Final Report

FDOT Contract No: BED33-977-01

Prepared for:

Research Center
Florida Department of Transportation
605 Suwannee Street, MS 30
Tallahassee, FL 32399

Prepared by:

University of North Florida
School of Engineering
1 UNF Drive
Jacksonville, FL 32224

Florida International University
Dept. of Civil & Environmental Eng.
10555 West Flagler Street, EC 3628
Miami, FL 33174

Project Manager: Jeffery Frost

June 2024

DISCLAIMER

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

METRIC CONVERSION TABLE

U.S. UNITS TO SI* (MODERN METRIC) UNITS

LENGTH

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
in	inches	25.400	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.610	kilometers	km
mm	millimeters	0.039	inches	in
m	meters	3.280	feet	ft
m	meters	1.090	yards	yd
km	kilometers	0.621	miles	mi

AREA

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
in^2	square inches	645.200	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.590	square kilometers	km^2
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.470	acres	ac
km^2	square kilometers	0.386	square miles	mi^2

VOLUME

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
fl oz	fluid ounces	29.570	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3

NOTE: volumes greater than 1,000 L shall be shown in m^3.

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Exploring Micromobility Services in Florida	5. Report Date June 2024 6. Performing Organization Code
7. Author(s) Thobias Sando, Ph.D., P.E., PTOE, Priyanka Alluri, Ph.D., P.E., RSP$_{2BI}$, Enock Mwambeleko, Kabhabhela C. Bukuru, and Abdallah Kinero.	8. Performing Organization Report No.
9. Performing Organization Name and Address University of North Florida School of Engineering 1 UNF Drive Jacksonville, FL 32224	10. Work Unit No. (TRAIS) 11. Contract or Grant No. BED33-977-01
12. Sponsoring Agency Name and Address Florida Department of Transportation Research Center 605 Suwannee Street, MS 30, Tallahassee, FL 32399	13. Type of Report and Period Covered Final Report April 2022 – June 2024 2. Government Accession No.
15. Supplementary Notes FDOT Project Manager: Jeffery Frost	

16. Abstract

The Florida Department of Transportation (FDOT), through its Connected and Automated Vehicle (CAV) Program, has expanded the agency's CAV initiatives to include electric and shared-use vehicles. Micromobility devices include motorized scooters (e-scooters) and electric bicycles (e-bikes) having no more than three wheels and capable of travel speeds no greater than 20 mph. This research analyzed the safety and mobility of micromobility systems in Florida. Analyses included survey questionnaires distributed to agencies and users in Florida. The state-of-the-practice of micromobility systems was also examined. Existing guidelines and processes adopted by agencies throughout the U.S. that have deployed micromobility systems were reviewed, and local agencies in Florida currently operating micromobility services were surveyed. Micromobility-related crash data were collected at 12 Florida cities, yielding a total of 463 crashes involving micromobility devices between December 2018 and June 2022. The majority of fatal and incapacitating injuries occurred at or within 50 ft of an intersection (46.5%), along a roadway segment (46.5%), during daylight hours (65.1%), in clear weather conditions (83.7%), on a Friday (30.2%), during the months of February (14%) and August (14%), involved users between the ages of 20 and 39 (46.5%), not wearing safety equipment (76.7%), and not impaired by alcohol (79.1%). Florida-specific crash modification factors (CMFs) were developed for roadway segments and signalized intersections. Safety and mobility guidelines and recommendations were presented for deploying shared micromobility systems, as well as suggested recommendations for the automobile original equipment manufacturers (AOEMs) of e-scooters and e-bikes in enhancing the overall quality and safety of micromobility products.

In addition to this research, the safety and mobility of golf carts (GCs) were analyzed using data gathered from several Florida GC communities. The findings from this study could help develop countermeasures for improving the safety of micromobility and golf cart users.

17. Key Words	18. Distribution Statement
Micromobility, golf carts, deployment guidelines, crash modification factors	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	210	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized.

ACKNOWLEDGMENTS

This research was funded by the Research Center of the Florida Department of Transportation (FDOT). The authors thank project manager Mr. Jeffery Frost and the General Engineering Consultants team, including Mr. Rupender Dahiya and W. D. Baldwin, for their guidance and support. Special thanks to Raj Ponnaluri, Ph.D., P.E., PTOE, PMP, for conceiving the research idea and providing leadership throughout the study and to Edith Wong, P.E., for her guidance during various project phases.

EXECUTIVE SUMMARY

The use of micromobility devices, such as e-scooters and e-bikes, are gaining in popularity nationwide and in Florida. The Florida Department of Transportation (FDOT), through its Connected and Automated Vehicle (CAV) Program, has expanded the agency's CAV initiatives to include electric and shared-use vehicles, leading to the term ACES (*Automated, Connected, Electric, and Shared-use* vehicles).

A micromobility device is any motorized transportation device made available for private use by reservation through an online application, website, or software for point-to-point trips and which is not capable of traveling at speeds greater than 20 miles per hour on level ground. This term includes motorized scooters and electric bicycles having no more than three wheels. At least 13 agencies in Florida have deployed micromobility systems in their jurisdiction, and 16 shared micromobility systems are currently operational through public-private partnerships. Several other deployments are currently in the planning phase.

The goal of this research was to examine micromobility systems currently operating in Florida to develop resources to assist agencies in considering the deployment of shared micromobility systems. Although not considered to be micromobility, the safety and mobility of golf carts (GCs) were also examined and included in this report as an addendum to this research.

State-of-the-Practice of Micromobility Systems

A synthesis of the state-of-the-practice of micromobility systems was performed through a literature review of existing guidelines and processes adopted by agencies throughout the U.S. Findings revealed that approaches in the regulation of micromobility services vary among states, with shared micromobility systems commonly regulated at the local level, using state laws as a road map. for enacting operational, infrastructure, and technology requirements, fee structure, data management requirements, and equity and public engagement regulations.

A survey questionnaire was also administered to local agencies in Florida currently operating micromobility services to assess the current state-of-the-practice across the five stages of the engineering process (i.e., Inception, Procurement, Design, Deployment, and Operation) for implementing micromobility services.

Safety Analysis of Micromobility Systems

A safety analysis of micromobility systems deployed in Florida was conducted on micromobility-related crashes occurring between December 2018 and June 2022. The data collection process resulted in a total of 463 crashes confirmed to involve micromobility devices. Resulting injuries from micromobility-related crashes included: fatal and severe injury (9.3%), minor injury (34.8%), possible injury (33.7%), property damage only (PDO) (22.2%).

A crash severity analysis was conducted to identify the factors influencing the injury severity of micromobility-related crashes, based on the KABCO scale. Two categories were analyzed: KAB (fatal, incapacitating, and non-incapacitating) and CO (possible and PDO). Factors found to increase the likelihood of KAB injury severity include: sidewalk width (< 5 ft), curbed shoulders, at-fault motorists, dark lighting conditions, and three or more travel lanes. Factors found to reduce the likelihood of KAB injury severity include: Annual Average Daily Traffic (AADT) (< 8,000 vehicles per day), rainy weather conditions, shoulder width (< 6 ft), divided roadways, vehicle maneuver (turning left or right), and roadways without bike lanes.

Crash Modification Factors (CMFs)

Crash modification factors (CMFs) were developed for micromobility-related crashes in Florida for both roadway segments and signalized intersections. The CMFs were developed based on data from Miami Beach and Miami Downtown regions, both of which have defined service areas for shared micromobility services. A cross-sectional analysis was used to develop the CMFs.

Mobility Analysis of Micromobility Systems

A mobility analysis of micromobility systems deployed in Gainesville, Florida, was conducted to evaluate the travel time of three modes of transport (i.e., micromobility devices, private car, and transit) used in the areas around the University of Florida (UF) campus to quantify the mobility benefits associated with choosing micromobility as the preferred mode of transportation for students and other campus users. A survey was also conducted to gain more information on the user experience of micromobility devices in Florida.

A comparative analysis of travel times was performed across the three transportation modes using a common origin-destination (O-D) route on the UF campus. Results showed that the average travel times for micromobility, private cars, and transit were 14.2 minutes, 21.3 minutes, and 25.2 minutes, respectively, revealing the travel time benefits of using micromobility devices around campus. A travel time reliability analysis also indicated micromobility as the most reliable mode of transportation, with a buffer index (BI) of 12.0%.

Micromobility Guidelines and Recommendations

Guidelines for deploying shared micromobility systems in Florida were developed and suggested safety improvements for e-scooters and e-bikes were recommended. Recommendations for the automobile original equipment manufacturers of e-scooters and e-bikes were also suggested.

Golf Carts in Florida

The safety and mobility of golf carts (GCs) were explored. A survey questionnaire was also administered to GC users in the Nocatee community in Jacksonville, in Miami around the Brightline station, and in The Villages community. The safety analysis concentrated on GC crashes reported at The Villages from January 2018 to February 2023. Several factors were significant in the injury severity of GC crashes. Divided roadways, the presence of traffic control devices, and paved shoulders were found to mitigate severity and fatality rates in GC crashes.

The mobility study was conducted in Jacksonville, in the Nocatee community, where GCs are used as the primary mode of transport. The study concentrated on the area around the Pine Island Academy, where children are dropped off and picked up from school using GCs. The analysis of relative delay, travel times, and queue delay revealed significant advantages for using GCs as an alternative mode of transportation in a school zone.

Shared micromobility can revolutionize the conventional project development process, and improve connectivity to other transportation modes, potentially leading to a modal shift to environmentally friendly and efficient means of transportation for urban areas. Guidance on deploying these systems and the operational and safety performance metrics developed from this research can assist Florida agencies in the deployment evaluation process.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS and ABBREVIATIONS

AADT	Annual Average Daily Traffic
ACES	Automated, Connected, Electric, and Shared
ADA	Americans with Disabilities Act
ANOVA	Analysis of Variance
API	Application Programming Interface
ATV	All-Terrain Vehicle
BCI	Bayesian Credible Interval
BI	Buffer Index
BLR	Bayesian Logistic Regression
CAV	Connected and Automated Vehicles
CBD	Central Business District
CI	Confidence Interval
CMF	Crash Modification Factor
CRF	Crash Reduction Factor
DOT	Department of Transportation
DUI	Driving under the Influence
DV	Dynamic Vision
DVS	Dynamic Vision Sensor
FARS	Fatality Analysis Reporting System
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
GEH	Geoffrey E. Havers
GC	Golf Cart
GPS	Global Positioning System
HRI	Honda Research Institute
IRB	Institute of Review Board
ITT	Invitation to Tender
LSV	Low-Speed Vehicle
MLE	Maximum Likelihood Estimation
MMD	Micromobility Device
mph	Miles per Hour
NACTO	National Association of City Transportation Officials
NHTSA	National Highway Traffic Safety Administration
NM	Non-Motorist
O-D	Origin-Destination
OCR	Optical Characteristics Recognition
OLR	Ordinal Logistic Regression
PBCAT	Pedestrian and Bicycle Crash Analysis Tool
PDO	Property Damage Only
POA	The Villages Property Owners' Association
RCI	Roadway Characteristics Inventory
RFA	Request for Application
RFP	Request for Proposal

RFQ	Request for Quotation
SI	Severe Injury
vph	Vehicle per Hour
VPSD	The Villages Public Safety Department
VRU	Vulnerable Road User

CHAPTER 1
INTRODUCTION

Transportation agencies in the United States (U.S.) are responsible for providing a transportation system that guarantees both the mobility of people and goods and the safety of users (Federal Highway Administration [FHWA], 2014). Recently, cities have been deploying micromobility systems in an attempt to tackle some of the urban transportation-related problems, such as traffic congestion (FHWA, 2014), air pollution (Arter et al., 2021), low public transportation ridership (Campbell & Brakewood, 2017), first- and last-mile problem (Oeschger et al., 2020), problems resulting from private car use (Bieliński & Ważna, 2020), and traffic safety issues (Turoń & Sierpiński, 2018). Shared micromobility systems may offer a means to minimize some of these transportation-related problems.

Florida Department of Transportation (FDOT), through its Connected and Automated Vehicle (CAV) Program, has deployed some of the most innovative emerging technology applications in the country. The CAV program aims at achieving the safety and mobility goals by collaborating with the industry, communicating on the policy objectives, coordinating for effective service delivery, and consulting while developing programmatic frameworks. Recently, FDOT's CAV initiatives have been expanded to include electric and shared-use vehicles, leading to the term ACES, which stands for *Automated, Connected, Electric, and Shared-use* vehicles. Shared micromobility, one of the rapidly growing emerging transportation strategies, involves shared-use electric vehicles and is considered part of ACES.

Micromobility devices are defined as motorized transportation devices designed to travel at speeds typically less than 30 miles per hour (mph) on level ground (Price et al., 2021). In Florida, the design speed for such devices is limited to 20 mph (Florida Statutes, 2023a). These devices are made available for private use by reservation through an online application, website, or software for point-to-point trips (Florida Statutes, 2023a). Micromobility devices include electric bikes (e-bikes), electric scooters (e-scooters), shared bicycles, and electric pedal-assisted bicycles. These devices can be owned and operated privately or as part of a shared system. As a result of FDOT's ACES initiative, shared micromobility has become a rapidly growing transportation strategy adopted by several agencies across the state. Figure 1.1 shows examples of shared micromobility devices.

Figure 1.1: Shared Micromobility Devices
(Source: Ross, 2021)

In general, there are two types of micromobility services:

- Docked, where electric scooters (e-scooters) and electric assist bicycles are rented and returned to a station. Stations typically allow payment and charging of the devices, reducing the need for repositioning and collection for overnight charging.

- Dockless, where micromobility service can be initiated and completed anywhere within a pre-defined zone. Dockless devices must be frequently collected for charging and repositioning and typically requires users to have a pre-installed smartphone application to reserve a device.

In Florida, at least 13 agencies have deployed micromobility systems in their jurisdiction. Most of these systems were launched as pilot programs since there were no established guidelines for deploying micromobility systems. Table 1.1 presents the list of micromobility systems in Florida. Florida Statute 316.008 gives the local government the authority to govern the operation of micromobility services in their jurisdiction (Florida Statutes, 2023b). In most cities, vendors have to apply for permits to operate. Vendors operating in Florida include Razor, Helbiz, Lime, Spin, DECO Bike LLC, Bird, Wheels, VeoRide, Spin, and HOPR Bike.

Table 1.1: Micromobility Programs in Florida

City/County	Micromobility Program	Vendors
Tallahassee	Shared Micromobility Program	Spin, VeoRide
Orlando	Bike Share / Scooter Share Program	Spin, Lime, Bird, Wheels, Razor, Helbiz
Gainesville	Micromobility Program	Bird, Spin, Veo
Jacksonville	Dockless Mobility Program / Electric Scooter Program	Bird, Lime
Pensacola	Shared Micromobility Program	VEO
St. Augustine	E-Bikeshare Program	Bolt
St. Petersburg	Coast Bike Share Program, Scooter Share Program	Razor, VeoRide
Tampa	Shared Micromobility Program	HOPR, Bird, Lime, Spin
Fort Pierce	E-scooter Share Program	Spin
Sarasota	Scooter and Bike Share Program	VeoRide
Punta Gorda	Free Bicycle Loaner Program	Team Punta Gorda
Broward County	Broward B-Cycle	Trek Bicycle
Miami Beach and Downtown Miami	Citi Bike Program	DECO Bike LLC

The primary goal of this research was to establish mobility and safety performance metrics to assist FDOT and other local agencies in evaluating shared micromobility systems and developing guidelines for deploying shared micromobility systems in Florida. To achieve the objectives, the state-of-the-practice of micromobility systems was examined, the safety and mobility of micromobility devices were explored, and user and agency surveys were administered. Additional study was conducted on golf carts operated in Florida, to examine the safety and mobility aspects of using this type of low-speed vehicle.

This report is organized as follows:

- Chapter 1 provides an introduction to micromobility devices and discusses the research objectives.
- Chapter 2 presents a synthesis of the state-of-the-practice of micromobility systems.
- Chapter 3 discusses the state-of-the-practice survey distributed to agencies/cities in Florida.
- Chapter 4 discusses the analysis of micromobility-related crashes in Florida.
- Chapter 5 discusses crash modification factors (CMFs) for micromobility-related crashes.
- Chapter 6 discusses the mobility benefits of micromobility systems.
- Chapter 7 presents guidelines and recommendations for micromobility systems.
- Chapter 8 discusses the safety aspects of golf carts operated in Florida.
- Chapter 9 discusses the mobility benefits of golf carts operated in Florida.
- Chapter 10 presents the conclusions from this research effort.

CHAPTER 2
STATE-OF-THE-PRACTICE

This chapter presents the state-of-the-practice of micromobility systems. Existing guidelines and processes for deploying micromobility services, from various agencies in the U.S., are presented. Mobility and safety characteristics of micromobility systems are also discussed.

2.1 Existing Guidelines

Shared micromobility services are increasingly being adopted by numerous cities in the U.S. Bai and Jiao (2020) noted that there had been a significant increase in the use of micromobility as a mode of transportation in U.S. cities. The rapid growth in shared micromobility usage has compelled cities to reevaluate their regulatory approaches aiming to optimize the public benefits stemming from these services.

States have adopted different approaches in the regulation of micromobility services. In most states, shared micromobility systems are regulated at the local level, with the states enacting laws that provide the road map for the local agencies enacting their own regulations. Guidelines regulating shared micromobility services cover several avenues (NACTO, 2019), as listed below.

- Options for Regulations
- Infrastructure Requirements
- Technology Requirements
- Operational Requirements
- Fees Structure
- Data Management Requirements
- Equity
- Public Engagement

The following subsections discuss practices by several agencies based on the above-mentioned list.

2.1.1 Options for Regulations

A variety of approaches were adopted by different agencies when launching micromobility services, such as e-scooters. Most agencies initiate these services through short-term pilot programs first, before opting for vendor licensing through time limited permits (Seattle DOT, 2024; Austin Transportation Department, 2019). This strategy was adopted due to the need to navigate the uncharted territory of micromobility regulation, where clear guidelines may be lacking. Pilot programs allow agencies to test the system and gather valuable data on usage patterns, safety concerns, and infrastructure requirements before committing to more extensive permitting schemes.

2.1.2 Infrastructure Requirements

Effective regulation of micromobility services necessitates careful consideration of diverse infrastructure requirements. One vital aspect is the provision of appropriate parking spaces. Some agencies provide parking corrals for micromobility devices to be parked (Austin Transportation Department, 2019). Clear guidelines are crucial to ensure these devices' orderly and safe parking, preventing obstruction to pedestrians using the sidewalks. Areas restricted to parking include areas immediately or adjacent to Americans with Disabilities Act (ADA) accommodations, transit zones, sidewalks with a width less than 4 ft, near fire hydrants, or any fixed regulatory or informational signs. (Austin Transportation Department, 2019). Equally important is the provision of infrastructure facilities, such as bike lanes, which will provide a safer environment for micromobility riders. Furthermore, ensuring proper pavement markings and clearly visible street signs that notify the presence of micromobility services and establish their right of way would contribute to enhancing the safety of micromobility riders.

2.1.3 Technology Requirements

Regulations on the level of technology are crucial in ensuring the safety and efficiency of these services. Agencies have established several guidelines to ensure the approved device types are consistent with the technological standards (Austin Transportation Department, 2019). This includes but is not limited to the power source, battery capacity, and charging mechanism. Almost all cities have integrated advanced geofencing technology to enforce compliance with designated operating areas and speed limits (Seattle DOT, 2024). This technology would ensure the devices are not used outside the zone in which they are permitted to operate. These technology requirements not only promote the responsible use of micromobility services but also contribute to a more sustainable and harmonious integration of these modes of transportation within the urban landscape.

2.1.4 Operational Requirements

One of the key features of a successful micromobility system is the effective operational guidelines. Several aspects are usually considered, such as fleet size, fleet rebalancing, fleet redistribution, and device maintenance. There is a great variance in the fleet size choice by different agencies, mainly due to the demand for the services and the capacity of the respective cities. Setting the minimum and maximum number of devices ensures that enough resources are available for the functioning of micromobility services. Fleet size can be measured statically or dynamically. Dynamic fleet size depends on performance metrics such as rides per vehicle per day (r/v/d) and not a fixed number (Austin Transportation Department, 2019). Other performance metrics adopted by cities include permit and requirement compliance. Table 2.1 summarizes the maximum number of micromobility devices allowed in select cities.

Table 2.1: Fleet Size Requirements

S/No	Agency/City	Maximum Fleet Size
1	Austin, TX	500 per company
2	Baltimore	1,000-2,000 per vendor
3	Charlotte, NC	-
4	Chicago, IL	3,500 citywide
5	Los Angeles, CA	3,000 per vendor
6	Santa Monica, CA	3,000 citywide
7	Seattle, WA	20,000
8	Washington DC	600 per device type(e-bike/e-scooter)

Source: (NACTO, 2019)

Most micromobility systems are hybrid systems in which docked and dockless systems operate simultaneously. Dockless systems allow users to park micromobility devices anywhere within the geofenced area. This creates an imbalance in the number of devices in certain stations/areas. This necessitates the need to regulate fleet redistribution to recreate the balance based on the demand, capacity, and the city's goals. In addition, improperly packed devices and damaged ones need to be relocated to designated parking spaces and garages/warehouses, respectively. In areas prone to natural disasters such as hurricanes, cities have included the requirement for emergency management plans to address how the devices will be handled.

Staffing requirements also play a significant role, necessitating efficient management to address issues promptly, from rebalancing devices to responding to user concerns (Seattle DOT, 2024). Lack of workforce to deal with these issues would affect the overall efficiency of the micromobility systems. In addition, cities/agencies establish maximum design speed requirements for micromobility devices. In some instances, like in Florida, the state enacts laws specifying the maximum design speed for the micromobility devices, with the agencies establishing their speed limit, which is usually less or equal to the state's limit. Table 2.2 summarizes the maximum speed established in various cities.

Table 2.2: Maximum Design Speed

S/No	Agency/City	Maximum Design Speed
1	Austin, TX	20 mph
2	Baltimore, MD	15mph
3	Charlotte, NC	15 mph(e-scooter), 20 mph (e-bikes)
4	Chicago, IL	15 mph
5	Los Angeles, CA	15 mph
6	Santa Monica, CA	15 mph(e-scooter), 20 mph (e-bikes)
7	Seattle, WA	15 mph
8	Washington DC	10 mph(e-scooter), 20 mph (e-bikes)

Source: (NACTO, 2019)

Whether micromobility riders can use sidewalks varies across cities and depends on local regulations and infrastructure considerations. Some cities permit micromobility riders to use sidewalks, particularly in areas with lower pedestrian traffic or high-speed roadway facilities (City of Baltimore, 2022; Austin Transportation Department, 2019). This approach can provide a safer space for micromobility users, especially when road conditions might be hazardous. However, other cities prohibit or restrict micromobility use on sidewalks due to potential conflicts with pedestrians and concerns about pedestrian safety (City of Chicago, 2023; LADOT, n.d.; City of Santa Monica, n.d.) These cities often emphasize using bike lanes or designated roadways to ensure a more organized flow of traffic. Table 2.3 presents the summary of whether select cities allow riding on sidewalks.

In summary, by outlining operational criteria such as fleet size, maintenance procedures, and staffing expectations, regulations can create a framework that supports the sustainable and effective operation of micromobility services within urban environments.

Table 2.3: Sidewalk Regulation

S/No	Agency/City	Sidewalk Usage
1	Austin, TX	Yes
2	Baltimore, MD	Yes
3	Charlotte, NC	N/A
4	Chicago, IL	No
5	Los Angeles, CA	No
6	Santa Monica, CA	No
7	Seattle, WA	No
8	Washington DC	No within CBD

2.1.5 Fee Structure

Fee structure requirements within micromobility service regulations are essential to establish a sustainable system. Cities are interested in regulating the fees charged by vendors to prevent overpricing, which would decrease the efficiency of the services and defend the users' interest in being pre-informed of all service charges (City of Chicago, 2023). In addition, cities also need to generate revenues from the services just like the vendors, and thus, fees charged are usually structured to balance those needs. The most popular fee structures for micromobility riders include a base rate to unlock the device and a per-minute rate for every minute the user travels. In terms of permit fees, cities/agencies charge one or a combination of these fee types: application fees, per-device fees, per-trip fees, and performance bonds (NACTO, 2019).

2.1.6 Data Management Requirements

Data management requirement is a crucial component of regulations pertaining to the operation of micromobility systems. Established regulations outline how data generated is collected, stored, and shared. Effective data management is essential as cities adopt regulations safeguarding user privacy (Austin Transportation Department, 2019) while ensuring data are available for municipalities to optimize urban planning. Data collected include trip patterns, user behavior, device locations, and collision history reports.

2.1.7 Equity and Public Engagement Requirements

Equity and public engagement regulations emphasize the importance of providing accessible and inclusive transportation options for all community members, regardless of their socioeconomic status or physical abilities (DCRegs, 2023). Cities demand that vendors provide reduced fare programs for users in various qualified categories, such as students, seniors, and persons in special programs such as the food assistance program in Washington (Seattle DOT, 2024). It is in the city's interest to ensure that the vendors operating within their jurisdiction do not provide services with bias, ensuring equitable service coverage. In addition, the vendors work with the cities to provide education to the members of the public on the benefits of active transportation, how to operate the devices and promote safety (Seattle DOT, 2024).

2.2 Mobility and Safety Characteristics of Micromobility Systems

The rapid proliferation of micromobility systems has prompted extensive research into understanding their mobility and safety characteristics. This section explores diverse approaches employed in studying the safety and mobility characteristics of micromobility systems.

2.2.1 Safety Characteristics

Despite the benefits of the micromobility systems, collisions are inevitable since, in most cases, the micromobility users share the same infrastructure with pedestrians and traffic vehicles. Over the years, researchers have extensively studied safety issues pertaining to vulnerable road users, mainly focusing on pedestrians and bicyclists. Only a few recent studies have investigated the safety performance of micromobility systems (Yang et al., 2020; Shah et al., 2021).

Most studies adopt data-driven approaches leveraging real-world data from micromobility systems to examine safety patterns. Previous studies used survey-based, observational (Fitt & Curl, 2020; Tian et al., 2022) and news article mining approaches to investigate e-scooter safety (Yang et al., 2020). With improved guidelines on data management, researchers have been able to analyze safety aspects based on real-world data from the operations of micromobility services (Karpinski et al., 2022; Fang, 2022; Shah et al., 2021; Ma et al., 2021).

Safety studies generally employ varying methodologies to analyze potential risks. Some studies rely on historical crash data to assess the safety of micromobility services by examining past incidents to identify patterns and risk factors (Shah et al., 2021; Cicchino et al., 2021). Conversely, other studies have focused on a proactive approach, which uses incidents such as near misses to provide valuable insights into potential hazards and unsafe conditions (Ma et al., 2021). One of the best methods to collect data on near collisions involves conducting a naturalistic study, which consists of observing the micromobility rider's behaviors and interactions with their surroundings in natural settings (Haworth et al., 2021; Ma et al., 2021; White et al., 2023).

Approaches can also be differentiated based on whether the studies focused on micro-level analysis, such as intersection level (Prabu et al., 2022; Hertach et al., 2018) or macro-level analysis that examines the entire transportation network or traffic zones (Cai et al., 2017). Micro-level analysis reveals more about the underlying causes of the crashes. In analyzing historical crash data, studies have investigated factors affecting both the severity and frequency of crashes involving micromobility devices (Yang et al., 2020; Shah et al., 2021). These methodological approaches involve using various models such as linear, logistic, probit, complementary log-log, and Bayesian regression models to investigate factors affecting the severity and frequency of micromobility-related crashes.

As further research and technological advancements continue, the insights gained in these safety studies will play a pivotal role in shaping regulations, infrastructure improvements, and education campaigns that promote the responsible and effective operation of micromobility services.

2.2.2 Mobility Characteristics

Cities have been adopting micromobility services due to their potential to offer multiple benefits by improving accessibility and mobility (Meng & Brown, 2021), offering solutions to first/last mile problems (Bieliński & Ważna, 2020), and facilitating modal shift from private cars especially on short trips (McGuckin & Fucci, 2018). Analyzing the mobility characteristics of micromobility involves a multifaceted approach that draws from various methodologies to comprehensively understand usage patterns (McGuckin & Fucci, 2018), user behaviors, and the impact on the existing transportation network.

One common method is data-driven analysis, which leverages the extensive data collected from micromobility systems to discover insights related to mobility functions. This approach examines trip durations, frequency, and distances traveled, shedding light on popular routes and peak usage times (Younes & Baiocchi, 2022). Global Positioning System (GPS) and sensor data from the micromobility devices provide valuable information about speeds, acceleration, and deceleration patterns, which can then be used to quantify mobility performance measures such as travel time savings, delay savings, and usage regularity (Ji et al., 2020).

Another approach involves observational studies conducted in real-world settings (Billstein & Svernlöv, 2021). Studies have adopted techniques such as naturalistic study to gather qualitative and quantitative data, which can be used to study the mobility characteristics of micromobility services. These studies offer a deeper understanding of user behaviors in different contexts, such as road interactions and parking habits. Moreover, naturalistic studies offer insights into the dynamics between riders, pedestrians, and vehicles. This mix of quantitative and qualitative research methods allows for a more holistic understanding of the complex mobility characteristics associated with micromobility services.

2.3 Micromobility and CAV Deployments

Integrating micromobility services with connected and automated vehicle (CAV) deployments presents a promising avenue for transforming urban transportation systems. This integration envisions a future where micromobility options seamlessly interact with CAVs to create a more efficient, sustainable, and safe mobility ecosystem (Sanders & Karpinski, 2022). One aspect of this integration involves the incorporation of CAV technology to enhance the safety of micromobility users. CAVs equipped with advanced sensors and communication capabilities can detect and respond to the presence of micromobility vehicles, ensuring smoother traffic flow and reducing the risk of collisions. Moreover, CAVs can communicate with nearby micromobility devices to anticipate their movements and adjust their driving behaviors, accordingly, creating a harmonious coexistence between various modes of transportation.

2.4 Engineering Process for Deploying Micromobility Services

In recent years, micromobility has emerged as a promising solution to address urban transportation challenges. Cities and agencies worldwide are actively embracing micromobility services such as bike-sharing and scooter-sharing to enhance urban mobility, reduce congestion, and promote sustainability. However, the successful implementation of such services requires a well-defined engineering process. This section provides a general overview of the key stages involved in the engineering process. These stages were developed based on discussions with the Jacksonville Downtown Investment Authority. The five key stages undertaken in establishing micromobility services include the inception stage, the procurement stage, the design stage, the deployment stage, and the operation stage.

2.4.1 Stage I: Inception Stage

The inception stage marks the initial conceptualization and planning phase of the micromobility service. During this stage, cities and agencies identify the need for micromobility services, conduct feasibility studies, and develop a strategic vision. Essential tasks at this stage involve analyzing the existing transportation infrastructure, evaluating demand patterns, assessing potential user groups, and determining the service's goals and objectives. The outcomes of this stage serve as the foundation for subsequent stages in the engineering process.

2.4.2 Stage II: Procurement Stage

In the procurement stage, cities and agencies initiate the process of selecting suitable service providers to implement and operate the micromobility services. This stage typically involves issuing requests for proposals (RFPs) or invitations to tender (ITT), where interested companies/vendors can submit their proposals. Evaluation criteria may include factors such as financial stability, technical expertise, operational capacity, sustainability measures, and compliance with regulatory requirements. Through a competitive selection process, cities aim to secure a partnership with a service provider that best aligns with their goals and meets the needs of their communities.

2.4.3 Stage III: Design Stage

The design stage focuses on the physical infrastructure and operational aspects required to successfully implement micromobility services. This stage constitutes the following sub-stages:

a. ***Route and Network Planning***: Cities and agencies analyze existing transportation networks and determine suitable routes for micromobility services. This process involves identifying key origin-destination pairs, considering factors such as population density, land use patterns, and existing infrastructure.

b. ***Parking Infrastructure***: Designing appropriate parking facilities is crucial for micromobility services. Cities and agencies must identify suitable locations for docking stations, parking plots, or parking corrals. Factors such as accessibility, right-of-way availability, user convenience, and safety must be considered during this stage.

c. ***Charging and Maintenance Infrastructure***: In the case of electric micromobility services, designing charging infrastructure becomes essential. Cities must plan the installation of charging stations strategically to ensure availability and accessibility. Additionally, maintenance facilities should be established to manage routine repairs and upkeep of vehicles. In most cases, the maintenance obligations are accomplished by vendors.

2.4.4 Stage IV: Deployment Stage

The deployment stage involves the physical implementation of the micromobility service infrastructure. This includes the installation of docking stations, parking facilities, charging stations (if applicable), and other necessary hardware. Cities and agencies work closely with the selected service provider to ensure the deployment aligns with the established design and meets local regulations and safety standards. This stage may also involve community engagement and public awareness campaigns to familiarize residents with the new service.

2.4.5 Stage V: Operation Stage

Once the infrastructure is in place, the operation stage focuses on the day-to-day management and maintenance of the micromobility services. This includes activities such as vehicle rebalancing, monitoring system performance, addressing customer inquiries, and conducting regular maintenance and repairs. Cities and agencies collaborate closely with the service provider to establish operational protocols, ensure compliance with regulations, and optimize service delivery.

2.4.6 Summary

The engineering process undertaken by cities and agencies in the establishment of micromobility services involves several distinct stages. From the inception stage to the operation stage, each stage plays a crucial role in ensuring the successful implementation, management, and optimization of these services. By following this comprehensive process, cities and agencies can effectively integrate micromobility services into their transportation systems, thereby fostering sustainable urban mobility and improving the quality of life for their residents.

CHAPTER 3
STATE-OF-THE-PRACTICE SURVEY

This chapter discusses the survey questionnaire distributed to agencies/cities in Florida. Questions included in the survey and responses from the participants are provided in Appendix A and Appendix B, respectively.

3.1 Survey Design

The survey design process involved a series of meticulous steps. Firstly, the research team identified key points of contact from each agency involved in the shared micromobility system in Florida. Subsequently, the team diligently crafted targeted questions that aimed to assess the current state of practice across the five essential stages: inception, procurement, design, deployment, and operation.

After finalizing the survey questions, the next step involved submitting them to the project managers for review and approval. The survey was designed to be concise, ensuring it wouldn't take too much time for respondents to complete. It consisted of 50 questions, which are provided in Appendix **A**. The questions were posted and administered online using the Qualtrics platform (http://www.qualtrics.com). Figure 3.1 presents an excerpt from the Qualtrics Platform.

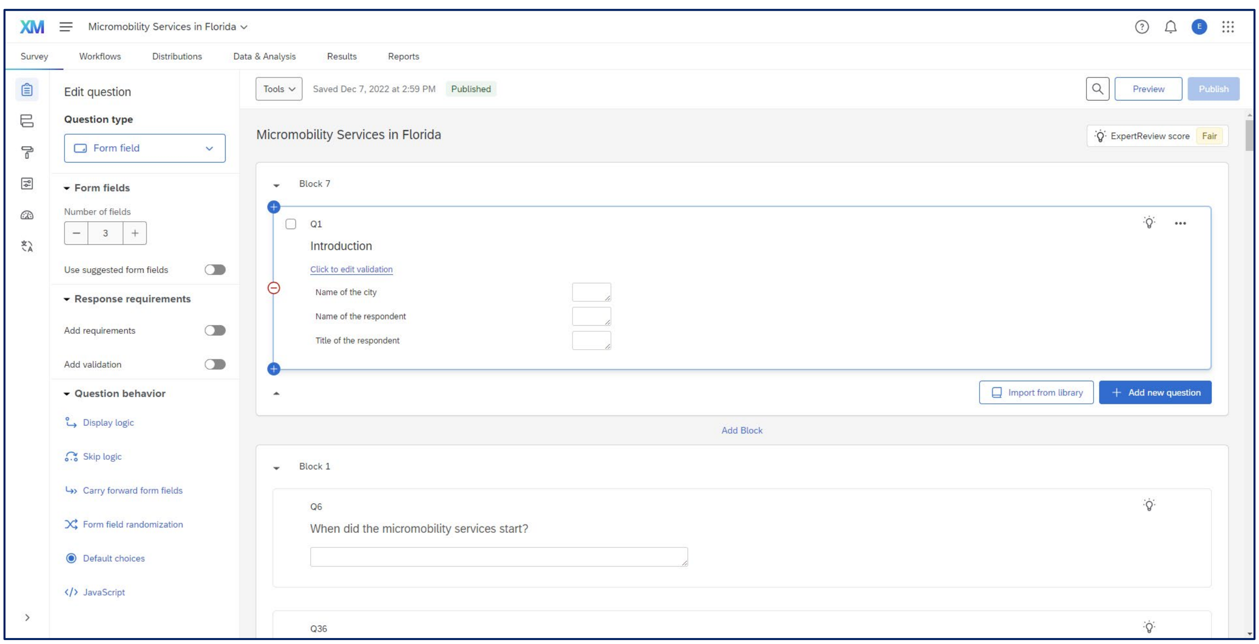


Figure 3.1: Excerpt from the Qualtrics Platform

3.2 Survey Distribution

The survey was distributed to several contacts from agencies/cities in Florida. The agencies were contacted via email, where they were provided with a link to the survey website. The email explained the purpose of the project, the estimated time required to complete the survey, and included detailed instructions on how to fill out the questionnaire. The contact information of the project manager and principal investigators was also shared.

Table 3.1 provides the list of invited agencies/cities and the respective positions of the respondents within those agencies. A total of seven agencies responded to the survey. The response rate was about 54%.

Table 3.1: List of the Invited Agencies

County	Agency/City	Position of Respondent
Miami-Dade	City of Miami	Assistant Director- Resilience and Public Works
St. Johns	City of St. Augustine	Mobility Manager
Broward	Fort Lauderdale	Transportation Division Manager
Alachua	Gainesville	Transportation Planning and Parking Manager
Escambia	Pensacola	Transportation Planner
Pinellas	St. Petersburg	Transportation Manager
Hillsborough	Tampa	Micromobility Engineer

3.3 Survey Results

Results from the survey are presented in Appendix B. The statewide state-of-the-practice survey questionnaire had five sets of questions depending on the stage:

- Inception Stage
- Procurement Stage
- Design Stage
- Deployment Stage
- Operation Stage

3.3.1 Inception Stage

3.3.1.1 Reasons for Establishing Micromobility Services

The survey aimed to identify the different reasons that initiated or warranted the establishment of micromobility services. Based on the responses from the agencies, around 60% (4 agencies) attributed the establishment of these services to the desire to offer alternative transportation options in downtown and central business district (CBD) areas. Additionally, two agencies stated that micromobility services were initiated as a solution to first-mile/last-mile problems, addressing gaps in existing transportation networks. One agency mentioned that resident demands played a significant role in establishing micromobility services.

Other reasons cited for the establishment of micromobility systems included the alleviation of traffic congestion and addressing limited parking areas. Table 3.2 summarizes the responses based on the reasons for establishing micromobility systems.

Table 3.2: Reasons for Establishing Micromobility Services

	City / Agency	Miami	St. Augustine	Ft Lauderdale	Gainesville	Pensacola	St. Petersburg	Tampa
Reasons for Establishing Micromobility Services	Alternative mode of transportation	X		X		X	X	
	Complement the range of transportation options / Provide first mile last mile options				X		X	
	Increase equity and accessibility						X	
	Respond to resident's demand							X
	Alleviate traffic congestion		X					
	Limited parking		X					

3.3.1.2 Methods of Initiating/Establishing Micromobility Services

The survey question aimed to identify how the shared micromobility systems were established at the beginning. Among the seven agencies that responded, most cities (5 out of 7) initially established micromobility systems as pilot programs. This approach can be attributed to the lack of standardized policies for establishing micromobility services during the times the respective cities were initiating these systems. However, some cities (e.g., Gainesville) took a different approach and immediately introduced a permanent program. Table 3.3 summarizes the responses based on the methods in which micromobility systems were established.

Table 3.3: Methods of Initiating Micromobility Services

City / Agency		Miami	St. Augustine	Ft Lauderdale	Gainesville	Pensacola	St. Petersburg	Tampa
Methods of Initiating Micromobility Services	The city introduced a permanent micromobility program				X			X
	The city introduced a pilot program	X		X		X	X	X
	Vendors applied for permits				X[1]		X	
	Private rental businesses on private property.		X					

[1] For Gainesville, the department issuing the permits is the city department of transportation.

3.3.1.3 Types of Micromobility Systems

The survey aimed to identify the type of micromobility system established in each city. Generally, shared micromobility systems can be categorized as either docked, dockless, or a hybrid of the two. Docked micromobility systems have designated locations where users must drop off the micromobility devices. In contrast, dockless micromobility systems allow users to drop the devices anywhere within specified geofencing parameters. A hybrid system combines both docked stations and dockless features.

Based on the responses, three agencies had hybrid systems in their jurisdictions, meaning they offered both docked and dockless options. Three other agencies had dockless systems exclusively, allowing greater flexibility for users in device drop-off locations. Meanwhile, one out of the seven agencies surveyed had a docked system only, where designated drop-off points were required. Table 3.4 summarizes the responses based on the type of micromobility system established in each city.

Table 3.4: Types of Micromobility Systems

City / Agency		Miami	St. Augustine	Ft Lauderdale	Gainesville	Pensacola	St. Petersburg	Tampa
Type of Micromobility Systems	Docked		X					
	Dockless	X			X	X		
	Hybrid			X			X	X

3.3.1.4 Preliminary Study(s) Prior to the Establishment of Micromobility System

The survey question aimed to identify whether the agencies or cities conducted any studies before establishing micromobility systems. The purpose of this question is to inform other agencies that are planning to establish micromobility systems about the suggested studies that should be done before initiating such shared micromobility systems. These studies typically include user experience and user perception studies, often conducted in the form of surveys.

Among the agencies that responded, only one agency (St. Petersburg) responded that they had conducted a study before initiating their micromobility system. The study was found to have provided valuable insights into user preferences and perceptions, helping to inform the city's decision-making process.

3.3.2 Procurement Stage

3.3.2.1 Procurement Methods

The survey question aimed to identify the methods used by cities and agencies to procure micromobility services. The responses to this question provide valuable information that can be used by other agencies planning to procure micromobility systems. The majority of cities reported that they prepared a request for proposals (RFP) to invite potential vendors. Preparing an RFP is a common and effective method to engage potential vendors, allowing cities to specify their requirements and evaluate proposals in a structured manner. Table 3.5 presents a summary of the responses based on how each city procured the micromobility services.

Table 3.5: Procurement Methods

City / Agency		Miami	St. Augustine	Ft Lauderdale	Gainesville	Pensacola	St. Petersburg	Tampa
Procurement Methods	Request for proposal						X	X
	Request for application							X
	Request for quotation					X		
	Vendors reach out to city (permits)				X			
	Solicitation of bids		X					
	As a pilot program	X		X				

3.3.2.2 Factors Considered in Selecting Vendors

The survey question aimed to identify the factors considered by cities and agencies in the vendor selection process when procuring micromobility services. The responses to this question offer valuable insights to other agencies planning to procure shared micromobility systems, helping them understand crucial considerations that will help them make informed decisions and establish successful micromobility systems.

Table 3.6 summarizes the responses based on the important factors that were taken into account during the vendor selection process. Some of the key factors reported by agencies include, the experience and reputation of the vendor, proposed cost structure, their capability to meet contractual obligations, their fleet availability, community engagement, compliance with relevant regulations and/or policies, and their operational plan, including the ability to enforce geofencing rules.

Table 3.6: Factors Considered in Selecting Vendors

City / Agency		Miami	St. Augustine	Ft Lauderdale	Gainesville	Pensacola	St. Petersburg	Tampa
Factors Considered in Selecting Vendors	Fleet availability	X						X
	Operational plan/ Ability to geofence					X	X	X
	Cost per hour			X				
	Community engagement (Incl. local crew)					X		X
	Reputation of the vendor/Experience		X				X	X
	Compliance to program goals and plans						X	X

3.3.2.3 Requirements for a Relocation Plan During Emergency Weather Conditions

The purpose of this question was to gather information on whether the agencies considered weather conditions in Florida, which is prone to extreme weather events like hurricanes. The focus was on investigating whether there were any requirements for relocating the micromobility devices in their fleets during adverse weather conditions. This consideration is essential not only to protect the assets but also to ensure the safety of the users. All seven agencies (100%) reported that they included a requirement for a relocation plan during emergency weather conditions.

3.3.3 Design Stage

3.3.3.1 Factors Considered During the Design of the Micromobility Network and Parking Areas

The survey question aimed to identify the various factors considered during the design of micromobility networks, including the design of parking slots. The responses provided valuable insights into the critical elements taken into account by cities and agencies when planning and implementing the construction of these networks.

One key factor was population density, which helped determine where the demand for micromobility services would be highest. Additionally, the availability of right-of-way played a crucial role in identifying suitable routes and areas for the micromobility network. Cities also took into account existing bicycle networks, ensuring seamless integration and connectivity with the overall transportation infrastructure. Accessibility was another essential consideration, ensuring that the micromobility services were conveniently accessible to various neighborhoods and areas within the city. To meet the demand and supply dynamics effectively, the planners worked on aligning the fleet size and distribution with the expected usage patterns. Interestingly, one agency stated that there were no significant restrictions, micromobility units could be circulated and parked anywhere with minimal restrictions. Table 3.7 summarizes the important factors considered during the design process.

Table 3.7: Factors Considered during Micromobility Network and Parking Areas Design

City / Agency		Miami	St. Augustine	Ft Lauderdale	Gainesville	Pensacola	St. Petersburg	Tampa
Factors Considered During the Design of the Micromobility Network and Parking Areas	Population density							X
	Right of way availability	X						
	Existing bicycle networks							X
	Accessibility						X	
	Demand and supply		X			X		
	Minimize disruption(s) to existing facilities						X	
	No restrictions				X			

3.3.3.2 Design Modifications Implemented to Promote the Safety of Road Users

The survey question was specifically designed to identify design changes that were made to enhance the safety of road users upon the introduction of micromobility systems. The responses from the agencies shed light on the crucial measures taken to ensure the well-being of both micromobility users and other road users. One of the significant design changes made was the addition of dedicated bicycle lanes, providing a safe space for micromobility devices and cyclists, separated from vehicular traffic. Furthermore, agencies introduced parking corrals, designated areas for micromobility devices to be parked, reducing clutter and potential hazards on sidewalks and other pedestrian spaces.

Other changes were implemented on signage and striping to keep the road users aware of the presence of micromobility devices and their right of way. Two of the agencies that responded, stated they utilized pilot program to gather data and insight helping to determine appropriate changes if any. Two additional agencies reported that no changes were implemented, possibly either due to the adequacy of existing facilities or a lower number of devices in use, which did not necessitate significant design changes. Table 3.8 presents a summary of the design modifications implemented to promote safety in the public right of way.

Table 3.8: Design Modifications to Promote Safety of Road Users

City / Agency		Miami	St. Augustine	Ft Lauderdale	Gainesville	Pensacola	St. Petersburg	Tampa
Design Modifications to Promote Safety of Road Users	None				X	X		
	Adding bicycle lane							X
	Parking corrals	X						
	Signage and striping		X					
	Pilot program used to determine parameters			X				

3.3.4 Deployment Stage

3.3.4.1 Number of Vendors Allowed to Operate at the Beginning of the Services

The survey question aimed to identify the number of vendors allowed to operate in the cities and agencies at the beginning of their micromobility services. This question was designed to provide valuable information about the strategies adopted by different agencies during the initial deployment phase of micromobility services. Out of the seven agencies that responded, two reported allowing more than five vendors to operate, promoting healthy competition and offering users a diverse range of options. On the other hand, two agencies chose to start with only one vendor, likely to establish a more controlled and structured rollout of micromobility services in their respective cities.

The variation in the number of vendors allowed reflects the different approaches taken by agencies, considering factors such as market dynamics, infrastructure readiness, and regulatory considerations. By understanding these different strategies, other agencies can make informed decisions when launching their own micromobility services, tailoring their approaches to suit the unique needs and characteristics of their cities. Table 3.9 summarizes the responses based on the number of vendors allowed to operate at the beginning of the micromobility services.

Table 3.9: Number of Vendors Allowed to Operate at the Beginning of the Services

City / Agency		Miami	St. Augustine	Ft Lauderdale	Gainesville	Pensacola	St. Petersburg	Tampa
Number of Vendors Allowed to Operate at the Beginning of the Services	1		X	X				
	2					X		
	3				X		X	
	4							
	5+	X						X

3.3.4.2 Number of Vendors Allowed to Operate Currently

The survey question aimed to identify whether there were any changes in the number of vendors allowed to operate in the cities and agencies compared to the beginning of the micromobility services. The main purpose of this question was to gain insights into the reasoning behind any such changes and understand the factors that may have influenced the decisions. Pensacola reported dropping one vendor in the pilot but are looking to replace the vendor. Other cities did not report any changes in their survey responses regarding vendor operations.

3.3.4.3 Number of Micromobility Devices Allowed to Operate Currently

The survey question aimed to identify the number of micromobility devices allowed to operate within the jurisdiction. This question was designed to gather information on the limits set by agencies regarding the number of micromobility devices allowed to operate in their respective cities. The number of micromobility devices allowed varies due to factors such as demand, infrastructure capacity, equity, and accessibility. The highest number of devices allowed reported was 6,900 devices in Tampa while the lowest was 100 devices in St. Augustine. This data sheds light on the agencies' strategies for regulating and balancing the number of devices. Table 3.10 summarizes the responses based on the total number of devices allowed to operate in the corresponding cities.

Table 3.10: Number of Micromobility Devices Allowed to Operate

City / Agency		Miami	St. Augustine	Ft Lauderdale	Gainesville	Pensacola	St. Petersburg	Tampa
Number of Micromobility Devices Allowed to Operate	600 (200 per vendor)				X			
	500					X		
	6900 (600 per vendor)							X
	1500						X	
	100		X					
	8			X				

3.3.5 Operation Stage

3.3.5.1 Payment Methods

The survey question aimed to identify the various approaches used to pay for the micromobility services adopted by different agencies. The responses revealed that some agencies utilized more than one payment method to facilitate user transactions.

In approximately 60% of the responses, agencies reported using mobile applications for payment, providing users with a convenient and seamless way to access and pay for the micromobility services. In about 30% of the responses, electronic cards were used as a payment method, offering an alternative option for users who may not prefer mobile app payments. Interestingly, only one agency (Fort Lauderdale) reported providing the micromobility services free of charge to the users. Figure 3.2 and Table 3.11 summarize the responses based on the payment methods.

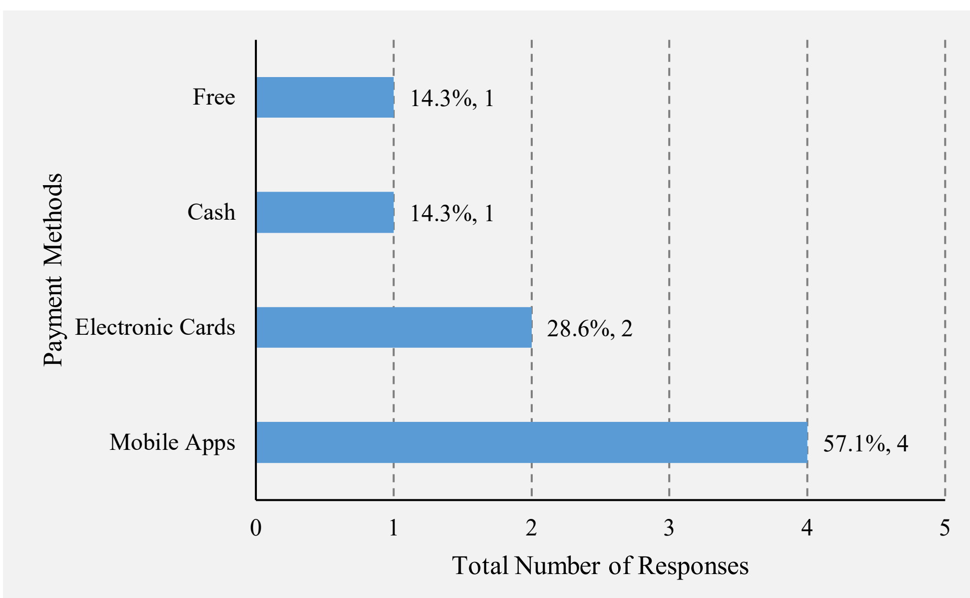


Figure 3.2: Payment Methods

Table 3.11: Payment Methods

City / Agency		Miami	St. Augustine	Ft Lauderdale[1]	Gainesville	Pensacola	St. Petersburg	Tampa
Payment Methods	Mobile apps	X	X		X	X	X	X
	Electronic cards				X			X
	Cash							X
	Free			X				

[1] Fort Lauderdale offers free rides on golf carts to Brightline customers only.

3.3.5.2 Age Restrictions

The survey question aimed to identify whether agencies have implemented any restrictions on the age of micromobility riders. The responses revealed that in some cases, there were differing age requirements between the vendors and the cities. For instance, in Pensacola, the vendors enforced an age limit of 18 years to ride the micromobility devices, while the city itself did not impose any restrictions. However, in all cities where vendor restrictions were in place, the age limit was set at 18 years old.

Table 3.12 presents a summary of the age restrictions imposed by the cities and agencies surveyed. The variations in age requirements highlight the importance of considering both vendor policies and city regulations when assessing the eligibility of riders for micromobility services. By understanding these age restrictions, cities and agencies can ensure compliance with safety standards and tailor their micromobility programs to best serve the needs and safety of their communities.

Table 3.12: Age Restrictions

City / Agency		Miami	St. Augustine	Ft Lauderdale	Gainesville	Pensacola	St. Petersburg	Tampa
Age Restrictions	None		X	X	X			
	16 years						X[2]	X[3]
	18 years	X				X[1]	X[1]	X[1]

[1] restricted by vendor; [2] privately owned (limit by city); [3] restricted by city

3.3.5.3 Speed Restrictions

The survey question aimed to identify speed restrictions imposed on the micromobility devices. The analysis considered speed regulations for travel lanes and bike lanes, as well as speed regulations for sidewalks. In 42.9% of the responses, agencies reported limiting the speed of micromobility devices to 15 mph when operating in travel lanes, promoting safe and controlled speeds in areas with vehicular traffic. However, on sidewalks, most agencies impose a lower speed limit of 12 mph, considering the presence of pedestrians and the need for enhanced safety in these pedestrian-dense areas.

It's essential to note that some agencies took a different approach and have banned the riding of micromobility devices on sidewalks entirely or only allow along select corridors. For example, cities like Pensacola and St. Petersburg prohibit the use of micromobility devices on sidewalks, emphasizing the need to prioritize pedestrian safety in those areas. Tables 3.13 and 3.14 present the speed limits imposed on micromobility users on travel lanes and sidewalks, respectively.

Table 3.13: Speed Restrictions of Micromobility Devices on Travel Lane

City / Agency:		Miami	St. Augustine	Ft Lauderdale[a]	Gainesville	Pensacola	St. Petersburg	Tampa
Speed Restrictions on Travel Lanes	25 mph		X					
	20 mph						X	
	15 mph				X	X		X
	12 mph							
	10 mph	X						

[a] Not applicable for Fort Lauderdale

Table 3.14: Speed Restrictions of Micromobility Devices on Sidewalk

City / Agency:		Miami	St. Augustine	Ft Lauderdale[a]	Gainesville	Pensacola	St. Petersburg	Tampa
Speed Restrictions on Sidewalk	15 mph				X[1]			
	12 mph		X					
	7 mph	X						
	Prohibited[2]						X	
	Unspecified					X		X

[a] Not applicable for Fort Lauderdale
[1] Some areas are restricted
[2] Micromobility devices are prohibited on sidewalk

3.4 Key Findings

This section presents the findings of the state-of-the-practice in the engineering process pertaining to establishing micromobility systems. The findings were based on the responses to the Qualtrics survey by the representatives of the agencies with established micromobility systems.

- The agencies that responded to the survey include: City of Miami, City of St. Augustine, Fort Lauderdale, Gainesville, Pensacola, St. Petersburg, and Tampa.
- Most agencies (Miami, Fort Lauderdale, Gainesville, Pensacola, and St. Petersburg) introduced micromobility systems to provide users with alternative modes of transportation and offer solutions to first/last mile problems.
- Five of the seven agencies that responded, started their micromobility system with a pilot program before moving on to a permanent program (Miami, Fort Lauderdale, Pensacola

St. Petersburg and Tampa). This can be attributed to the absence of clear guidance and specific policies during the initiation period.

- Miami, Gainesville, and Pensacola reported having a dockless system where the users can park the devices within a defined geofenced area, while only one agency reported having a docked system (St. Augustine). Additionally, Fort Lauderdale, St. Petersburg reported to have a hybrid system that constitutes both the dockless and docked systems.

- Only St. Petersburg reported to have conducted a preliminary study before the micromobility system was established. These studies are crucial as they usually offer user perceptions, experience, and expectations of the system that is about to be deployed.

- As expected, most agencies procured their micromobility systems through an RFP (St. Augustine, Gainesville, Pensacola, St. Petersburg, and Tampa), which helps the city engage with potential vendors more efficiently as they specify their requirements.

- In the procurement process, agencies considered different factors while selecting vendors, such as fleet availability, experience and reputation of the vendor, their compliance with the program goals and plans, operational plan, and community engagement.

- All agencies realized the need for a relocation plan during emergency weather conditions, especially since Florida is prone to extreme weather conditions such as hurricanes.

- Agencies considered several factors, such as population density, right-of-way availability, existing infrastructure, demand and supply, and accessibility while designing a micromobility network and parking areas.

- To promote the safety of all road users, agencies implemented several design modifications to existing infrastructure, such as adding bicycle lanes, signage and striping, and parking corrals whenever necessary.

- Several payment methods, such as the use of mobile apps, electronic cards, and cash were adopted by the agencies.

- An age restriction of 18 years or older was imposed by the vendor(s) across all cities. In some instances, the city either had no restrictions at all (Pensacola) or had set the age limit to less than 18 years (e.g., Tampa).

- Speed restrictions were also imposed on micromobility devices, with limits varying depending on the travel location. Most agencies limit the speed at 15 mph for travel lanes, while for sidewalks, most agencies limit the speed at 12 mph. It is worth noting that some agencies outright prohibit micromobility devices on sidewalks.

CHAPTER 4
SAFETY ANALYSIS OF MICROMOBILITY SYSTEMS

This chapter discusses the analysis of micromobility-related crashes in Florida. The specific focus was on the characteristics of micromobility crashes and the factors associated with increased injury severity.

4.1 Background

Despite the benefits of the micromobility systems, there are safety concerns since, in most cases, the micromobility users share the same infrastructure with pedestrians and vehicular traffic (Karpinski et al., 2022). The literature on micromobility services is limited, including understanding the safety issues associated with micromobility services. While researchers have extensively studied vulnerable road user (VRU) safety, much focus has been on pedestrians and bicyclists. Only a few recent studies have investigated the safety performance of micromobility systems (Yang et al., 2020; Shah et al., 2021). Previous studies used survey-based, observational (Fitt & Curl, 2020; Tian et al., 2022), and news article mining approaches to investigate e-scooter safety (Yang et al., 2020). Studies have also investigated factors influencing crash occurrence and severity (Yang et al., 2020; Cicchino et al., 2021).

Over the years, researchers have associated several factors with the severity of VRU injuries. These factors include but are not limited to driver and vehicle-related factors, environmental-related factors, non-motorist related factors, and spatial and temporal factors. For example, studies have claimed that even though female pedestrians tend to sustain severe injuries (Tay et al., 2011), male pedestrians are at a higher risk of being involved in a crash (Kim et al., 2008a). Studies concluded that older pedestrians are associated with an increased risk of severe injuries (Sze & Wong, 2007; Kim et al., 2008b).

Other factors that have been found to increase the severity of pedestrian crash injuries include alcohol impairment (Kim et al., 2008b), higher speed (Peng et al., 2020), type of vehicle involved (Jang et al., 2013), nighttime crash occurrence (Jang et al., 2013), increase in number of lanes, and wider roads (Sze & Wong, 2007), pedestrian crossing the road (Sze & Wong, 2007), pedestrian red light violation, weather condition (Jang et al., 2013) and light condition (Abegaz et al., 2014).

4.2 Crash Data Analysis

4.2.1 Data Sources

The crash data used in this study was obtained from Signal Four Analytics, and roadway characteristics data was obtained from the FDOT's Roadway Characteristics Inventory (RCI) database. The following sections explain in detail how the data were extracted, and the variables of interest obtained from the database.

4.2.1.1 Signal Four Analytics

This project investigated crashes involving micromobility devices in Florida between December 2018 and June 2022. Crash data were obtained from Signal Four Analytics, an interactive Web-based system designed to support law enforcement and research institutions for crash mapping and analysis. Crash reports were extracted from locations/cities that were reported to have at least one established micromobility system. As shown in Figure 4.1, the following locations met this criterion: Miami, Jacksonville, Tampa, Orlando, Gainesville, Tallahassee, Pensacola, Fort Lauderdale, St. Petersburg, St. Augustine, Sarasota, and Port St. Lucie

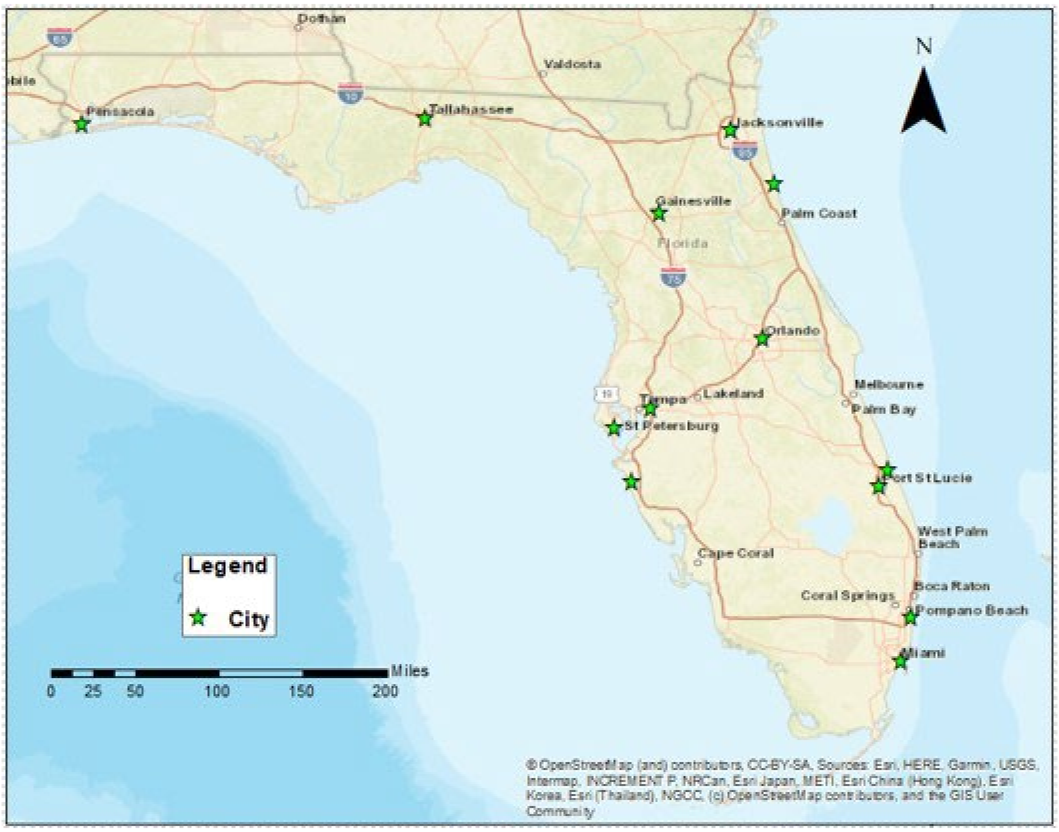


Figure 4.1: Study Locations

The dataset included crashes that were found to have occurred within service areas where micromobility devices were permitted to operate. In most cases, the areas under consideration were the downtown areas of these cities. This procedure was fundamental to reducing the number of police reports to review since no particular variable could be used to exclusively identify and extract micromobility-related crashes from the database.

Variables extracted from Signal Four Analytics include the following:

- Crash attributes:
    - crash severity,

- crash location,
- crash temporal characteristics,
- light condition,
- weather condition,
- road surface condition,
- trafficway description,
- vehicle maneuver, and
- non-motorist maneuver.

- Roadway characteristics:
  - posted speed limit,
  - shoulder type,
  - the number of lanes, and
  - intersection characteristics.

- Other variables:
  - driver's age,
  - driver's gender,
  - non-motorist's age, and
  - non-motorist's gender.

These attributes were instrumental in analyzing the crash data to identify factors contributing to the injury severity of micromobility-related crashes.

4.2.1.2 Roadway Characteristics Inventory (RCI)

FDOT maintains and updates the RCI database for the state of Florida. This database has information on more than 200 roadway characteristics (FDOT, 2023). The most recent roadway characteristics were used in this analysis. In this database, the variables of interest were mainly roadway geometric characteristics. The following variables were extracted from the RCI database:

- surface width,
- sidewalk width,
- shoulder width,
- presence of a bike lane,
- presence of a sidewalk barrier, and
- traffic volume.

Table 4.1 summarizes the variables used in the analysis and their corresponding sources.

Table 4.1: List of Data Variables and Their Sources

Data Variables	Attributes	Data Sources
Crash Data	▪ Crash severity ▪ Crash time ▪ Crash location ▪ Type of road users (drivers and/or non-motorists) ▪ Road surface condition ▪ Lighting condition ▪ Weather condition	▪ Signal Four Analytics
Roadway Geometric Characteristics	▪ Traffic volume ▪ Number of lanes ▪ Posted speed limit ▪ Surface width ▪ Intersection characteristics	▪ Signal Four Analytics ▪ Roadway Characteristics Inventory (RCI)
Demographic Variables	▪ Non-motorist gender ▪ Non-motorist age ▪ Driver gender ▪ Driver age	▪ Signal Four Analytics
Roadside Infrastructure	▪ Presence of a shared path ▪ Presence of a sidewalk barrier ▪ Sidewalk width	▪ Roadway Characteristics Inventory (RCI)

4.2.2 Data Processing

No specific variable in the crash database could be used to identify micromobility-related crashes. Therefore, a text-mining algorithm was developed to identify crashes involving shared micromobility devices. Crash reports with the keywords 'micromobility', 'scooter', 'motorized', 'e-bike', and 'electric' were extracted using the Tesseract package in ***R*** software. A final inspection was also performed to eliminate crashes with the keywords but not involving micromobility devices as defined by the Florida statutes. A crash report confirmed to involve micromobility devices was labeled as "YES" and included in the final dataset, while if a crash report did not involve a micromobility device, it was labeled as "NO" and excluded for further analysis. Figure 4.2 summarizes the steps followed in retrieving the data from the database.

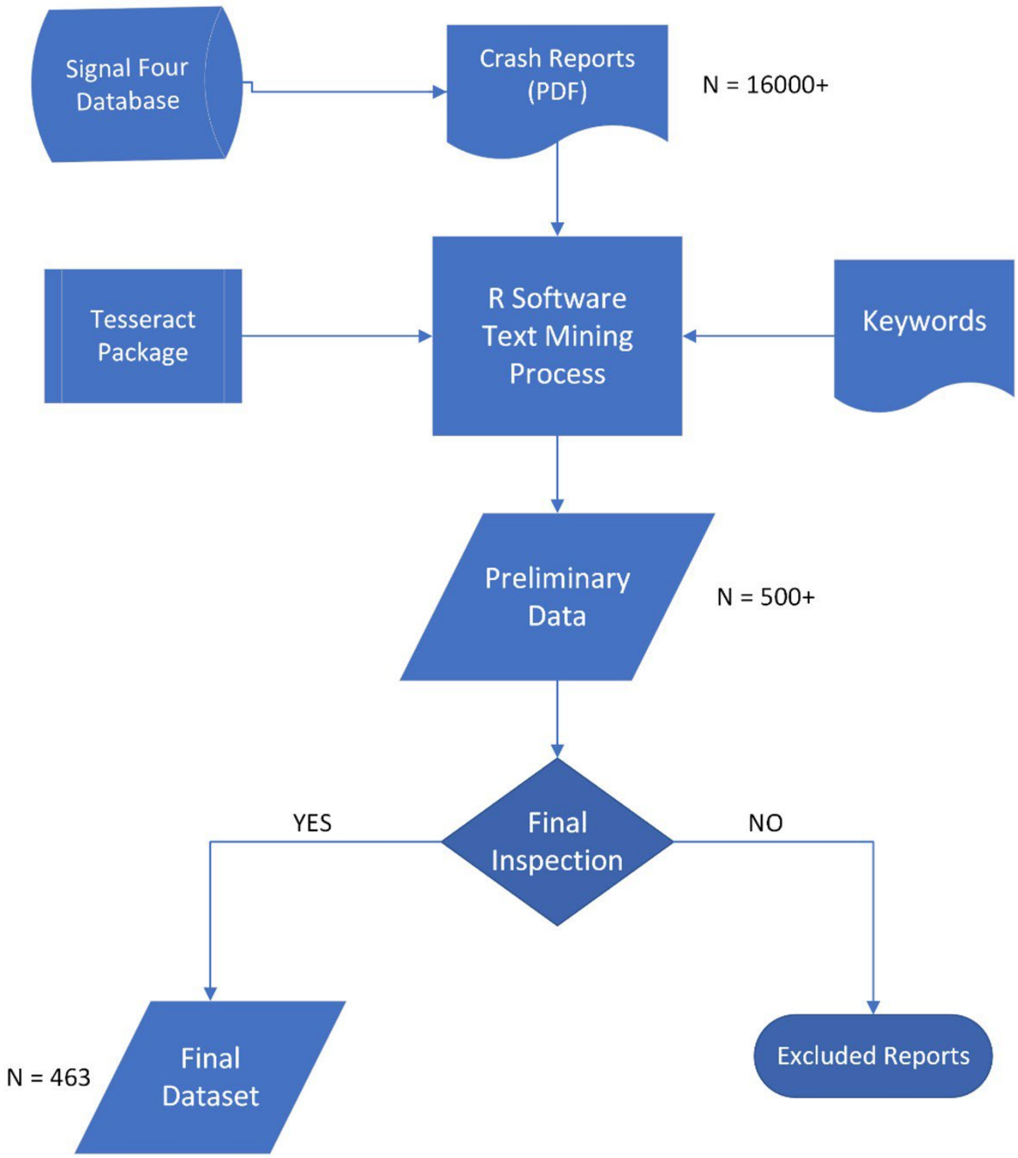


Figure 4.2: Data Processing Algorithm

A total of 463 crashes involving shared micromobility devices were identified. Out of these 463 crashes, 404 (85%) involved electric scooters with and without seats, and 59 (15%) involved electric bikes. In most crash reports, the micromobility user was correctly identified as a non-motorist. Note that the crashes analyzed in this project included only police-reported crashes. The crash data were extracted mainly from the non-motorist level.

Out of the 463 crashes, 424 (92%) crash reports identified the micromobility rider as a non-motorist, while in the remaining 8%, the micromobility user was labeled as a driver. For all crashes retrieved from the non-motorist level, the micromobility rider was assigned a non-motorist description. Figure 4.3 summarizes the crash data based on this description. In the majority of crashes, the non-motorist was described as "other pedestrian" (30.0%), 11.7% were reported as a bicyclist, and over 20% of crashes involving e-scooters were categorized as "other cyclist."

Furthermore, in over 20% of the crashes, the non-motorist description was described as an occupant of a non-motor vehicle transport device. Some of the police reports described micromobility users as drivers. This variability makes it harder to retrieve crash reports involving micromobility devices. A new non-motorist description specific to micromobility-related crashes would greatly help the data retrieval process.

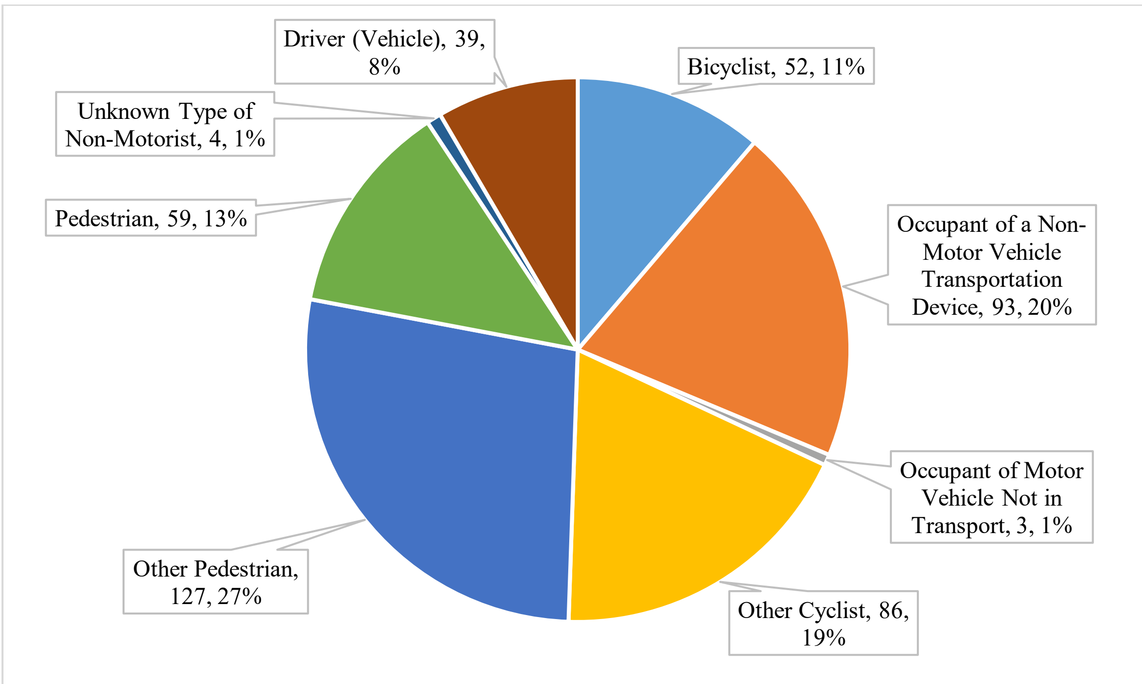


Figure 4.3: Data Summary of Micromobility Crashes Based on Non-motorist Description

4.2.3 Summary

The research investigated micromobility-related crashes in Florida between December 2018 and June 2022. Data were extracted from the Signal Four Analytics database. Due to the absence of a specific variable in the crash database to identify micromobility-related crashes, a text-mining approach using ***R*** software was adopted to retrieve the relevant data. The Tesseract package, which incorporates a powerful Optical Character Recognition (OCR) engine, was utilized to accomplish the text-mining process. OCR enabled the extraction of written or typed text from images, such as photos and scanned documents, converting them into machine-encoded text. Crash reports with the keywords 'micromobility', 'scooter', 'motorized', 'e-bike', and 'electric' were extracted. A final inspection was performed to eliminate crash reports with the keywords but not involving micromobility devices. By the end of the process, 463 crashes were confirmed to involve micromobility devices.

4.3 Exploratory Analysis

This section presents the general characteristics of crashes involving micromobility devices. The exploratory analysis aims to determine the general patterns in the data using summary statistics and graphical representation. Selected descriptive statistics are presented, followed by the Pedestrian and Bicycle Crash Analysis Tool (PBCAT), a tool provided by the Federal Highway Administration (FHWA). The next part discusses the results of the police report review using the in-house web application. Figure 4.4 below presents the spatial distribution of the micromobility crashes in Florida.

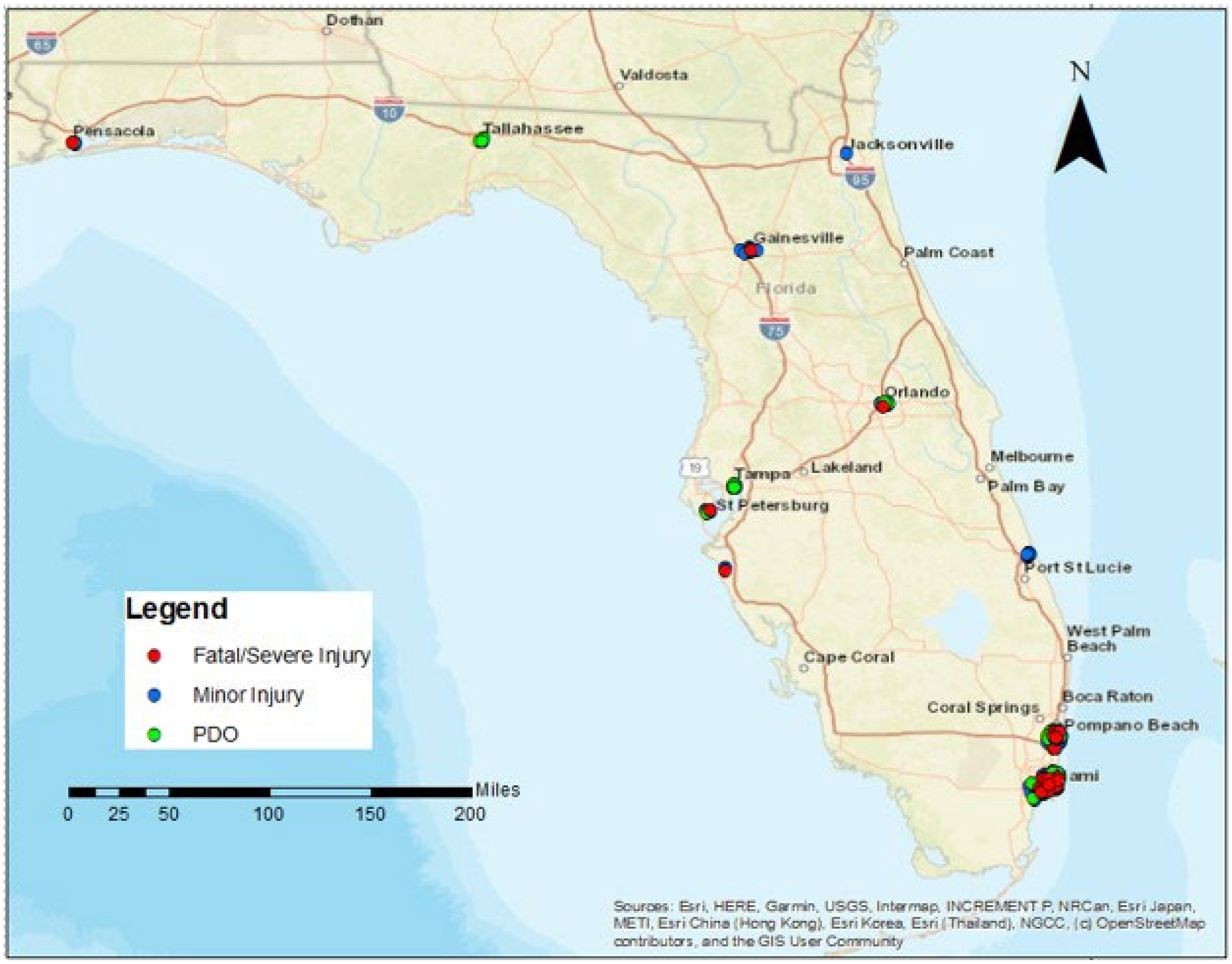


Figure 4.4: Spatial Distribution of Micromobility Crashes in Florida by Severity

4.3.1 Descriptive Statistics

This section provides descriptive statistics of the following factors related to micromobility-related crashes: temporal, crash, driver-related, non-motorist-related, and environmental characteristics.

4.3.1.1 Crash Severity

Table 4.2 and Figure 4.5 present the crash data summary based on injury severity. The data shows that about 9% of all micromobility-related crashes resulted in a fatality or severe injury; 35% resulted in minor injury, approximately 34% resulted in possible injury, and 22% resulted in property damage only (PDO).

Table 4.2: Crash Statistics by Crash Severity

Injury Severity	Count	Percent (%)
Fatal and Severe Injury	43	9.3
Minor Injury	161	34.8
Possible Injury	156	33.7
Property Damage Only (PDO)	103	22.2
Total	**463**	**100.0**

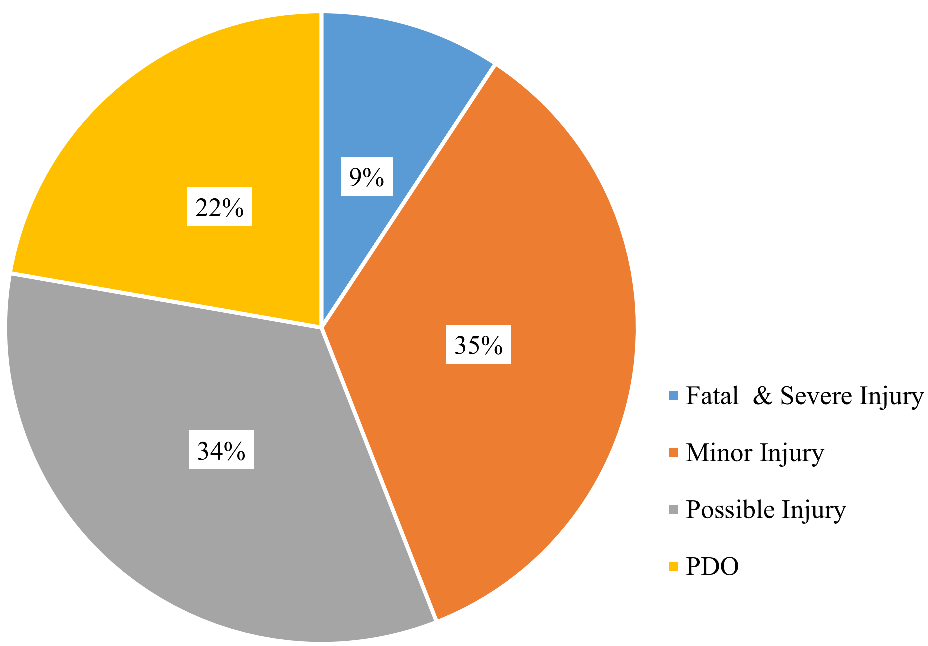


Figure 4.5: Crash Statistics by Crash Severity

4.3.1.2 Crash Location

The crash data was categorized based on the crash location in relation to the roadway. Table 4.3 summarizes the frequency of crashes based on the crash location. Out of the 463 crashes, 254 (54.9%) occurred at or within 50 feet of an intersection. The travel lane is the second most frequent crash location (13.0%), followed by sidewalks (10.8%). The highest proportion of fatal and severe injury micromobility-related crashes occurred at intersections (46.5%).

Table 4.3: Crash Statistics Based on Crash Location

Crash Location	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
At or within 50 ft of an Intersection	20	46.5	172	54.3	62	60.2	254	54.9
Travel Lane	9	20.9	40	12.6	11	10.7	60	13.0
Sidewalk	4	9.3	34	10.7	12	11.7	50	10.8
Driveway Access	2	4.7	25	7.9	5	4.9	32	6.9
Bicycle Lane	2	4.7	25	7.9	1	1.0	28	6.0
Shoulder/Roadside	1	2.3	12	3.8	5	4.9	18	3.9
Other/Unknown	5	11.6	9	2.8	7	6.8	21	4.5
Total	**43**	**100**	**317**	**100**	**103**	**100**	**463**	**100**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

Type of Intersection

Table 4.4 summarizes the crash statistics based on the type of intersection. Based on the data, most micromobility-related crashes were found to occur at intersections. The risk of crashes occurring at intersections is always higher due to collision conflicts between vehicles and non-motorists or between non-motorists. The highest proportion of fatal and severe injury micromobility-related crashes occurred on four-way intersections (41.9%).

Table 4.4: Crash Statistics Based on the Type of Intersection

Type of Intersection	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
Four-way Intersection	18	41.9	133	42.0	49	47.6	200	43.2
T-Intersection	2	4.7	35	11.0	13	12.6	50	10.8
Roundabout	0	0.0	3	0.9	0	0.0	3	0.6
Five-point Intersection	0	0.0	1	0.3	0	0.0	1	0.2
Roadway segment	20	46.5	141	44.5	37	35.9	198	42.8
Other	3	7.0	4	1.3	4	3.9	11	2.4
Total	**43**	**100**	**317**	**100**	**103**	**100**	**463**	**100**

Note: Other includes, Shared path and Parking lot; K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

4.3.1.3 Temporal Characteristics

The crash data analyzed in this project involved crashes between December 2018 to June 2022. Crashes were categorized based on the day, month and year that they occurred. Table 4.5 summarizes the crashes based on the day of the week. Based on the data, Friday experienced the highest proportion of fatal and severe injury crashes (30.2%).

Table 4.6 summarizes the crashes based on the month of the year. Most crashes occurred in March (13.2%), while June experienced the fewest number of micromobility-related crashes (5.4%). February and August had the highest proportion of fatal and severe injury micromobility-related crashes (14.0%). Table 4.7 presents the crash statistics based on the year the crash occurred.

Table 4.5: Crash Statistics Based on the Day of the Week

Day of Week	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
Monday	5	11.6	43	13.6	13	12.6	61	13.2
Tuesday	6	14.0	44	13.9	17	16.5	67	14.5
Wednesday	6	14.0	43	13.6	13	12.6	62	13.4
Thursday	4	9.3	59	18.6	11	10.7	74	16.0
Friday	13	30.2	43	13.6	19	18.4	75	16.2
Saturday	4	9.3	48	15.1	22	21.4	74	16.0
Sunday	5	11.6	37	11.7	8	7.8	50	10.8
Total	**43**	**100**	**317**	**100**	**103**	**100**	**463**	**100**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

Table 4.6: Crash Statistics Based on the Month of the Year

Month of the Year	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
January	4	9.3	26	8.2	7	6.8	37	8.0
February	6	14.0	31	9.8	10	9.7	47	10.2
March	4	9.3	42	13.2	15	14.6	61	13.2
April	2	4.7	33	10.4	11	10.7	46	9.9
May	3	7.0	24	7.6	12	11.7	39	8.4
June	1	2.3	18	5.7	6	5.8	25	5.4
July	3	7.0	22	6.9	5	4.9	30	6.5
August	6	14.0	19	6.0	6	5.8	31	6.7
September	4	9.3	22	6.9	4	3.9	30	6.5
October	4	9.3	31	9.8	9	8.7	44	9.5
November	3	7.0	16	5.0	10	9.7	29	6.3
December	3	7.0	33	10.4	8	7.8	44	9.5
Total	**43**	**100**	**317**	**100**	**103**	**100**	**463**	**100**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

Table 4.7: Crash Statistics Based on the Crash Year

Year	K+A	B+C	PDO	Total Count
	Count	Count	Count	
2018*	1	8	0	9
2019	7	71	31	109
2020	9	62	17	88
2021	18	116	35	169
2022*	8	60	20	88
Total	**43**	**317**	**103**	**463**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.
Note: * 2018 – December only; 2022 – January to June.

4.3.1.4 Driver Characteristics

Table 4.8 summarizes the crash statistics based on the driver's contributing factors. This variable identifies the driver's actions that may have contributed to the traffic crash. Failing to yield the right of way contributed to the highest proportion of micromobility-related crashes (20.9%), followed by careless or aggressive driving, contributing to over 11% of fatal and severe injury crashes. Other contributing factors included driver's actions, such as improper turning, following too closely, improper backing, running off the roadway, and failure to keep in the proper lane.

Table 4.8: Crash Statistics by Driver's Contributing Factors

Driver's Contributing Factor	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
No contributing factor	17	39.5	119	37.5	50	48.5	186	40.2
Failed to yield the right of way	9	20.9	69	21.8	11	10.7	89	19.2
Careless or aggressive driving	5	11.6	40	12.6	12	11.7	57	12.3
Disregarded signs or signals or markings	0	0.0	7	2.2	5	4.9	12	2.6
Other contributing factor	7	16.3	48	15.1	9	8.7	64	13.8
Unknown	5	11.6	34	10.7	16	15.5	55	11.9
Total	**43**	**100**	**317**	**100**	**103**	**100**	**463**	**100**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

4.3.1.5 Non-motorist Characteristics

Gender

Table 4.9 provides the distribution of crashes based on the gender of the micromobility user. Unlike drivers, who are mandated to have a license, micromobility riders are not required to. The situation has led to missing information on non-motorist gender in 87% of the crashes.

Table 4.9: Crash Statistics Based on the Non-motorist's Gender

Non-motorist Gender	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
Male	3	7.0	27	8.5	12	11.7	42	9.1
Female	0	0.0	16	5.0	2	1.9	18	3.9
Unknown	40	93.0	274	86.4	89	86.4	403	87.0
Total	**43**	**100**	**317**	**100**	**103**	**100**	**463**	**100**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

Safety Equipment

The Florida Statute does not mandate micromobility riders to wear safety gear. However, most cities recommend the use of helmets while operating micromobility devices. Because the use of safety equipment is not required, it is no surprise that most crashes involved micromobility riders without any safety equipment. As presented in Table 4.10, the highest proportion of fatal and severe injury crashes occurred when the micromobility users were not wearing safety equipment (76.7%), while only 7.0% involved micromobility riders with safety equipment. Safety equipment includes a helmet, protective pads, reflective clothing, and lighting.

Table 4.10: Crash Statistics Based on Safety Equipment

Safety Equipment	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
Yes	3	7.0	15	4.7	5	4.9	23	5.0
No	33	76.7	271	85.5	86	83.5	390	84.2
Unknown	7	16.3	31	9.8	12	11.7	50	10.8
Total	**43**	**100**	**317**	**100**	**103**	**100**	**463**	**100**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

Age of the Non-motorist

The regulations on the minimum age allowed to ride micromobility devices vary across jurisdictions. Some cities do not have any age restrictions, while some have established a minimum age to legally operate micromobility devices on public streets. For example, the City of St. Petersburg has set the minimum age for riders to be 16 years (St. Petersburg Code of Ordinances, 2019). Table 4.11 summarizes the crash distribution based on the age of the micromobility user. In the analysis, the age variable was divided into three categories: users under the age of 20, users between the ages of 20 to 39 years, and users aged 40 and older. The highest proportion of fatal and severe injury crashes involved micromobility users between the ages of 20 and 39 years (46.5%), followed by 40 years and older riders (18.6%).

Table 4.11: Crash Statistics Based on the Non-motorist Age Group

Age of the Non-motorist	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
0-19	6	14.0	36	11.4	9	8.7	51	11.0
20-39	20	46.5	133	42.0	48	46.6	201	43.4
40+	8	18.6	44	13.9	16	15.5	68	14.7
Unknown	9	20.9	104	32.8	30	29.1	143	30.9
Total	**43**	**100**	**317**	**100**	**103**	**100**	**463**	**100**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

Alcohol-related Crashes

Table 4.12 summarizes the number of crashes involving alcohol-impaired riders. In most crashes (84.7%), the non-motorist was not suspected of being alcohol-impaired. While intoxication is not prevalent in this data, the dangers of operating a transportation device on roadways, while impaired are paramount.

Table 4.12: Crash Statistics Based on Non-motorist Alcohol Involvement

Presence of Alcohol	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
Yes	0	0.0	1	0.3	1	1.0	2	0.4
No	34	79.1	274	86.4	84	81.6	392	84.7
Unknown	9	20.9	42	13.2	18	17.5	69	14.9
Total	**43**	**100**	**317**	**100**	**103**	**100**	**463**	**100**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

Non-motorist Action

Table 4.13 summarizes the crash statistics based on the non-motorists' contributing factors. This variable identifies the micromobility user's actions that may have contributed to the traffic crash. Failing to yield the right of way contributed to the highest proportion of micromobility-related crashes (10.4%), followed by failure to obey traffic signs, signals, or officers (6.3%). The micromobility user's actions did not contribute to over 45% of micromobility-related crashes. Other contributing factors include improper passing and improper turns.

Table 4.13: Crash Statistics Based on the Non-motorist's Action

Non-motorist Contributing Factor	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
No Improper Action	17	39.5	153	48.3	42	40.8	212	45.8
Failure to Yield Right-of-Way	5	11.6	32	10.1	11	10.7	48	10.4
Failure to Obey Traffic Signs, Signals, or Officer	2	4.7	22	6.9	5	4.9	29	6.3
Wrong-Way Riding	1	2.3	13	4.1	2	1.9	16	3.5
Dart/Dash	5	11.6	6	1.9	4	3.9	15	3.2
Other	6	14.0	53	16.7	25	24.3	84	18.1
Unknown	7	16.3	38	12.0	14	13.6	59	12.7
Total	**43**	**100**	**317**	**100**	**103**	**100**	**463**	**100**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

4.3.1.6 Environmental Factors

The study analyzed two environmental-related variables: light condition and weather condition. The lighting condition variable was classified into four major categories: daylight, dusk, dawn, and dark. Table 4.14 presents the crash statistics by lighting conditions, revealing that most micromobility-related crashes occurred during the day (65.9%). Furthermore, it is noteworthy that the highest proportion of fatal and severe injury crashes also occurred in daylight (65.1%). This can be attributed to the fact that the majority of micromobility users ride the devices during the day.

Table 4.14: Crash Statistics Based on Lighting Conditions

Lighting Conditions	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
Daylight	28	65.1	211	66.6	66	64.1	305	65.9
Dark	14	32.6	91	28.7	35	34.0	140	30.2
Dusk	1	2.3	13	4.1	2	1.9	16	3.5
Dawn	0	0.0	2	0.6	0	0.0	2	0.4
Total	**43**	**100**	**317**	**100**	**103**	**100**	**463**	**100**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

Table 4.15 presents the crash statistics by weather condition. The weather condition variable was classified into three major categories: clear, cloudy, and rainy. Most crashes occurred when the weather was clear (90.3%), which is favorable for operating micromobility devices. Only about 4% of the crashes occurred when the weather was rainy. Micromobility riders typically avoid riding in adverse weather conditions, as these devices do not provide adequate protection against rain.

Table 4.15: Crash Statistics Based on Weather Conditions

Weather Conditions	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
Clear	36	83.7	283	89.3	99	96.1	418	90.3
Cloudy	6	14.0	19	6.0	2	1.9	27	5.8
Rainy	1	2.3	15	4.7	2	1.9	18	3.9
Total	**43**	**100**	**317**	**100**	**103**	**100**	**463**	**100**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

4.3.2 Pedestrian and Bicycle Crash Analysis (PBCAT)

The Pedestrian and Bicycle Crash Analysis Tool (PBCAT) is a tool that helps road safety professionals analyze crash data about non-motorist-related crashes to better understand and address non-motorist road user safety risks (FHWA, 2023). PBCAT is one of the most common crash typology tools used in practice. The crash types are based on the combination of different factors such as location, traffic control device, the direction of travel for both vehicle and non-motorist, etc. This project used the latest version of PBCAT, Version 3.0.

The objective of using this standard framework was to consistently identify the crash types for the crashes involving micromobility devices. The crash types of interest were based on the combination of motorist and non-motorist maneuvers. Table 4.16 summarizes the possible crash types. The crash type is denoted such that the first letter represents the motorist maneuver, and the second part describes the non-motorist maneuver at the time of the crash. For example, the crash type "S-PS" represents a crash type where a motorist was moving in a straight direction and the micromobility user was traveling in a parallel path same direction as the motorist. Figure 4.6 presents examples of crash types and their nomenclature.

Table 4.16: Crash Types Based on the Motorist's and Non-motorist's Maneuvers

Maneuver		Non-motorist Maneuver				
		CR: Crossing Path from Motorist's Right	**CL:** Crossing Path from Motorist's Left	**PS:** Parallel Path Same Direction	**PO:** Parallel Path Opposite Direction	**OU/UN:** Other/ Unknown
Motorist Maneuver	B: Backing	B-CR	B-CL	B-PS	B-PO	B-OU/B-UN
	E: Entering traffic lane	E-CR	E-CL	E-PS	E-PO	E-OU
	L: Turning left	L-CR	L-CL	L-PS	L-PO	L-OU
	P: Parked	P-CR	P-CL	P-PS	P-PO	P-OU
	R: Turning Right	R-CR	R-CL	R-PS	R-PO	R-OU
	S: Going Straight	S-CR	S-CL	S-PS	S-PO	S-OU
	N: Non-collision	N-CR	N-CL	N-PS	N-PO	N-OU
	O: Other Maneuver	O-CR	O-CL	O-PS	O-PO	O-OU
	U: Unknown Maneuver	U-CR	U-CL	U-PS	U-PO	U-OU

Figure 4.6: Crash Type Examples
(Source: Thomas et al., 2021)

4.3.2.1 PBCAT Analysis Results

PBCAT tool was utilized to classify the crashes with respect to the maneuvers performed by both the motorist and the non-motorist at the time of the crash. The maneuvers were initially analyzed independently and subsequently analyzed together. Table 4.17 presents the crash distribution based on the motorist's maneuver. The highest proportion of fatal and severe injury crashes occurred when the vehicle was moving straight (58.1%). Right-turning vehicles accounted for 14.0% of fatal and severe injury crashes, followed by left-turning vehicles at approximately 11.6%.

Table 4.17: Crash Statistics Based on the Motorist's Maneuver

Motorist Maneuver	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
S: Going Straight	25	58.1	144	45.4	47	45.6	216	46.6
R: Turning Right	6	14.0	84	26.5	20	19.4	110	23.8
L: Turning Left	5	11.6	52	16.4	13	12.6	70	15.1
N: Non - Collision	1	2.3	8	2.5	3	2.9	12	2.6
E: Entering Traffic Lane	2	4.7	8	2.5	2	1.9	12	2.6
P: Parked	1	2.3	4	1.3	5	4.9	10	2.2
B: Backing	1	2.3	2	0.6	0	0.0	3	0.6
O: Other / Unknown	2	4.7	15	4.7	13	12.6	30	6.5
Total	**43**	**100**	**317**	**100**	**103**	**100**	**463**	**100**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

Table 4.18 summarizes the distribution of micromobility-related crashes based on the non-motorist maneuver. Based on the data, micromobility users seem vulnerable when crossing the roadways, especially from the vehicle's passenger side (29.2%). The second highest frequency of crashes occurred when the non-motorist was crossing from the driver's side of the vehicle (22.7%).

The PBCAT tool was also used to determine the most prevalent crash types based on the combination of motorist and non-motorist maneuvers. The nomenclature of the crash types is such that the first letter represents the vehicle's movement at the time of the crash, whereas the second combination of letters represents the movement of the micromobility rider. Table 4.19 presents crash distribution based on the motorist and non-motorist maneuvers. This analysis was conducted separately for e-scooters and e-bikes. The results suggest that for micromobility-related crashes involving e-scooter, the most prevalent crash types are those of crash type "S-CR" and "S-CL". In addition, for e-bike crashes, the most prevalent crash type is "L-PO" with over 15% of all e-bike crashes.

Table 4.18: Crash Statistics Based on Non-motorist's Maneuver

Non-motorist Maneuver	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
CR: Crossing Path from Motorist's Right	12	27.9	100	31.5	23	22.3	135	29.2
CL: Crossing Path from Motorist's Left	7	16.3	74	23.3	24	23.3	105	22.7
PS: Parallel Path Same Direction	13	30.2	62	19.6	26	25.2	101	21.8
PO: Parallel Path Opposite Direction	7	16.3	51	16.1	14	13.6	72	15.6
FC: Non-Motorist Fall or Crash	1	2.3	8	2.5	3	2.9	12	2.6
ST: Stationary	1	2.3	2	2.3	3	2.9	6	1.3
OU/UN: Other/Unknown	2	4.7	20	4.7	10	9.7	32	6.9
Total	**43**	**100**	**317**	**100**	**103**	**100**	**463**	**100**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

Table 4.19: Crash Types Based on the Motorist and Non-motorist Maneuvers

Maneuver		Non-motorist Maneuver: CR Crossing Path from Motorist's Right		CL Crossing Path from Motorist's Left		PS Parallel Path Same Direction		PO Parallel Path Opposite Direction		OU/UN Other/ Unknown		Total of Motorist Maneuver (%)	
Device Type		S	B	S	B	S	B	S	B	S	B	S	B
Motorist Maneuver	B: Backing	0.2%		0.2%				0.2%				**0.7**	**0.0**
	E: Entering Traffic Lane	1.5%	1.7%	0.5%	1.7%		1.7%			0.2%		**2.2**	**5.1**
	L: Turning left	1.5%	1.7%	3.2%	1.7%	2.7%	3.4%	6.4%	15.3%	0.2%		**14.1**	**22.0**
	P: Parked					1.2%	1.7%	0.7%		0.2%		**2.2**	**1.7**
	R: Turning Right	8.4%	5.1%	3.2%	3.4%	5.7%	13.6%	4.7%	3.4%	1.2%	1.7%	**23.3**	**27.1**
	S: Going Straight	16.8%	8.5%	14.9%	11.9%	9.4%	13.6%	2.2%	1.7%	4.7%	1.7%	**48.0**	**37.3**
	N: Non-collision									2.7%	1.7%	**2.7**	**1.7**
	O: Other Maneuver	1.2%		0.5%	1.7%	0.7%	1.7%	0.2%		0.2%		**3.0**	**3.4**
	U: Unknown Maneuver	1.0%	1.7%	0.5%				0.2%		2.0%		**3.7**	**1.7**
Total % of e-scooters / e-bikes crashes		**30.7**	**18.6**	**23.0**	**20.4**	**19.8**	**35.6**	**14.9**	**20.3**	**11.6**	**5.1**	**100**	**100**

Note: S = e-Scooter; B = e-Bike; Blank space = 0.0%.

4.3.3 Police Report Review

Micromobility-related police crash reports were also reviewed via a web tool that streamlines the review process. Information from the police report was collected by answering a set of questions designed to elicit information that was otherwise not retrievable from the database. It is worth noting that certain micromobility-related crashes have occurred in off-road areas that are not currently included in the latest RCI GIS shapefiles. This review process aimed to fill in such missing data.

A total of 463 crash reports were reviewed. Information collected from the police review includes the presence of a bike lane, the presence of a sidewalk barrier, whether or not there is on-street parking, and whether the left turn is permitted or protected. Table 4.20 summarizes the questions asked in the police review tool.

Table 4.20: Information Collected from the Police Report Review

Question	Description	Attribute Values
Sidewalk barrier	Presence or absence of a sidewalk barrier	Yes or No
Number of lanes	Total number of lanes	Number (Integer)
Bike lane	Presence or absence of a bike lane and type of bike lane, if present	Yes-Designated, Yes-Buffered, Yes-Sharrow, Yes-Other, No
Street parking	Presence or absence of a street parking and whether on one side or both sides of the road	Yes- on both sides, Yes - on one side, No
Intersection type	Type of Intersection	Four-way Intersection, T-Junction, Driveway Access, Travel lane
Stop control	Whether a stop sign is on the minor approach only or all way	Minor road(s) only, All-way
Left turn vehicle	Crash location for crashes involving left-turn vehicles	Signalized intersection, Major unsignalized intersection, Driveway access
Left turn phase	Whether the left turn is permitted or protected on signalized intersection	Protected, Permitted

4.3.3.1 On-street Parking

Table 4.21 summarizes the crash data based on the presence of on-street parking. This information was analyzed to check whether on-street parking is associated with increased micromobility-related crash frequency and severity. The highest proportion of fatal and severe injury crashes occurred on roadways without on-street parking (65.1%). Furthermore, roadways with on-street parking on both sides were associated with almost 21.0% of fatal and severe injury crashes, followed by roadways with on-street parking on one side only (14.0%).

Table 4.21: Crash Statistics Based on the Presence of On-street Parking

On-street Parking	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
No	28	65.1	199	62.8	61	59.2	288	62.2
Yes – On both sides	9	20.9	77	24.3	29	28.2	115	24.8
Yes – On one side only	6	14.0	41	12.9	13	12.6	60	13.0
Total	**43**	**100**	**317**	**100**	**103**	**100**	**463**	**100**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

4.3.3.2 Bike Lane

Table 4.22 presents the crash statistics based on the presence of bike lanes. Three types of bike lanes were considered: buffered, designated (conventional), and sharrow (shared). Figure 4.7 illustrates the different types of bike lanes. The highest proportion of fatal and severe injury crashes occurred on roadways without bike lanes (67.4%). Furthermore, as presented in Table 4.22, roadways with shared lanes had the highest proportion of fatal and severe injury crashes (20.9%) compared to the other types of bike lanes, followed by conventional bike lanes (9.3%). Roadways with buffered bike lanes had the lowest proportion of fatal and severe injury crashes (2.3%) compared to the other categories analyzed.

Table 4.22: Crash Statistics Based on the Presence of Bike Lane

Presence of a bike lane	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
No	29	67.4	223	70.3	80	77.7	332	71.7
Yes - Buffered	1	2.3	10	3.2	3	2.9	14	3.0
Yes - Designated	4	9.3	31	9.8	11	10.7	46	9.9
Yes - Sharrow	9	20.9	53	16.7	9	8.7	71	15.3
Total	**43**	**100**	**317**	**100**	**103**	**100**	**463**	**100**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

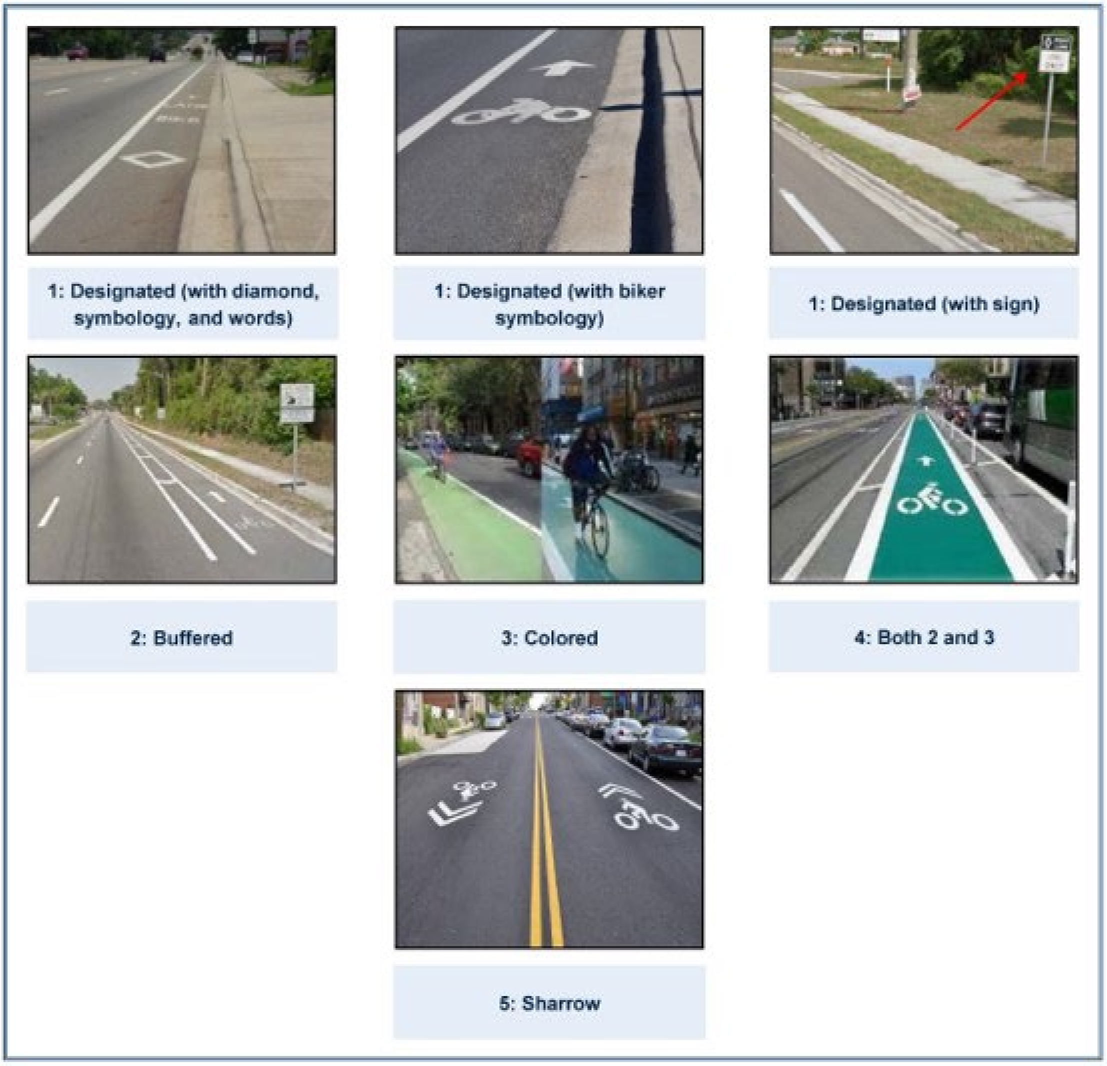


Figure 4.7: Types of Bike Lanes
(Source: FHWA, 2023)

4.3.3.3 Left Turn Crashes

Left Turn Crash Location

Left-turning crashes were also reviewed using the in-house web tool. The first objective was to identify the location of these crashes and the conditions associated with their occurrences. Typically, left-turning crashes can occur at intersections or driveway access. A total of 70 crashes were confirmed to involve left-turning vehicles. Table 4.23 presents the summary of left-turning crashes. The data was categorized into three crash locations: signalized intersection, major unsignalized intersection, or driveway access. Signalized intersections had the highest overall proportion of left-turning crashes (57.1%), and among those, the highest proportion of fatal and severe injury crashes was observed (60.0%). This was followed by major unsignalized intersections associated with 27.1% of left-turning crashes.

Table 4.23: Statistics for the Left-turning Crashes

Left Turning Crashes	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
Signalized Intersection	3	60.0	28	53.8	9	69.2	40	57.1
Major Unsignalized Intersection	1	20.0	16	30.8	2	15.4	19	27.1
Driveway Access	1	20.0	8	15.4	2	15.4	11	15.7
Total	**5**	**100**	**52**	**100**	**13**	**100**	**70**	**100**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

Left Turn Green Phase

The study further analyzed the crash reports, specifically focusing on left-turn crashes that occurred at signalized intersections. The purpose was to summarize the crashes based on the signalization treatment. Generally, there are three ways to accommodate left-turning traffic at intersections: permissive, compound (protected/permissive or permissive/protected) and protected. Out of 40 left-turning crashes at signalized intersections, 19 (47.5%) occurred on intersections with a permitted left turn, while 21 (52.5%) occurred on intersections with a protected or a compound left turn. Figure 4.8 presents a typical left-turning crash.

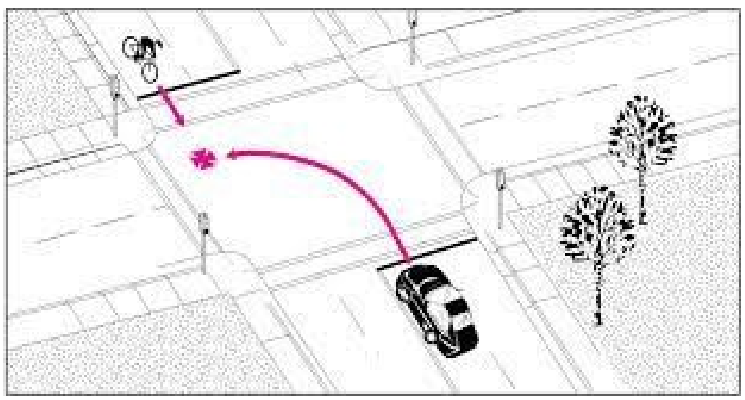


Figure 4.8: Typical Left-turn Crash
(Source: NCHRP, 2020)

4.3.3.4 Stop Controlled Intersections

The crashes that occurred at stop-controlled intersections were further analyzed. The analysis made a distinction based on whether the stop sign was present on only minor approaches or all approaches (all-way) at the intersections. A total of 100 crashes were confirmed to have occurred at stop-controlled intersections. Table 4.24 presents the summary of the crashes at stop-controlled intersections. The highest proportion of fatal and severe injury crashes occurred at intersections, with stop signs on minor approaches (92.3%).

Table 4.24: Crash Statistics at Stop-controlled Intersections

Stop Controlled Intersections	K+A		B+C		PDO		Total Count	%
	Count	%	Count	%	Count	%		
All Way	1	7.7	12	19.0	4	16.7	17	17.0
Minor approaches only	12	92.3	51	81.0	20	83.3	83	83.0
Total	**13**	**100**	**63**	**100**	**24**	**100**	**100**	**100**

K-fatal injury; A-incapacitating injury; B-non incapacitating injury; C-possible injury; PDO-Property Damage Only.

4.3.4 Key Findings

Key findings from the descriptive statistics of the crash data involving micromobility users from December 2018 through June 2022 include:

- About 10% of micromobility-related crashes resulted in fatalities or severe injuries.
- About 45% of micromobility-related crashes resulted in at least a minor injury.
- About 55% of the micromobility-related crashes occurred at or within 50 ft of an intersection.
- Intersection-related crashes were found to be more severe compared to the crashes at other locations.
- Most micromobility-related crashes occurred on Thursday, Friday, or Saturday.
- Most micromobility-related crashes occurred in February and March.
- The driver's action(s) contributed to the crash in about 50% of micromobility-related crashes.
- Failure to yield the right of way was the leading driver's action contributing to fatal and severe injury crashes (20.9%).
- In about 84% of the crashes, micromobility users did not wear safety equipment.
- Most fatal and severe injury crashes occurred during daylight and clear weather conditions.
- About 71% of micromobility-related crashes occurred on roadways without a dedicated bike or shared lanes.
- About 83% of micromobility crashes on stop-controlled intersections occurred on intersections with stop signs on minor approaches only.
- More crashes occurred on roadways with on-street parking on both sides compared to those with on-street parking on one side only.
- The most prominent crash types were "L-PO" for e-bikes and "S-CR"/"S-CL" for e-scooters.

4.4 Factors Contributing to Injury Severity of Micromobility-Related Crashes

A crash severity analysis was conducted to identify the factors influencing the injury severity of micromobility-related crashes. Injury severity is often reported on a KABCO scale, namely fatal (K), incapacitated injury (A), non-incapacitated injury (B), possible injury (C), or property damage only (O). To obtain statistically reliable estimates, this research used two injury severity categories by combining fatal (K), incapacitated (A), and non-incapacitated injury (B) (i.e., KAB); The other category combined possible injury (C) and PDO (O) (i.e., CO).

4.4.1 Bayesian Regression Model

The Bayesian regression model was used to explore the influence of various factors on the severity of micromobility-related crashes. The model was developed using the R studio software. The study adopted the Bayesian approach for the estimation of the predictor values. Thus, the model results give the distribution of betas instead of a single beta value when the maximum likelihood estimation (MLE) approach is used. In the Bayesian modeling technique, the prior distribution of each model parameter should be specified. In the absence of informative priors commonly obtained from previous studies that performed similar analyses, non-informative priors were assigned to the model parameters (Kruschke, 2013). The non-informative priors impose a minimal influence over the estimates and allow the data characteristics to dominate (Ntzoufras, 2009). This study used non-informative priors in the estimation of parameters.

The response variable is considered a binary variable with a KAB crash ($Y = 1$) and a CO crash ($Y = 0$), and can be defined with a vector of explanatory variables X_i, as presented in Equation 4.1.

$$Y_i = \begin{cases} 1\, for\ KAB\ crash \\ 0\, for\ CO\ crash \end{cases} \tag{4.1}$$

$$Y_i \sim Bernouli\ (\lambda_i)$$

$$logit\ (\lambda_i) = \beta_o + \beta_j X_i + \varepsilon_i$$

$$\beta_o \beta_j \sim N(0, 10)$$

$$\varepsilon_i \sim N(0, \sigma^2)$$

$$\sigma \sim Half\ Normal\ (0{,}10)$$

where,

λ_i represents the severity function of observation i,
β_j represents the vector of explanatory variables,
$N(0, 10)$ represents the prior distribution of the regression coefficient,
ε_i represents the stochastic error term, and
$Half\ Normal\ (0{,}10)$ represents the prior distribution of the disturbance term.

This analysis used Bayesian inference, which incorporates prior parameter information, to estimate model parameters. For the regression coefficients β_o and β_j, the non-informative priors were defined as normal distributions with a mean of zero and a standard deviation of 10.

4.4.2 Data Description

In Florida, injury severity is generally categorized into five categories: fatal (K), incapacitating (A), non-incapacitating (B), possible injury (C), and PDO (O). The Bayesian regression analysis performed in this research combined fatal (K), incapacitating (A), and non-incapacitating (B) injuries to form the first category. Possible injury (C) and PDO (O) were combined to form the second category. The data used in the Bayesian regression model were obtained from Signal Four Analytics and the FDOT RCI databases.

As presented in Table 4.25, the road type variable was categorized into three categories: one-way trafficway, two-way undivided, and two-way divided, which accounted for 15%, 60%, and 25% of the KAB crashes, respectively. Roadway grade was divided into two groups: level and downhill/uphill. On average, over 96% of KAB crashes occurred on level roadway segments, while only 4% occurred on sloping roadway segments.

The crash location variable was divided into two categories: intersection and non-intersection related crashes. Approximately 55% of KAB crashes occurred at intersections, while the remaining (45%) occurred at non-intersections. Sidewalk width was categorized into two groups: sidewalks with less than five feet (ft) and at least five ft. The former accounted for only about 5% of KAB crashes, while the latter accounted for the remaining 95%. Shoulder width was divided into two categories: shoulder widths < 6 ft and ≥ 6 ft. Roadways with shoulders less than six feet were associated with about 73.5% of KAB crashes, while roadways with a shoulder width of at least six ft were associated with the remaining 26.5%.

Weather conditions were divided into three classes: clear, cloudy, and rainy, associated with 90%, 6%, and 4%, respectively, of KAB crashes. About one-third of KAB crashes occurred during dark conditions, while the remaining two-thirds occurred in daylight. Furthermore, about 51% of KAB crashes occurred during peak hours, while 49% occurred during non-peak hours. Also, almost 60% of crashes occurred on weekends, while the remaining 40% occurred on weekdays.

The posted speed limit of the roadways was divided into two categories: roadways with a speed limit greater than 30 mph and those with less than or equal to 30 mph. The former was associated with about 30% of KAB crashes, while the latter was associated with the remaining 70%. Roadways with AADT greater than 15,000 vehicles per day (vpd) were associated with 48.8% of KAB crashes, while roadways with an AADT less than 8,000 vpd were associated with about 23% of KAB crashes. Roadways with curbed shoulders were associated with 52% of all KAB crashes, while the remaining 48% occurred on roadways with non-curbed shoulders.

Vehicle maneuver was categorized into three classes, where 56.7% of KAB crashes occurred while the vehicle was moving straight, and 26.2% and 17.1% of KAB crashes occurred when the vehicle was turning right and left, respectively. Male drivers accounted for over 70% of KAB crashes, while female drivers accounted for the remaining 30%. Male micromobility riders, on the other hand, were involved in over 60% of KAB crashes, while female riders were involved in the remaining 40%.

The age of the micromobility users was categorized into three classes: users under 19 years, users between the age of 20 and 39, and over 40 years. The driver's age variable was classified into four groups: drivers over 60 years, drivers between the ages of 40 and 59 years, drivers between the ages of 20 and 39, and teenagers (age <19). Most KAB crashes involved drivers between the ages of 40 to 59 years. Teenage drivers accounted for 6% of KAB crashes. Almost 20% of KAB crashes involved teenage micromobility riders, with about 25% involving riders of age 40 years or older. Lastly, in 13% of KAB crashes, both the driver and the micromobility rider were found to be at fault. While in most cases (48%), the driver was at-fault. In contrast, in 35% of the crashes, the non-motorists were found to be at-fault.

Table 4.25: Data Description

Variables	Levels	KAB		CO	
		Count	%	Count	%
Roadway					
Type of shoulder	Non-curbed	98	48.0%	161	62.2%
	Curbed	106	52.0%	98	37.8%
Road surface condition	Dry	192	94.1%	243	93.8%
	Wet	12	5.9%	16	6.2%
Roadway alignment	Straight	196	98.5%	246	97.2%
	Curve	3	1.5%	7	2.8%
Roadway grade	Level	192	96.0%	250	98.4%
	Uphill/downhill	8	4.0%	4	1.6%
Total lanes	1 or 2	86	42.6%	114	44.7%
	3+	116	57.4%	141	55.3%
Crash location	Intersection	106	52.0%	147	57.0%
	Non-Intersection	98	48.0%	111	43.0%
Trafficway	One-way	29	14.6%	41	16.3%
	Two-way Divided	50	25.3%	70	27.8%
	Two-way Undivided	119	60.1%	141	56.0%
Sidewalk width	Sidewalk width < 5 ft	7	4.1%	5	2.3%
	Sidewalk width ≥ 5 ft	165	95.9%	213	97.7%
Shoulder width	Shoulder width ≥ 6 ft	45	26.5%	51	23.4%
	Shoulder width < 6 ft	125	73.5%	167	76.6%
Posted speed limit	Speed ≤ 30 mph	124	70.5%	168	76.7%
	Speed > 30 mph	52	29.5%	51	23.3%
Presence of a bike lane	Yes	64	32.0%	67	26.4%
	No	136	68.0%	187	73.6%
AADT	< 8,000 vpd	39	22.9%	51	23.6%
	8,000 – 15,000 vpd	48	28.2%	44	20.4%
	> 15,000 vpd	83	48.8%	121	56.0%

Note: KAB refers to Fatal (K), Incapacitating (A), and Non-Incapacitating (B) Injury; CO refers to Possible Injury (C) and No Injury (O); NM = non-motorist; AADT = Annual Average Daily Traffic; mph = miles per hour; vpd = vehicles per day.

Table 4.25: Data Description (continued)

Variables	Levels	KAB		CO	
		Count	%	Count	%
Non-motorist					
Non-motorist maneuver	Crossing	119	62.6%	139	57.4%
	Parallel	71	37.4%	103	42.6%
Presence of alcohol	Yes	1	0.6%	1	0.4%
	No	170	99.4%	222	99.6%
Non-motorist gender	Male	13	61.9%	29	74.4%
	Female	8	38.1%	10	25.6%
Non-motorist age	0-19	28	18.8%	23	13.5%
	20-39	86	57.7%	115	67.3%
	40+	35	23.5%	33	19.3%
Vehicle/Driver					
Vehicle maneuver	Straight ahead	106	56.7%	129	55.1%
	Turning Left	32	17.1%	39	16.7%
	Turning Right	49	26.2%	66	28.2%
At-fault party	Both at fault	20	13.0%	21	10.5%
	Driver at fault	74	48.1%	72	36.0%
	NM at fault	53	34.4%	85	42.5%
	None at fault	7	4.5%	22	11.0%
Driver gender	Male	126	72.4%	145	65.6%
	Female	48	27.6%	78	35.3%
Driver age	0-19	10	5.8%	8	3.6%
	20-39	64	37.4%	94	42.7%
	40-59	68	39.8%	83	37.7%
	60+	29	17.0%	35	15.9%
Presence of alcohol	Yes	2	1.2%	3	1.4%
	No	169	98.8%	218	98.6%
Environmental					
Lighting condition	Daylight	131	64.2%	175	67.6%
	Dark	73	35.8%	84	32.4%
Weather condition	Clear	184	90.2%	234	90.3%
	Cloudy	12	5.9%	15	5.8%
	Rainy	8	3.9%	10	3.9%
Crash					
Time of the day	Peak hour	104	51.0%	125	48.3%
	Non-Peak hour	100	49.0%	134	51.7%
Type of day	Weekend	119	58.3%	145	56.0%
	Weekday	85	41.7%	114	44.0%

Note: KAB refers to Fatal (K), Incapacitating (A), and Non-Incapacitating (B) Injury; CO refers to Possible Injury (C) and No Injury (O); NM = non-motorist; AADT = Annual Average Daily Traffic; mph = miles per hour; vpd = vehicles per day.

Some of the variables in Table 4.25 were not used in the formulation of the model for a variety of reasons. Non-motorist age and gender were excluded due to missing data. Roadway alignment and grade were also excluded due to a high imbalance across the response variable. The last category of variables removed from the model included highly correlated variables.

4.4.3 Correlation

The variable correlation was checked before fitting the model. The check was done since using multiple variables that are highly correlated with each other may sometimes be redundant or may worsen the performance of the model. Figure 4.9 presents the variable correlation in this study. It's worth noting the selection of levels in our variables affects the correlation values. Based on Figure 4.9, weather and road surface conditions were highly correlated, and the former was used in the model formulation.

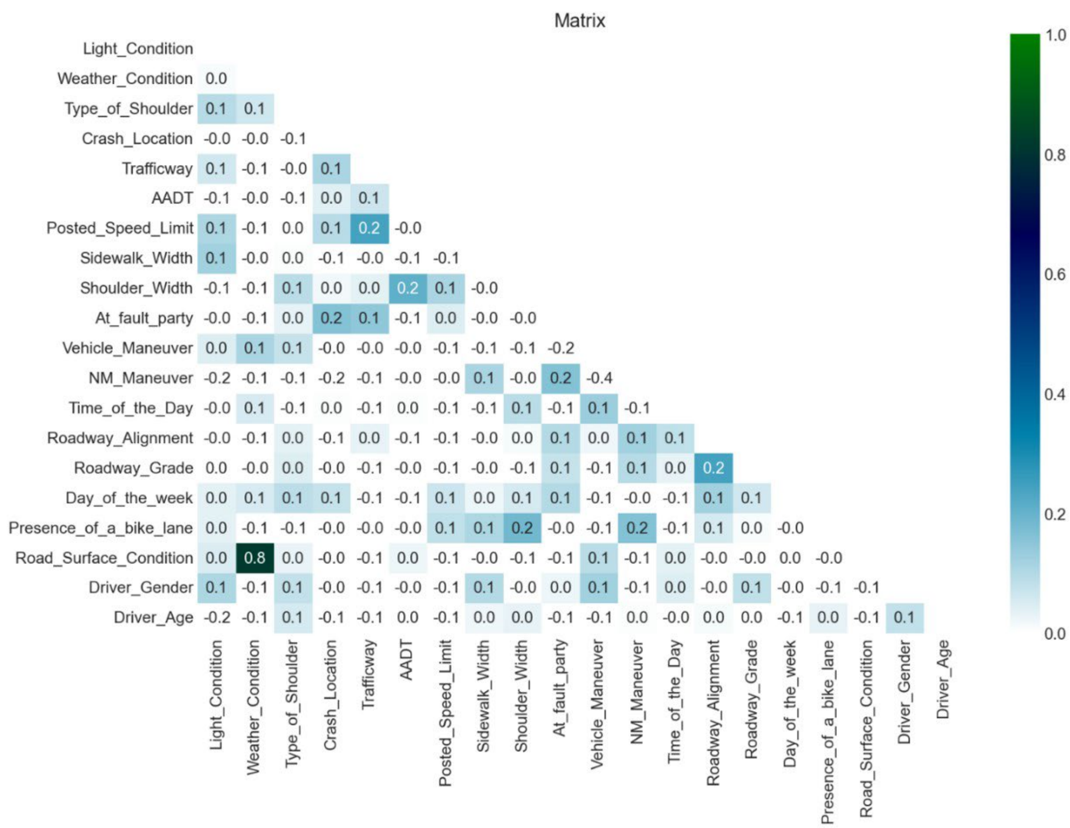


Figure 4.9: Variable Correlation

4.4.4 Model Results

The Bayesian regression model analyzed the factors influencing injury severity in micromobility-related crashes. Out of the 16 explanatory variables, 11 were found to be significant at various Bayesian Credible Intervals (BCI). Table 4.26 summarizes the significant variables and their corresponding BCIs. Table 4.27 presents the results of the Bayesian regression model.

Table 4.26: Summary of the Significant Variables

Variables	Bayesian Credible Interval (BCI)
Type of shoulder	95%
Annual Average Daily Traffic	
Sidewalk width	90%
Weather conditions	
At faulty party	80%
Presence of a bike lane	
Lighting conditions	70%
Shoulder width	
Trafficway	60%
Total lanes	50%
Vehicle maneuver	

Table 4.27: Bayesian Regression Model Results

Variables	Levels	Mean	SE	OR	BCI	
					Lower	Upper
Intercept		**-0.336**	**0.912**	**0.71**	**-2.006**	**1.451**
Type of shoulder	Non-curbed	Base				
	Curbed	**0.949**	**0.337**	**2.58**	**0.327[a]**	**1.602[a]**
AADT	8,000 – 15,000 vpd	Base				
	< 8,000 vpd	**-0.962**	**0.471**	**0.38**	**-1.992[a]**	**-0.095[a]**
	15,000+ vpd	-0.304	0.398	0.74	-1.035[f]	0.501[f]
Sidewalk Width	Sidewalk width ≥ 5 ft	Base				
	Sidewalk width < 5 ft	**2.343**	**1.577**	**10.41**	**0.147[b]**	**5.060[b]**
Weather Conditions	Clear	Base				
	Cloudy	-0.035	0.581	0.97	-1.059	0.846
	Rainy	**-1.634**	**0.983**	**0.20**	**-3.288[b]**	**-0.109[b]**
At-fault	None at fault	Base				
	Driver at fault	**0.804**	**0.627**	**2.23**	**0.002[c]**	**1.603[c]**
	NM at fault	0.041	0.672	1.04	-0.796	0.896
	Both at fault	0.061	0.772	1.06	-0.952	1.002
Presence of a bike lane	Yes	Base				
	No	**-0.410**	**0.328**	**0.66**	**-0.849[c]**	**-0.001[c]**
Lighting conditions	Daylight	Base				
	Dark	**0.384**	**0.339**	**1.47**	**0.023[d]**	**0.724[d]**
Shoulder Width	Shoulder width ≥ 6 ft	Base				
	Shoulder width < 6 ft	**-0.447**	**0.425**	**0.64**	**-0.838[d]**	**-0.012[d]**
Trafficway	Two-way Undivided	Base				
	One-way	-0.273	0.426	0.76	-0.619	0.065
	Two-way Divided	**-0.338**	**0.368**	**0.71**	**-0.634[e]**	**-0.030[e]**
Total lanes	1 or 2	Base				
	3+	**0.248**	**0.354**	**1.28**	**0.002[f]**	**0.484[f]**

Note: SE =Standard Error; OR = Odds Ratio; BCI = Bayesian Credible Interval; NM = non-motorist; AADT = Annual Average Daily Traffic; vpd = vehicles per day. **Values in bold are significant**; a = 95%; b = 90%; c = 80%; d = 70%; e = 60%; f = 50%.

Table 4.27: Bayesian Regression Model Results (continued)

Variables	Levels	Mean	SE	OR	BCI	
					Lower	Upper
Intercept		**-0.336**	**0.912**	**0.71**	**-2.006**	**1.451**
Vehicle Maneuver	Straight ahead	Base				
	Turning Right	**-0.320**	**0.386**	**0.73**	**-0.584[f]**	**-0.062[f]**
	Turning Left	**-0.391**	**0.476**	**0.68**	**-0.713[f]**	**-0.073[f]**
Crash Location	Intersection	Base				
	Non-Intersection	0.091	0.333	1.10	-0.569	0.710
Posted Speed Limit	Speed ≤ 30	Base				
	Speed >30	0.211	0.354	1.23	-0.462	0.900
Non-motorist Maneuver	Parallel	Base				
	Crossing	0.215	0.398	1.24	-0.557	1.003
Time of the day	Non-Peak hour	Base				
	Peak hour	0.172	0.312	1.19	-0.460	0.822
Day	Weekday	Base				
	Weekend	0.088	0.316	1.09	-0.504	0.673

Note: SE =Standard Error; OR = Odds Ratio; BCI = Bayesian Credible Interval; NM = non-motorist; AADT = Annual Average Daily Traffic; vpd = vehicles per day. **Values in bold are significant**; a = 95%; b = 90%; c = 80%; d = 70%; e = 60%; f = 50%.

4.4.5 Summary

The following factors were found to increase the likelihood of KAB injury severity in micromobility-related crashes:

- ***Sidewalk width (< 5 ft)***: Sidewalk widths of less than 5 ft increase the likelihood of KAB injuries by 10.4 times, compared to sidewalk widths of ≥ 5 ft [Odds ratio = 10.41, 90% BCI (0.147, 5.060)].
- ***Curbed shoulders***: Roadways with curbed shoulders increase the likelihood of a KAB injury by almost 2.6 times, compared to roadways with non-curbed shoulders [Odds ratio = 2.58, 95% BCI (0.327, 1.602)].
- ***At-fault motorists***: Crashes where the driver of a vehicle is determined to be at-fault increases the likelihood of KAB injuries by 123%, compared to no-fault crashes, i.e., no one involved is determined to be at-fault [Odds ratio = 2.23, 80% BCI (0.002, 1.603)].
- ***Dark lighting conditions***: Crashes occurring during dark conditions are 47% more likely to result in a KAB injury, compared to daylight conditions [Odds ratio = 1.47, 70% BCI (0.023, 0.724)].
- ***Three or more travel lanes***: Roadways with three or more travel lanes increase the likelihood of a KAB injury by 23%, compared to roadways with fewer than three lanes [Odds ratio = 1.28, 50% BCI (0.002, 0.484)].

The following factors were found to reduce the likelihood of KAB severity in micromobility-related crashes:

- ***AADT (< 8,000 vpd)***: Crashes that occur on roadways with AADT volumes of < 8,000 vpd are 60% less likely to result in KAB injuries, compared to roadways with AADT volumes of 8,000 to 15,000 vpd [Odds ratio = 0.38, 95% BCI (-1.992, -0.095)].
- ***Rainy weather conditions***: Crashes that occur during rainy conditions are 80% less likely to result in KAB injuries, compared to clear conditions [Odds ratio = 0.20, 90% BCI (-3.288, -0.109)].
- ***Shoulder width (< 6 ft)***: Shoulder widths of less than 6 ft decrease the likelihood of KAB injuries by 36%, compared to shoulder widths of ≥ 6 ft [Odds ratio = 0.64, 70% BCI (-0.838, -0.012)].
- ***Divided roadways***: Crashes that occur on two-way divided roadways are 29% less likely to result in KAB injuries, compared to two-way undivided roadways [Odds ratio = 0.71, 60% BCI (-0.634, -0.030)].
- ***Vehicle maneuver (turning left or right)***: Crashes that involve a vehicle turning right or turning left are 27% [Odds ratio = 0.73, 50% BCI (-0.584, -0.062)] and 32% [Odds ratio = 0.68, 50% BCI (-0.713, -0.073)], respectively, less likely to result in KAB injuries, compared to crashes that involve a vehicle moving straight.
- ***No bike lanes***: Crashes that occur on roadways without bike lanes are 34% less likely to result in KAB injuries, compared to roadways with bike lanes present [Odds ratio = 0.66, 80% BCI (-0.849, -0.001)].

Based on the model results, roadways with curbed shoulders and at least three lanes have shown to increase the likelihood of KAB crashes. These characteristics are indicative of a high-speed roadway where the crash impact tends to be severe. Also, sidewalk width less than 5 ft has been associated with an increased likelihood of KAB crashes.

CHAPTER 5
CRASH MODIFICATION FACTORS (CMFs)

This chapter focuses on crash modification factors (CMFs) for micromobility-related crashes in Florida. The objective involved developing CMFs for both roadway segments and signalized intersections.

5.1 Introduction

Micromobility devices are any motorized transportation devices incapable of traveling at speeds greater than 20 miles per hour (mph) on level ground. These devices are made available for private use by reservation through an online application, website, or software for point-to-point trips. Micromobility devices include electric bikes (e-bikes), electric scooters (e-scooters), shared bicycles, and electric pedal-assisted bicycles. These devices can be owned and operated privately or as part of a shared system. As part of the Florida Department of Transportation (FDOT's) Automated, Connected, Electric, and Shared (ACES) Transportation initiative, shared micromobility has been one of the rapidly growing transportation strategies adopted by several agencies across the state of Florida.

The substantial increase in the usage of micromobility systems in Florida and the US at large, increases the need to analyze safety implications and the occurrence of crashes involving micromobility systems. In recent years, transportation agencies have implemented diverse strategies to combat micromobility crash occurrences and severity, such as ensuring bicycle facilities such as bike lanes, proper parking corrals, speed limit reduction, bicycle boulevards, etc., are installed before permitting micromobility systems to operate. However, the specific impact of such strategies that they may have on reducing micromobility-related crashes remains uncertain. This research aims to assess the safety implications of various on-street facilities and strategies towards safety of micromobility users.

5.1.1 Crash Modification Factor (CMF)

A CMF is a multiplicative factor that is used to compute the expected number of crashes when a particular countermeasure is implemented at a specific site.

- A CMF greater than 1.0 indicates an expected increase in crashes when a particular countermeasure is implemented.
- A CMF less than 1.0 indicates an expected reduction in crashes when a particular countermeasure is implemented.

For example, a CMF of 0.6 indicates a 40% expected reduction in crashes, while a CMF of 1.2 indicates a 20% expected increase in crashes.

5.1.2 Study Area

The study area for this project was targeted to include cities in Florida with established shared micromobility systems. Most of these cities have defined service areas for shared micromobility services, which served as guidelines for selecting the study areas. In this research, the CMFs were developed based on data from Miami Beach and Miami Downtown regions. However, note that the unique characteristics of tourist-heavy regions such as Miami Beach and Miami Downtown could potentially influence the effectiveness and applicability of the estimated CMFs. Their impact could vary in areas with different urban layouts, traffic patterns, or levels of shared micromobility usage. For example, the results may not be entirely applicable to cities such as Tampa or Jacksonville. For this reason, it is important to note that the estimated CMFs in this research effort may be more suitable for tourist regions.

5.2 Data

This section explains the data used in the analysis. It discusses the data sources and data collection efforts undertaken in this research.

5.2.1 Data Sources

This study utilized multiple data sources to achieve its objectives. Geometric, traffic, and crash data were obtained from the following data sources.

i) Google Maps
ii) Florida GIS shapefiles
iii) Signal Four Analytics
iv) FDOT Roadway Characteristic Inventory (RCI)

5.2.2 Roadway Segment Data

A total of 11 variables were examined for both the Miami Beach and Miami Downtown regions. The data for these variables, apart from the Annual Average Daily Traffic (AADT), were manually collected using Google Maps. The AADT data were obtained from the FDOT ArcGIS shapefile. The classification and categorization of these variables were in alignment with the guidelines provided in the FDOT Roadway Characteristics Inventory (RCI) Handbook. The following variables were considered in the analysis of the roadway segments.

- **Section AADT:** This variable represents an estimate of the Annual Average Daily Traffic (AADT) traversed on the roadway section. The natural logarithm of AADT was utilized in the development of the negative binomial models. AADT values for the roadway segments were obtained from FDOT GIS shapefiles.

- **Number of Lanes:** This variable represents the total number of lanes on the segment. Information related to the number of lanes was collected manually from the Google Maps. For both divided and undivided roadways, only the total numbers of lanes were considered.

- **Bicycle Lane:** This variable identifies roadway segments with a dedicated bike lane. The presence or absence of a dedicated bike lane was considered in the analysis. This information was manually collected from Google Maps.

- **Sharrow Lanes:** This variable represents the roadway segments with sharrow lanes. The presence or absence of sharrow lanes was considered in the analysis. This information was manually collected from Google Maps. Roadway segments coded as having sharrow lanes featured sharrow pavement markings.

- **Median Type:** This variable represents the type of median of the roadway segment for divided roadways. Undivided roadways were coded as having no median in the analysis. Information related to the median type of the segment was manually collected from Google Maps. The different types of medians considered in the analysis include paved, raised traffic separators, vegetation, curb & vegetation, and others, including roundabouts and traffic circles. Figure 5.1 presents the median type categories.

- **Sidewalk:** This variable identifies roadway segments with sidewalks. The presence or absence of a sidewalk was considered in the analysis. This information was manually collected from Google Maps.

- **Sidewalk Barrier:** This variable identifies roadway segments with sidewalk barriers, which serve to separate vulnerable road users from regular traffic. The presence or absence of a sidewalk was considered in the analysis. This information was manually collected from Google Maps.

- **Trafficway/ Road Type:** This variable identifies whether the roadway is divided or undivided. This information was manually collected from Google Maps.

- **Posted Speed Limit:** This variable represents the posted speed limit on the roadway segment. This information was retrieved from Google Maps-Street View.

Figure 5.1: Median Type Categories

- **Shoulder Type:** This variable represents the type of shoulder on the roadway segment. The different shoulder types considered in the analysis include raised curb, paved, paved with a warning device, lawn, and curb & gutter. Figure 5.2 presents the shoulder type categories. The information on the shoulder type for each segment was manually collected from Google Maps.

Figure 5.2: Shoulder Type Categories

Table 5.1 presents the descriptive statistics of the roadway segment data.

Table 5.1: Descriptive Statistics of Roadway Segments

Attribute	Attribute Category	Value
Roadway Length (miles)	---	103.9
Crash Frequency (2021-2023)	Total	86
Section AADT (veh/day)	Minimum value	1,900
	Maximum value	53,000
	Average	17,574
	Standard Deviation	13,615
Number of Lanes	1&2	28.6
	3&4	58.4
	5&6	16.3
Median Type (miles)	No median	47.1
	Paved	17.3
	Curb & Vegetation	38.1
	Raised Traffic Separator	1.5
Bicycle Lane (miles)	Absent	69.0
	Present	34.3
Shoulder Type (miles)	Raised Curb	2.1
	Paved	62.8
	Paved with a warning device	1.1
	Lawn	7.6
	Curb & Gutter	30.3
Speed Limit (miles)	Speed limit – 20 mph	4.6
	Speed limit – 25 mph	20.6
	Speed limit – 30 mph	61.2
	Speed limit – 35 mph	8.8
Sidewalk (miles)	Absent	17.5
	Present	85.6
Sidewalk Barrier (miles)	Absent	51.3
	Present	52.0
Trafficway (miles)	Undivided	64.4
	Divided	39.0
Sharrow Lanes (miles)	Absent	51.1
	Present	52.2

5.2.3 Intersection Data

Data pertaining to signalized intersections were manually collected from Google Maps and Google Earth. The following variables were considered in the CMFs estimation for signalized intersections.

- **Major Road AADT:** This variable represents an estimated average number of vehicles that travel on the major road approaching the intersection daily over the course of a year. Major road AADT was retrieved from the FDOT ArcGIS shapefile.

- **Number of Intersection Legs:** This variable represents the total number of roadways entering an intersection, and was used to identify the type of intersection. Intersection types were classified as either four-leg or three-leg intersections. This information was manually collected from Google Maps.

- **Number of Approaches with Exclusive Right Turn Lane:** This variable identifies the number of approaches with exclusive right turn lanes. This information was manually collected from Google Maps.

- **Number of Approaches with Exclusive Left Turn Lane:** This variable identifies the number of approaches with exclusive left turn lanes. This information was manually collected from Google Maps.

- **Presence of Bicycle Facility:** This variable represents whether an intersection features a dedicated bike lane or a sharrow lane from any approach. This information was manually collected from Google Maps.

- **Presence of Lighting:** This variable identifies whether the intersection has street lights or not. This information was manually collected from the Google Maps Street View.

- **Number of Approaches with Permitted Left Turn Signal:** This variable represents the number of approaches with permitted LT signal. Permitted left turn signals allow drivers to make left turns simultaneously with opposing through movements, requiring drivers to yield. This information was manually collected from the Google Maps Street View.

- **Number of Approaches with Protected-Permitted LT Signal:** This variable represents the number of approaches with protected-permitted LT signal. This information was manually collected from the Google Maps Street View.

- **Number of Approaches that are One-way Streets:** This variable identifies the number of approaches that are one-way streets. This information was manually collected from the Google Maps Street View.

- **Number of Approaches with No Turn Right on Red Sign:** This variable represents the number of approaches with no turn on red sign. This information was manually collected from the Google Maps Street View.

Figures 5.3 and 5.4 present the spatial location of the signalized intersections in Miami Downtown and Miami Beach, respectively. Table 5.2 presents the descriptive summary of signalized intersections.

Figure 5.3: Signalized Intersections in Miami Downtown

Figure 5.4: Signalized Intersections in Miami Beach

Table 5.2: Descriptive Statistics of Signalized Intersections

Attribute	Attribute Category	Three-Leg Intersection	Four-Leg Intersection	Total
Number of Sites	---	89	298	387
Total Crashes	---	20	128	148
AADT on Major Roads (veh/day)	Minimum value	2050	2050	-
	Maximum value	47500	121000	-
	Average	19957	21139	-
	Standard Deviation	10743	13722	-
No. of Legs	---	3	4	-
No. of Approaches with Left Turn Lanes	0	33	94	127
	1	42	70	112
	2	14	82	96
	3	-	27	27
	4	-	25	25
No. of Approaches with Right Turn Lanes	0	58	186	244
	1	29	80	109
	2	2	31	33
	3	-	1	1
No. of Approaches which are One-way Streets	0	49	129	178
	1	33	107	140
	2	7	62	69
No. of Approaches with Permitted LT Signal	0	19	55	74
	1	21	54	75
	2	28	106	134
	3	21	16	37
	4	-	67	67
No. of Approaches with Protected-Permitted LT Signal	0	63	184	247
	1	17	41	58
	2	9	41	50
	3	-	20	20
	4	-	12	12
No. of Approaches with No Right Turn on Red	0	82	259	341
	1	7	28	35
	2	-	5	5
	3	-	2	2
	4	-	4	4
Presence of Bike Lane	1	28	70	98
	2	61	228	289
Presence of Lighting	1	-	1	1
	2	89	297	386

For each of these variables, a specific base condition was considered to help understand the relative effect of different traffic control measures and physical characteristics on the safety performance of signalized intersections.

5.2.4 Crash Data

The crash data used in this study were obtained from the Signal Four Analytics database. This study utilized data from crashes involving micromobility devices that occurred in Florida between January 2021 and December 2023. Signal Four Analytics provided the crash data. Signal Four Analytics is an interactive Web-based system designed to support law enforcement and research institutions' crash mapping and analysis needs. Crash reports were extracted from the Signal Four Analytics, specifically Miami Beach and Miami Downtown regions. The data processing procedure involved the following steps.

5.2.4.1 Text-mining Algorithm

No specific variable in the crash database could be used to identify micromobility-related crashes. Therefore, a text-mining algorithm was developed to identify crash reports involving shared micromobility devices. Crash reports with the keywords 'micromobility', 'scooter', 'e-scooter', 'motorized', 'e-bike',' Citi Bike', 'DECOBIKE' and 'electric' were extracted using the Tesseract package in R software. This step was important to reduce the number of crash reports that need to be manually reviewed to ensure that the crashes indeed involved micromobility devices.

5.2.4.2 Police Crash Report Review

After the text-mining process, the next step was to manually review the crash reports that had at least one of the keywords to ensure they actually involved micromobility devices. This step was important because crash reports may have the keywords, but not involve micromobility. For example, a crash that involves an electric wheelchair would be included because it has the keyword "electric". Such crashes were removed from the dataset.

A total of 301 crashes involving shared micromobility devices were identified. Out of these 301 crashes, 156 (50%) were from Miami Downtown, while 155 crashes occurred in Miami Beach. For the purpose of this analysis, intersection-related crashes were defined based on the 250-ft buffer from the intersection. Figure 5.5 displays the summary of the descriptive characteristics of the crash data. Figures 5.6 and 5.7 present the spatial distribution of the crash data across Miami Beach and Miami Downtown, respectively.

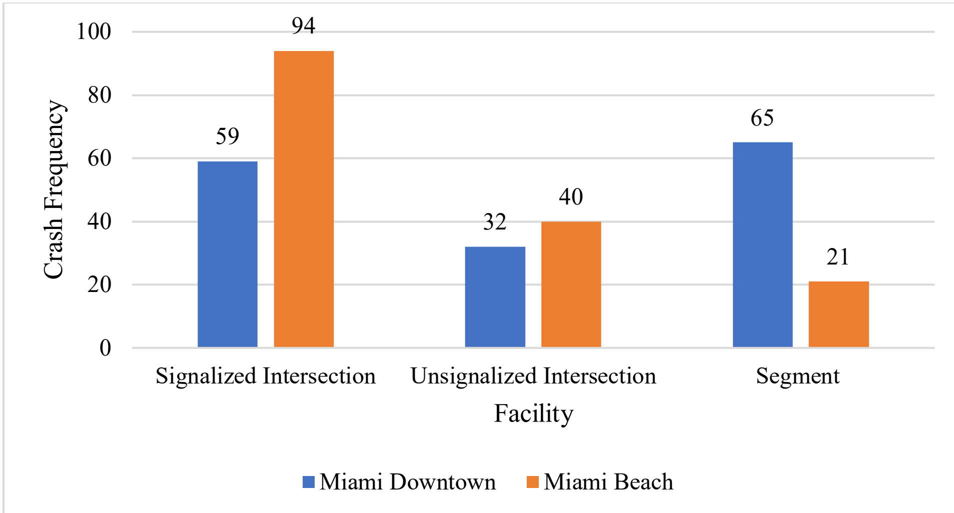


Figure 5.5: Crash Statistics by Facility Type

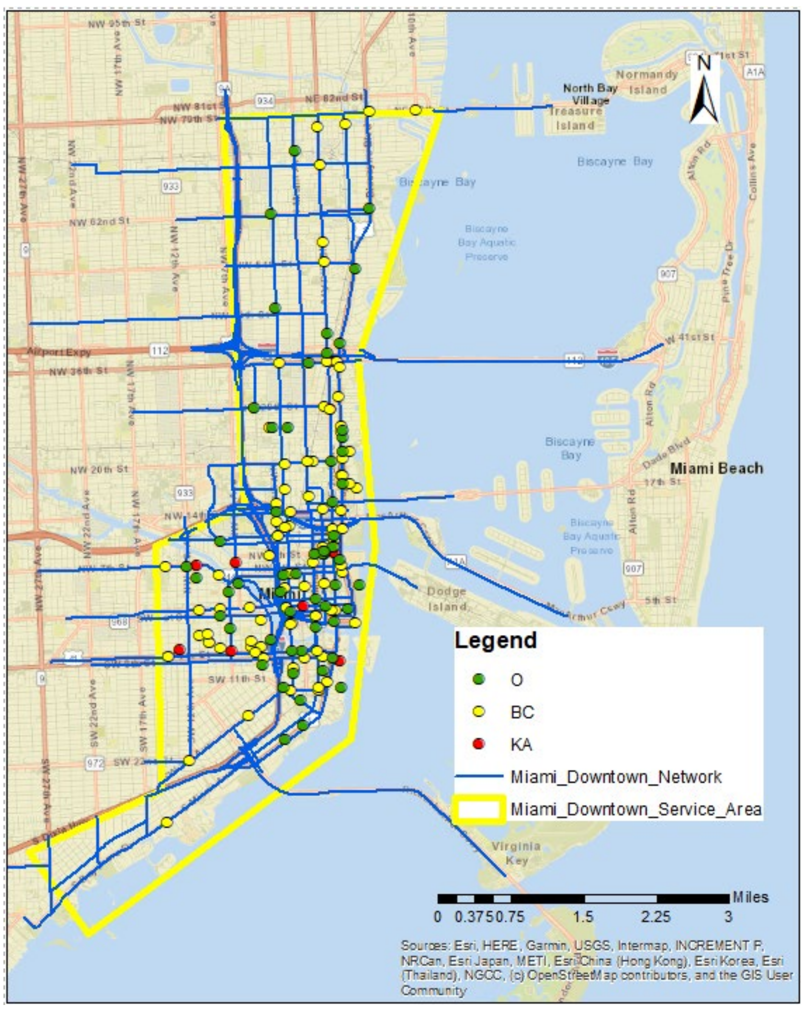


Figure 5.6: Spatial Distribution of Micromobility Crashes in Miami Downtown

Figure 5.7: Spatial Distribution of Micromobility Crashes in Miami Beach

5.3 Methodology

A cross-sectional analysis was used to develop CMFs for micromobility crashes in Florida. Cross-sectional studies serve as an effective approach for estimating CMFs in situations where conducting before-and-after studies is not feasible. This could be due to a lack of adequate crash data before and after the implementation of a specific engineering measure, uncertainty regarding when a treatment was applied, or challenges in isolating the impact of a countermeasure from other influencing factors. This is especially true when estimating CMFs for micromobility crashes in Florida. Given the nature of the datasets available for this research, along with an evaluation of methodological strengths and weaknesses, a cross-sectional study was determined to be the most appropriate method for developing CMFs.

In cross-sectional studies, crash experience at locations with and without a specific feature is studied, and then the difference in safety is attributed to that feature. The CMF can be estimated from the ratio of average crash frequency for sites with and without the treatment/ countermeasure.

As demonstrated in Figure 5.8, the studies only measure the "after" period. Control sites are chosen to compare with the treated site(s). The assumption is that the average value of the performance measure for all similar sites would be the same, so any difference among the averages would be due to the application of the strategy(s) at the sites.

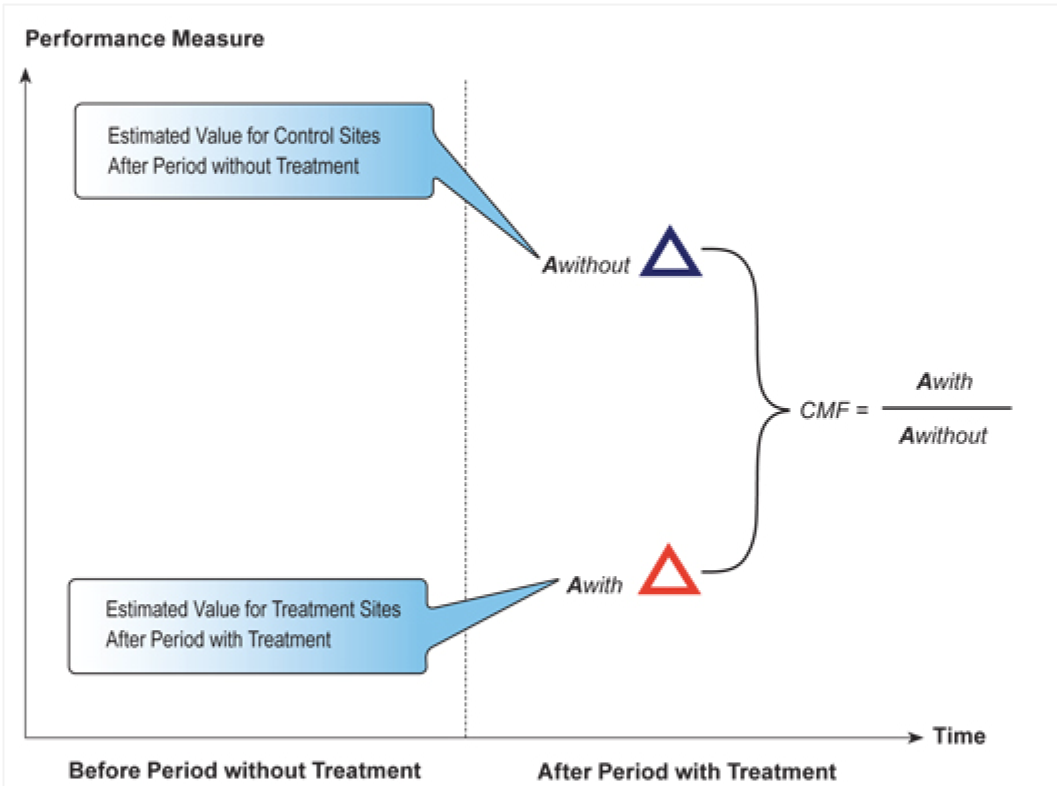


Figure 5.8: Cross-Sectional Study

This research used a Zero Inflated Negative Binomial Model (ZINB) to develop the relevant multivariate regression models. The models have crash frequency as the dependent variable, i.e., response variable, and the roadway characteristics as independent variables, i.e., explanatory variables. Equation 5.1 illustrates the basic form of a multivariate regression model.

The multivariate regression models attempt to address all the variables that have the potential for safety improvement. The models are developed using crash data from sites both with and without the treatment/countermeasure. The change in crashes from a unit change in a specific variable can be estimated from the regression model. The CMFs are then deduced from the model parameters.

$$\mu_i = e^{\beta_0 + \beta_1 \times \ln AADT + \ldots + \beta_k \times X_{ik} + OFFSET} \quad (5.1)$$

where,

μ_i = crash frequency on a road section i,
AADT = average annual daily traffic on a road section (vehicle/day),
X_{ik} = roadway characteristic k of road section i,
β_0 = model intercept/constant,
$\beta_1, \beta_2 \ldots, \beta_k$ = model coefficients, and
OFFSET = ln (3× (segment length)) for segments to predict crash frequency in crashes per mile. The number 3 was used since the analysis period was three years.

The Zero-inflated distributions are two regime models: predicting the zero-inflation probability and predicting a constant zero-inflation probability across observations. The first part (i.e., the zero-inflation probability model) governs whether the given frequency is a zero or a positive number. The second part of the distribution then takes care of the positive frequency. Both parts of the model are used to make full use of the data with excess zeros. The model was computed using the pscl package on the open-source program "R". Equation 5.2 presents the probability distribution of the ZINB random variable y_i.

$$Prob(y_i = j) = \begin{cases} \pi_i + (1 - \pi_i)\, g(y_i = 0), if\ j = 0 \\ (1 - \pi_i)\, g(y_i), if\ j > 0 \end{cases} \tag{5.2}$$

where, π_i is the proportion of true zeros that cannot be explained by the NB model, and $g(y_i)$ follows the negative binomial distribution as presented in Equation 5.3:

$$g(y_i) = Prob\ (Y = y_i \mid \mu_i, \alpha) = \frac{\Gamma(y_i + \alpha^{-1})}{\Gamma(y_i + 1)\Gamma(\alpha^{-1})}\ (\frac{1}{1+\alpha\mu_i})^{\alpha^{-1}} (\frac{\alpha\mu_i}{1+\alpha\mu_i})^{y_i} \tag{5.3}$$

where, μ_i is the mean crash frequency, and α is the over-dispersion parameter.

CMFs can be inferred from the estimated model parameters, i.e., coefficients; and as the model form is log-linear, the CMFs can be calculated as the exponent of the associated coefficient of the countermeasure variable, as shown in Equation 5.4:

$$CMF = exp\left(\beta_k \times (X_{kt} - X_{ku})\right) = exp(\beta_k) \tag{5.4}$$

where, X_{kt} is roadway characteristic k (i.e., countermeasure) of a treated site, and X_{ku} is roadway characteristic k (i.e., countermeasure) of an untreated site.

5.4 Results

5.4.1 CMFs for Roadway Segments

This section discusses the estimated CMFs for micromobility-related crashes on roadway segments. Due to the lack of enough data points, a single model was used to estimate CMFs for roadway segments with different numbers of lanes. ZINB model for the roadway segments was developed by considering the following variables.

- Section AADT
- Number of Lanes
- Median Type
- Bicycle Lane
- Sharrow Lanes
- Sidewalk
- Sidewalk Barrier
- Trafficway
- Speed Limit
- Shoulder Type

Before fitting the model, the correlation between variables was examined. This step is crucial because including multiple highly correlated variables can be superfluous or even impair the model's effectiveness. Figure 5.9 presents the variable correlation for the roadway segment model. It's worth noting the selection of levels in our variables affects the correlation values. Based on Figure 5.9, the variables 'Trafficway' and 'Median Type' were highly correlated, and the latter was used in the model formulation. Also, the variable 'Number of Lanes' was removed from the model as it was correlated to variables 'AADT', 'Median Type', and 'Trafficway' and hence was removed from the model formulation.

Table 5.3 presents the results of the NB model for roadway segments. Table 5.4 presents the summary of the estimated CMFs for total crashes involving micromobility devices on roadway segments. Table 4 includes the model coefficients and the corresponding CMFs. Only the variables that were significant at a 70% confidence interval were used to estimate the CMFs.

The interpretation of the CMFs can be as follows, a unit increase in the explanatory/predictor variable results in an increase or decrease of a certain percentage of micromobility-related crashes per mile per year.

- The presence of a paved median type increases the probability of micromobility-related crashes by 160% compared to when the roadway segment does not have a median.
- The presence of a curb and vegetation median type decreases the probability of micromobility-related crashes by 90% compared to when the roadway segment does not have a median.
- The presence of a sidewalk barrier of any kind decreases the probability of micromobility-related crashes by 70% compared to when the roadway segment does not have a sidewalk barrier.
- The presence of a dedicated bike lane decreases the probability of micromobility-related crashes by 80% compared to when the segment does not have a dedicated bike lane.

- The presence of a sharrow lane increases the probability of micromobility-related crashes by almost five times compared to when the roadway segment does not have a dedicated bike lane.

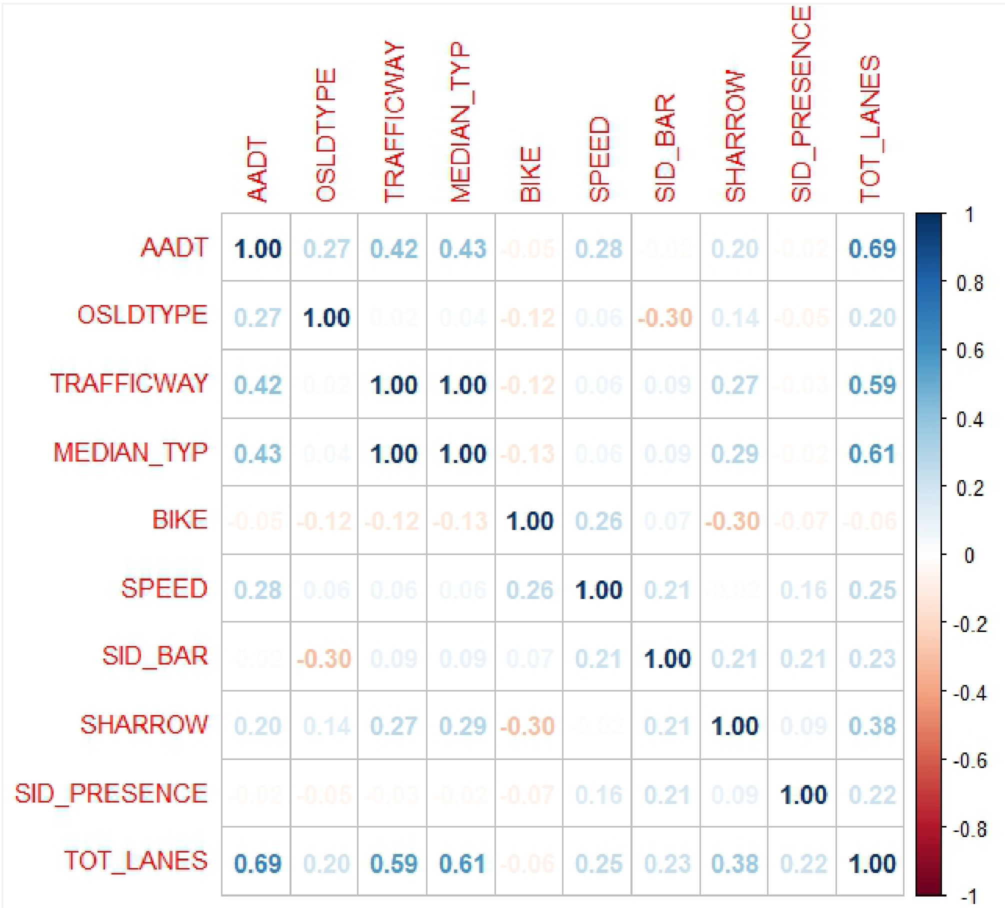


Figure 5.9: Variable Correlation for Roadway Segment Model

Note: **NB:** AADT = Section Average Annual Daily Traffic,
TOT_LANES = Total Number of Lanes,
MEDIAN_TYP = Median Type,
BIKE = Presence of Bicycle Lane,
SHARROW = Presence of Sharrow Lanes,
SIDEWALK = Presence of Sidewalk,
SID_BAR = Presence of Sidewalk Barrier,
TRAFFICWAY = Road Type,
SPEED = Speed Limit, and
OSLDTYPE = Shoulder Type.

Table 5.3: ZINB Model Results for Roadway Segments

Base	Level	Estimate	Std. Error	z value	Pr(>|z|)
	Intercept	-27.39	3049.00	-0.009	0.9928
	Section AADT	1.23	0.62	1.963	0.0496
Median Type = No Median	Paved	0.94	0.82	1.146	0.2517
	Curb and Vegetation	-2.07	0.77	-2.678	0.0074
Speed Limit = 25 mph	Speed Limit = 20 mph	-18.64	9966.00	-0.002	0.9985
	Speed Limit = 30 mph	0.00	0.61	-0.005	0.9956
	Speed Limit = 35 mph	-19.05	8716.00	-0.002	0.9982
Absence of Sidewalk Barrier	Presence of Sidewalk Barrier	-1.16	0.57	-2.03	0.0423
Absence of Bike Lane	Presence of Bike Lane	-1.39	0.74	-1.878	0.0603
Shoulder Type = Lawn	Raised Curb	0.34	8924.00	0	0.9999
	Paved	16.46	3049.00	0.005	0.9956
	Paved with warning	1.34	4457.00	0	0.9997
	Curb and Gutter	14.90	3049.00	0.005	0.9961
Absence of Sharrow Lane	Presence of Sharrow Lane	1.59	0.63	2.535	0.0112
Absence of Sidewalk	Presence of Sidewalk	-0.10	0.85	-0.122	0.9032
	Log(theta)	15.64	417.80	0.037	0.9701

Table 5.4: CMFs for Micromobility Crashes on Roadway Segments

Variable	Estimate	CMF
Intercept	-27.3867	-
Median Type: Paved[a]	0.9431	2.6
Median Type: Curb and Vegetation[a]	-2.0708	0.1
Speed Limit = 20 mph	-18.6356	-
Speed Limit = 30 mph	-0.0033	-
Speed Limit = 35 mph	-19.0534	-
Section AADT	1.2268	-
Presence of Sidewalk Barrier[b]	-1.1546	0.3
Presence of Bike Lane[c]	-1.3905	0.2
Shoulder Type: Raised Curb	0.3429	-
Shoulder Type: Paved	16.4574	-
Shoulder Type: Paved with Warning	1.3431	-
Shoulder Type: Curb and Gutter	14.9	-
Presence of Sharrow Lane[d]	1.5891	4.9
Presence of Sidewalk	-0.1028	-

Note: --- Not significant at 70% CI,
[a] The base condition for type of median is no median,
[b] The base condition for sidewalk barrier is absence of a sidewalk barrier,
[c] The base condition for bike lane is absence of a bike lane, and
[d] The base condition for sharrow lane is absence of a sharrow lane.

5.4.2 CMFs for Four-Leg Signalized Intersections

This section discusses the estimated CMFs for micromobility-related crashes on signalized intersections. The CMFs were estimated for four-leg signalized intersections and three-leg signalized intersections. All ZINB models for the signalized intersection were developed by considering the following variables.

- Major AADT
- Number of legs
- Number of approaches with a right turn lane
- Number of approaches with left turn lane
- Presence of a bicycle facility
- Presence of lighting
- Number of approaches with permitted LT signal
- Number of approaches with protected-permitted LT signal
- Number of approaches with no turn right on red
- Number of approaches which are one-way streets

Before fitting the model, the correlation between variables was examined. This step is crucial because including multiple highly correlated variables can be superfluous or even impair the model's effectiveness. Figure 5.10 presents the variable correlation for the four leg intersections model.

Table 5.5 presents the results of the ZINB model for four-leg signalized intersections. Table 5.6 presents the summary of the estimated CMFs for crashes involving micromobility devices on four-leg signalized intersections. The table includes the model coefficients and the corresponding CMFs. Only the variables that were significant at a 70% confidence interval were used to estimate CMFs.

The interpretation of the CMFs can be as follows, a unit increase in the explanatory/predictor variable results in an increase or decrease of a certain percentage of micromobility-related crashes per mile per year.

- Presence of bicycle facilities increases micromobility crashes by 70%
- Two approaches with permitted LT signal increase micromobility crashes by 40% at 60% CI
- Three approaches with permitted LT signal reduce micromobility crashes by 60%
- One approach with a protected-permitted LT signal reduces micromobility crashes by 60%
- Three approaches with protected-permitted LT signal reduce micromobility crashes by 40% at 60% CI
- An intersection with one approach as a one-way street reduces micromobility crashes by 50%

- An intersection with two approaches as one-way streets reduces micromobility crashes by 60%
- One approach with an exclusive LT lane increases micromobility crashes by 30% at 60% CI
- Four approaches with exclusive LT lanes increase micromobility crashes by 100%

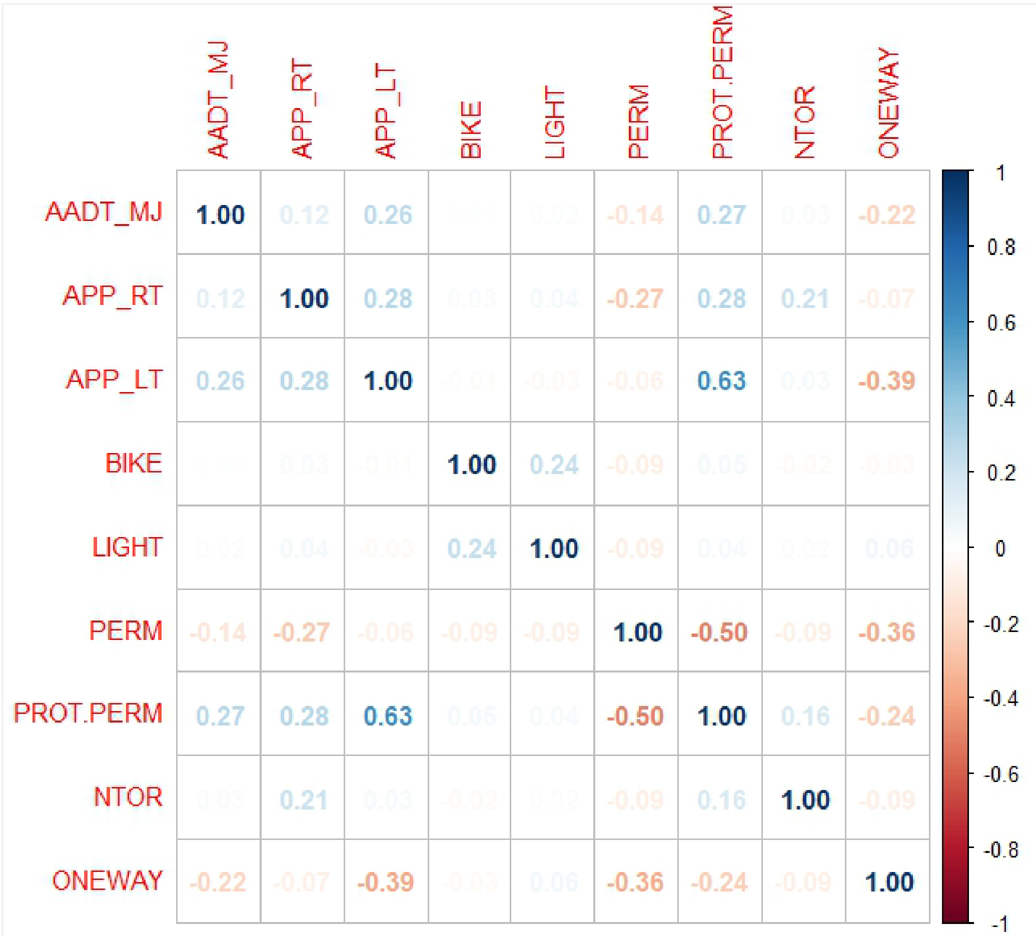


Figure 5.10: Variable Correlation for Four-Leg Signalized Intersection Model

Note: **NB:** AADT_MJ = Major Road AADT,
INTLEGS = Number of legs,
APP_RT = Number of approaches with an exclusive right turn lane,
APP_LT = Number of approaches with an exclusive left turn lane,
BIKE = Presence of bicycle facility,
LIGHT = Presence of lighting,
PERM = Number of approaches with permitted left turn signal,
PROT.PERM = Number of approaches with protected-permitted left turn signal,
NTOR = Number of approaches with no turn right on red sign, and
ONEWAY = Number of approaches which are one-way streets.

Table 5.5: ZINB Model Results for Four-Leg Signalized Intersections

Base	Levels	Estimate	Std. Error	z value	Pr(>|z|)
	(Intercept)	-0.39	1.85	-0.210	0.833
	Major Road AADT	-0.02	0.18	-0.121	0.903
0 approach with LT lanes	1 approach with exclusive LT lanes	0.26	0.30	0.866	0.386
	2 approaches with exclusive LT lanes	0.00	0.33	-0.013	0.989
	3 approaches with exclusive LT lanes	0.24	0.44	0.549	0.582
	4 approaches with exclusive LT lanes	0.69	0.59	1.169	0.242
0 approach with RT lanes	1 approach with RT lanes	0.14	0.26	0.54	0.588
	2 approaches with RT lanes	-0.01	0.46	-0.015	0.988
	3 approaches with RT lanes	0.21	1.12	0.188	0.850
Absence of bicycle facility	Presence of a bicycle facility	0.51	0.28	1.822	0.068
0 approach with permitted LT	1 approach with permitted LT	-0.09	0.41	-0.212	0.832
	2 approaches with permitted LT	0.36	0.38	0.963	0.335
	3 approaches with permitted LT	-0.97	0.86	-1.135	0.256
	4 approaches with permitted LT	-0.20	0.46	-0.434	0.664
0 approaches with protected-permitted LT	1 approach with protected-permitted LT	-0.85	0.51	-1.679	0.093
	2 approaches with protected-permitted LT	-0.08	0.36	-0.209	0.834
	3 approaches with protected-permitted LT	-0.55	0.60	-0.92	0.357
	4 approaches with protected-permitted LT	-16.47	1357.0	-0.012	0.990
0 approaches with No Turn on Red	1 approach with No Turn on Red	0.07	0.33	0.222	0.824
	2 approaches with No Turn on Red	-0.02	0.85	-0.025	0.979
	3 approaches with No Turn on Red	-16.44	3908.0	-0.004	0.996
	4 approaches with No Turn on Red	-14.58	2179.0	-0.007	0.994
0 approaches which are One-way Street	1 approach is a One-way Street	-0.76	0.29	-2.649	0.008
	2 approaches are One-way Street	-0.92	0.39	-2.331	0.019
	Log(theta)	15.32	101.30	0.151	0.879

Table 5.6: CMFs for Micromobility Crashes on Four-Leg Signalized Intersections

Variables	Estimate	CMFs
(Intercept)	-0.39	
Major Road AADT	-0.02	---
1 approach with LT lanes[a]	0.26	1.3[f]
2 approaches with LT lanes	0.00	---
3 approaches with LT lanes	0.24	---
4 approaches with LT lanes[a]	0.69	2.0
1 approach with RT lanes	-0.14	---
2 approaches with RT lanes	-0.01	---
3 approaches with RT lanes	0.21	---
Presence of bicycle facility[b]	0.51	1.7
1 approach with permitted LT	-0.09	---
2 approaches with permitted LT[c]	0.36	1.4[f]
3 approaches with permitted LT[c]	-0.97	0.4
4 approaches with permitted LT	-0.20	---
1 approach with protected-permitted LT[d]	-0.85	0.4
2 approaches with protected-permitted LT	-0.08	---
3 approaches with protected-permitted LT[d]	-0.55	0.6[f]
4 approaches with protected-permitted LT	-16.47	---
1 approach with No Turn on Red	0.07	---
2 approaches with No Turn on Red	-0.02	---
3 approaches with No Turn on Red	-16.44	---
4 approaches with No Turn on Red	-14.58	---
1 approach is a One-way[e]	-0.76	0.5
2 approaches are One-way[e]	-0.92	0.4

Note: --- Not significant at 70% CI

[a] The base condition for number of approaches with LT lanes is 0 approaches with LT lanes

[b] The base condition for presence of bicycle facility is absence of bicycle facility

[c] The base condition for number of approaches with permitted LT is 0 approaches with permitted LT

[d] The base condition for number of approaches with protected permitted LT is 0 approaches with protected permitted LT

[e] The base condition for number of approaches which are one-way street is 0 approaches which are one-way street

[f] Significant at 60% CI

5.4.3 *CMFs for Three-Leg Signalized Intersections*

This section discusses the estimated micromobility CMFs for three-leg signalized intersections. Before fitting the model, the correlation between variables was examined. This step is crucial because including multiple highly correlated variables can be superfluous or even impair the model's effectiveness. Figure 5.11 presents the variable correlation for the three-leg signalized intersections model.

Figure 5.11: Variable Correlation for Three-Leg Signalized Intersection Model

Note: **NB:** AADT_MJ = Major Road AADT,
APP_RT = Number of approaches with an exclusive right turn lane,
APP_LT = Number of approaches with an exclusive left turn lane,
BIKE = Presence of bicycle facility,
LIGHT = Presence of lighting,
PERM = Number of approaches with permitted left turn signal,
PROT.PERM = Number of approaches with protected-permitted left turn signal,
NTOR = Number of approaches with no turn right on red sign, and
ONEWAY = Number of approaches which are one-way streets.

It is worth noting the selection of levels in our variables affects the correlation values. The "LIGHT" variable was dropped in the three-legged intersection analysis since it only had one level.

Table 5.7 presents the ZINB model results for three-leg signalized intersections. Table 5.8 presents the summary of the estimated CMFs for crashes involving micromobility devices on three-leg signalized intersections. The table includes the model coefficients and the corresponding CMFs. Only the variables that were significant at a 70% confidence interval were used to estimate CMFs.

Table 5.7: ZINB Model Results for Three-Leg Signalized Intersections

Base	Level	Estimate	Std. Error	z value	Pr (>|z|)
	(Intercept)	2.5998	3.1576	0.82	0.410
	Major Road AADT	-0.4767	0.3384	-1.41	0.158
0 approach with LT lanes	1 approach with LT lanes	-0.1747	0.582	-0.30	0.764
	2 approaches with LT lanes	-0.2629	0.8843	-0.29	0.766
0 approach with RT lanes	1 approach with RT lanes	0.4458	0.5594	0.80	0.425
	2 approaches with RT lanes	-14.747	3901.22	-0.00	0.997
Absence of bicycle facility	Presence of bicycle facility	0.5323	0.5884	0.91	0.365
0 approach with permitted LT	1 approach with permitted LT	0.7205	0.917	0.79	0.432
	2 approaches with permitted LT	0.7897	0.7419	1.06	0.287
	3 approaches with permitted LT	0.3787	0.7904	0.48	0.631
0 approaches with protected-permitted LT	1 approach with protected-permitted LT	-0.6702	0.7567	-0.89	0.375
	2 approaches with protected-permitted LT	-0.1547	0.9975	-0.16	0.876
0 approach with No Turn on Red	1 approach with No Turn on Red	0.3585	0.8538	0.42	0.674
0 approach is a One-way	1 approach is a One-way	-1.0079	0.6161	-1.64	0.101
	2 approaches are One-way	-1.2904	1.1707	-1.10	0.270
	Log(theta)	19.910	11.1336	1.79	0.073

The interpretation of the CMFs can be as follows, a unit increase in the explanatory/predictor variable results in an increase or decrease of a certain percentage of micromobility-related crashes per mile per year.

- The presence of a bicycle facility on a three-leg signalized intersection increases micromobility crashes by 70%.
- Two approaches with permitted LT signal increase micromobility crashes by 2.2 times.
- One approach with a protected-permitted LT signal decreases micromobility crashes by 50%.
- A three-leg signalized intersection with one approach as a one-way street decreases micromobility crashes by 60%.
- A three-leg signalized intersection with two approaches as one-way streets decrease micromobility crashes by 70%.

Table 5.8: CMFs for Micromobility Crashes on Three-Leg Signalized Intersections

Variables	Estimate	CMF
(Intercept)	2.5998	
Major Road AADT	-0.4767	---
1 approach with LT lanes	-0.1747	---
2 approaches with LT lanes	-0.2629	---
1 approach with RT lanes	0.4458	---
Presence of Bicycle Facility [a]	0.5323	1.7
1 approach with permitted LT	0.7205	---
2 approaches with permitted LT [b]	0.7897	2.2
3 approaches with permitted LT	0.3787	---
1 approach with protected-permitted LT[c]	-0.6702	0.5
2 approaches with protected-permitted LT	-0.1547	---
1 approach with No Turn on Red	0.3585	---
1 approach is a One-way[d]	-1.0079	0.4
2 approaches are One-way[d]	-1.2904	0.3

Note: --- Not significant at 70% CI,
[a] The base condition for presence of bicycle facility is absence of bicycle facility,
[b] The base condition for number of approaches with permitted LT is 0 approaches with permitted LT,
[c] The base condition for number of approaches with protected permitted LT is 0 approaches with protected permitted LT,
[d] The base condition for number of approaches which are one-way street is 0 approaches which are one-way street, and
[e] Significant at 60% CI.

5.5 Summary

The following subsections present the estimated Florida-specific CMFs values for micromobility crashes at roadway segments and signalized intersections.

5.5.1 Roadway Segments

A total of five CMFs values were estimated. Table 5.9 summarizes the CMFs and crash reduction factors (CRFs) estimated for roadway segments. CRFs represent the percentage crash reduction that might be expected after implementing a given countermeasure. A negative CRF indicates that the implementation of a countermeasure is expected to lead to a percentage increase in crashes.

Table 5.9: Summary of the Estimated CMFs and CRFs for Roadway Segments

Base Condition	Level	CMFs	CRF
No Median	Paved	2.6	-160%
	Curb and Vegetation	0.1	90%
Absence of Sidewalk Barrier	Presence of Sidewalk Barrier	0.3	70%
Absence of Dedicated Bike Lane	Presence of Bike Lane	0.2	80%
Absence of Sharrow Lane	Presence of Sharrow Lanes	4.9	-390%

5.5.2 Signalized Intersections

A total of nine and five CMFs values were estimated from the four-leg and three-leg signalized intersections, respectively. Table 5.10 summarizes the values of the CMFs and CRFs.

Table 5.10: Summary of the Estimated CMFs and CRFs for Signalized Intersections

Base Condition	Level	Four-Leg Intersection		Three-Leg Intersection	
		CMF	CRF	CMFs	CRF
0 approaches with LT lanes	1 approach with LT lanes	1.3	-50%	-	-
	4 approaches with LT lanes	2.0	-170%	-	-
Absence of bicycle facility	Presence of bicycle facility	1.7	-70%	1.7	-70%
0 approaches with permitted LT signal	2 approaches with permitted LT	1.4	-40%	2.2	-120%
	3 approaches with permitted LT	0.4	60%	-	-
0 approaches with protected-permitted LT signal	1 approach with protected-permitted LT	0.4	60%	0.5	50%
	3 approaches with protected-permitted LT	0.6	40%	-	-
0 approaches that are one-way streets	1 approach is a one-way street	0.5	50%	0.4	60%
	2 approaches are one-way street	0.4	60%	0.3	70%

CHAPTER 6
MOBILITY ANALYSIS OF MICROMOBILITY SYSTEMS

This chapter presents the findings of the mobility analysis of micromobility systems deployed in Gainesville, Florida. The mobility analysis consisted of a travel time study, conducted to evaluate the travel time of different modes of transport used in the areas around the University of Florida (UF) campus. The primary objective was to quantify the mobility benefits associated with choosing micromobility as the preferred mode of transportation for students and other campus users.

6.1 Study Area

The study area included the area around the UF campus in Gainesville, Florida, shown in Figure 6.1. The selection of Gainesville as the study area was due to the fact that the students use all the modes of transport for their travel around the campus.

6.2 Data Collection

The data collection process consisted of collecting the travel time of different modes of transport from a common origin point to a destination point. This was completed by taking several trips from the origin to the destination. The origin for all trips was the HUB, surrounded by a classroom hall for students, and the destination was the Southwest Recreation Center. Figure 6.1 shows the two study locations. The mode of transport used for the study included transit, private cars, and micromobility vehicles with various routes. Figures 6.2 through 6.4 show the various routes used by the study team. This study was conducted for three different times during weekdays, AM Peak, PM Peak, and Off Peak. The AM Peak hours were from 8:00 a.m. to 11:00 a.m., the Off-Peak hours were from 12:00 p.m. to 3:00 p.m., and the PM Peak hours were from 3:00 p.m. to 6:00 p.m.

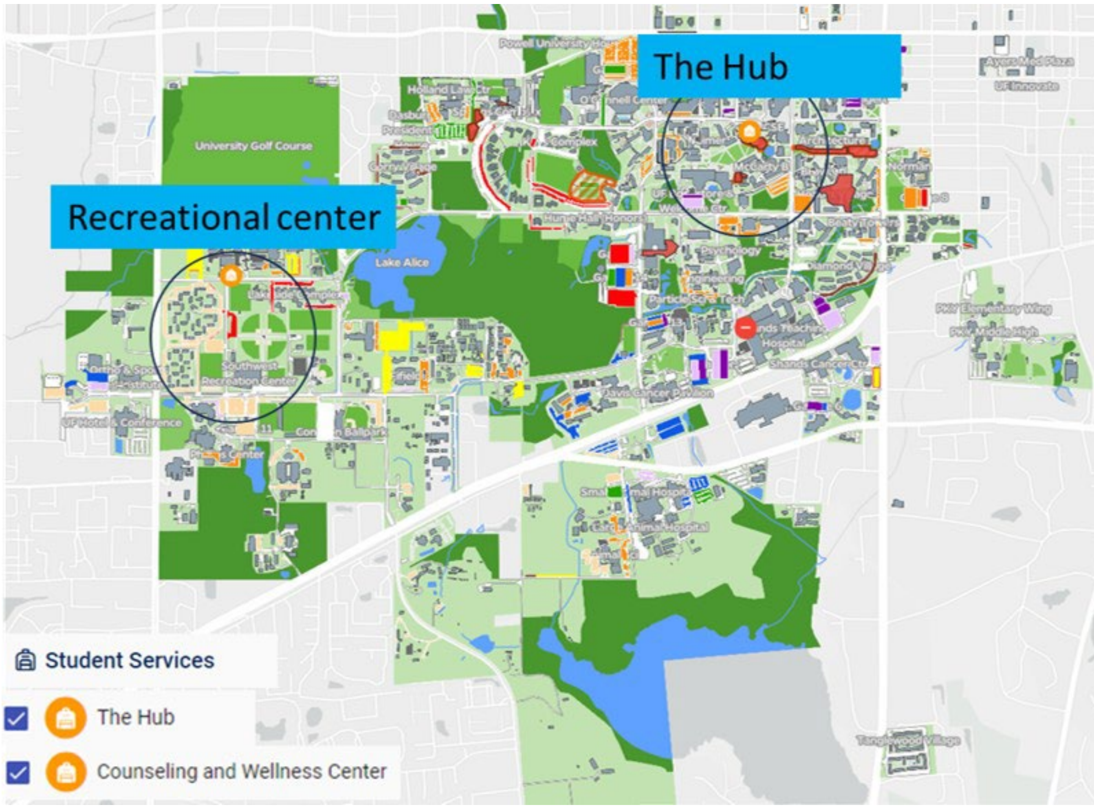


Figure 6.1: Travel Time Study Areas

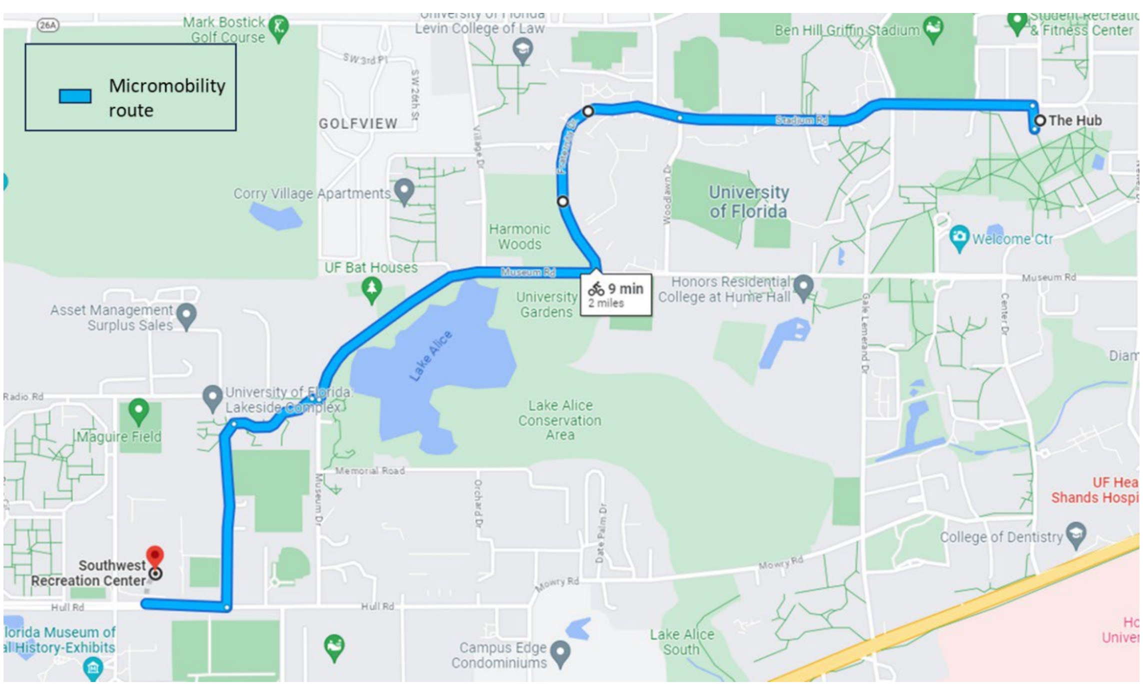


Figure 6.2: Micromobility Travel Route

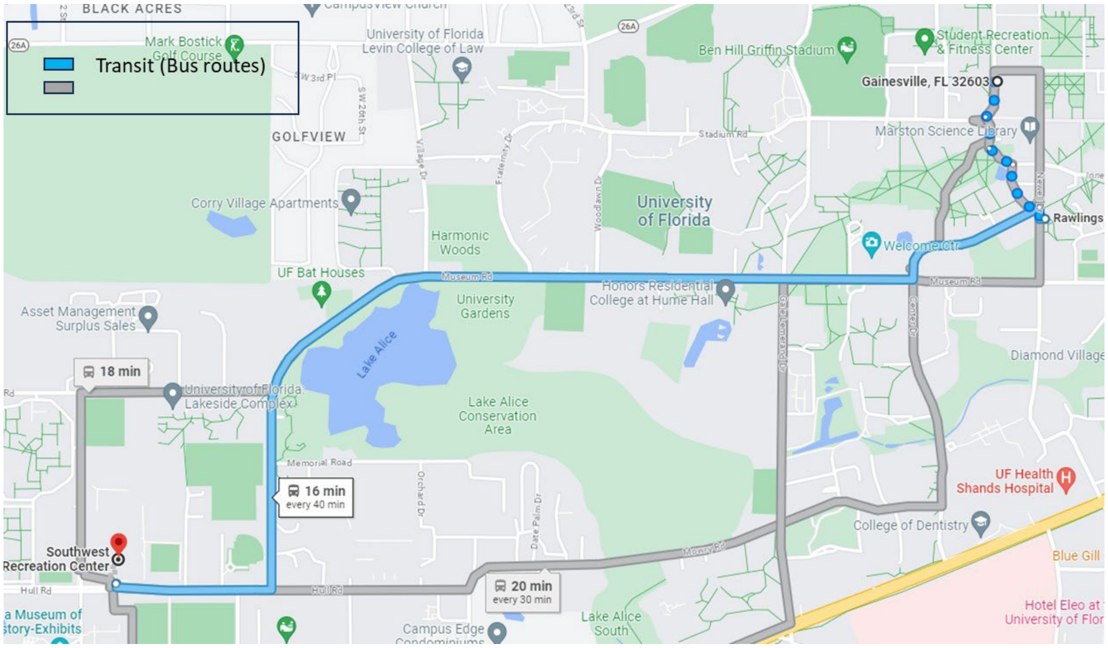


Figure 6.3: Transit (Bus) Travel Routes

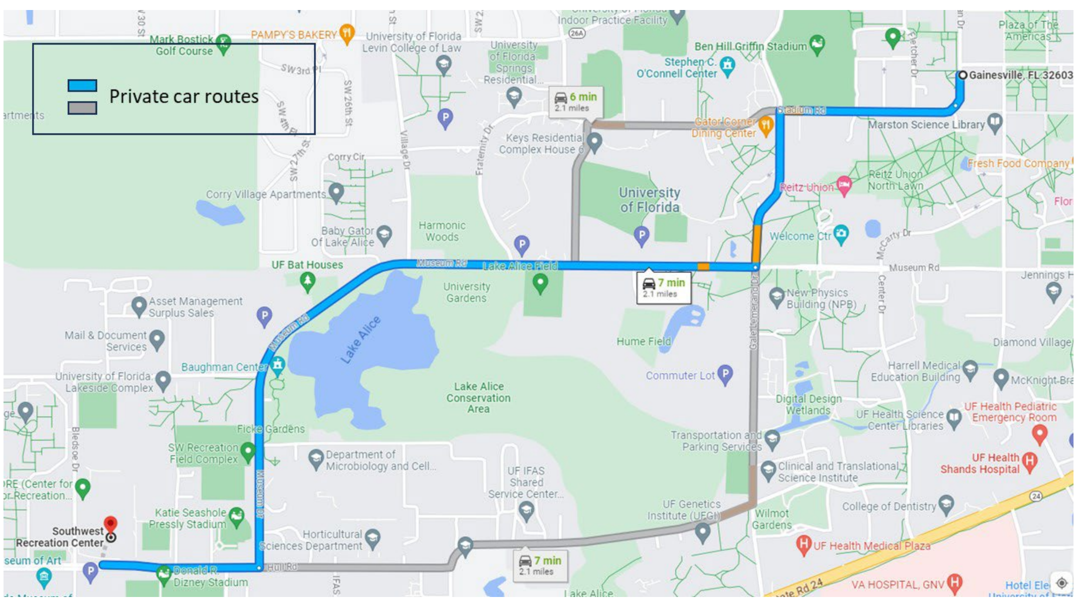


Figure 6.4: Private Car Travel Route

The resources used for this study included:

- Smart Phones
- Safety gears
- One private vehicle

The manpower for the study included drivers and crew members to ride e-scooters and transit (bus). All participants were civil engineering graduate students from the University of North Florida and Florida International University. Figure 6.5 shows one of the students on an e-scooter rented for the data collection effort.

Figure 6.5: Student Participant on an E-Scooter

6.3 Methodology

The mobility study involved a comparative analysis of travel times across three transportation modes: transit, private car, and micromobility devices. The selected origin-destination (O-D) pair for the study was the route between the HUB and the Recreation Center (see Figure 6.1). Analyses on the collected data included descriptive analysis showing travel time comparison of different modes of transport, an ANOVA test to show that there is a difference in travel time between the modes of transport, and a travel time reliability analysis. The data used for the analyses included data collected on-site and API data extracted from Google®.

6.3.1 Descriptive Analysis

The descriptive analysis was performed for all three modes of transport. The analysis considered all factors of travel from origin to destination, such as waiting time for the bus, walking from parking or bus stop to the destination, parking time for vehicles, and time taken on-route. Figures 6.6 through 6.8 and Tables 6.1 through 6.3 show the average time taken for all travel components for the three modes of transport considered in the study. The analysis shows that the total travel time for a bus is longer compared to private vehicles and micromobility. This is because the students tend to take time waiting for the buses, and during the trip, there is more than one stop, leading to delays in reaching their destination. The travel time for private vehicles is also longer than for micromobility (e-scooters) because the students tend to take time to find parking and walk to their car from the origin or towards their destination. Parking areas for e-scooters are always present in front of a building with available space, as shown in Figure 6.9. The term **waiting time** stands for the time the students take when waiting for the bus at bus stops, **On-route** stands for the time when a mode of transport is on the road, and **walking** stands for the time taken to walk from the origin (The HUB) to where a bus stop is present or to where their car is parked. **Walking** (Gym) stands for the time it takes for the students to walk from bus stops or parking lots to the recreational center gym. **Parking** stands for the time spent in a parking lot to get a parking space. The **total travel time** combines all factors to obtain the total time for the trip for a particular mode.

Table 6.1: Transit (Bus) Travel Time (seconds)

Waiting Time	On route	Walking (Gym)	Total Travel Time
289	1077	148	1514

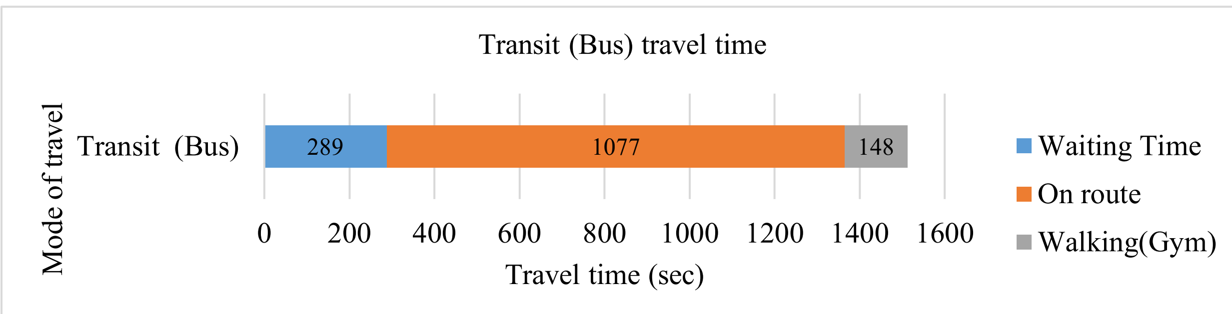


Figure 6.6: Transit (Bus) Travel Time

Table 6.2: Private Vehicle Travel Time (seconds)

Walking	On-route	Parking	Walking (Gym)	Travel Time
351	441	272	211	1275

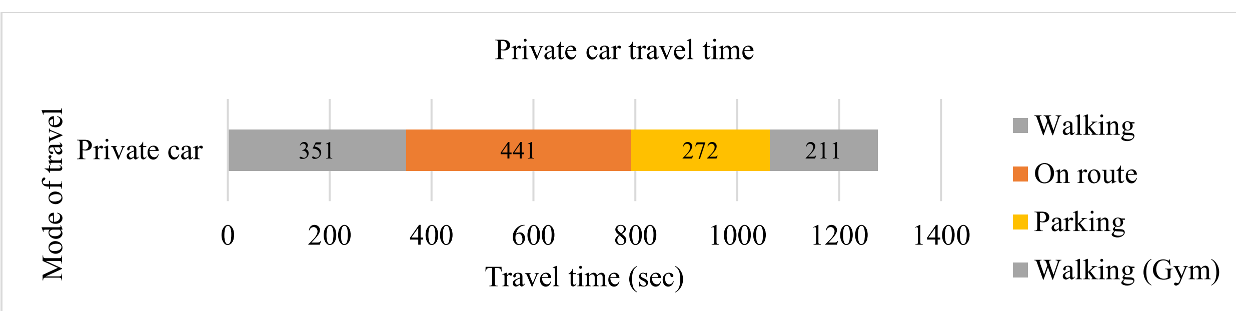


Figure 6.7: Private Car Travel Time

Table 6.3: Micromobility Travel Time (seconds)

On-route	Walking (Gym)	Travel Time
639	213	852

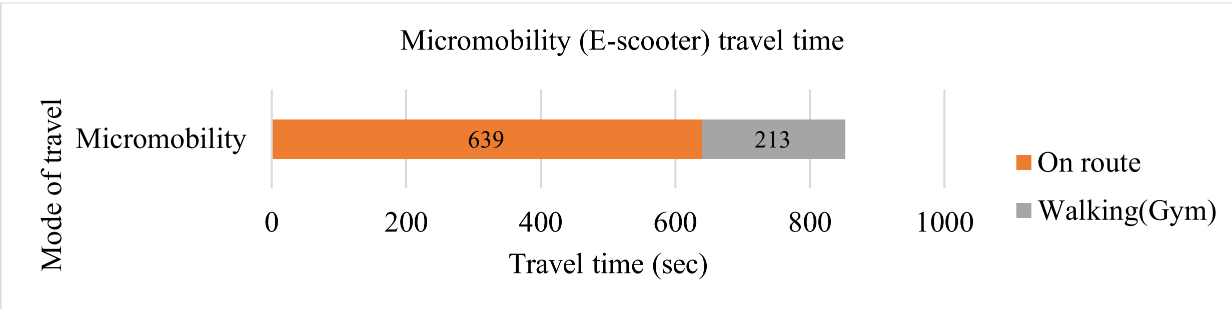


Figure 6.8: E-scooter Travel Time

Figure 6.9: E-scooter Parking at the HUB

6.3.2 *The Analysis of Variance (ANOVA) Test*

The ANOVA test was used to compare the travel time of the three modes of transport. This analysis was performed to determine if there was a significant difference in travel times between the different modes of transportation. The null hypothesis in the comparison of the three groups (modes of transport) was that "the population means of three groups are all the same." However, the alternative hypothesis was not that "the population means of three groups are all different" but rather that "at least one of the population means of three groups is different." In other words, the null hypothesis (H_0) and the alternative hypothesis (H_1) for the study were as follows:

$$H0;\ \mu T = \mu C = \mu MM$$
$$H1;\ \mu T = \mu C \ or\ \mu C = \mu MM \ or\ \mu T = \mu MM$$

The study considered a 95% Confidence level (0.05). The F-value obtained from the study was 197.8499. Since the F-value was greater than F-critical, the null hypothesis was rejected. This means that there is enough evidence to suggest that the mean travel times across the three travel times are not equal for at least two of the three travel modes. Table 6.4 shows the data summary and results of the ANOVA test.

Table 6.4: Data Summary and ANOVA Results

<table>
<tr><th colspan="7">DATA SUMMARY</th></tr>
<tr><th colspan="2">Groups</th><th>Count</th><th colspan="2">Sum</th><th>Average</th><th>Variance</th></tr>
<tr><td colspan="2">Column 1</td><td>53</td><td colspan="2">80222.84</td><td>1513.639</td><td>64441</td></tr>
<tr><td colspan="2">Column 2</td><td>53</td><td colspan="2">67595.06</td><td>1275.379</td><td>17313.48</td></tr>
<tr><td colspan="2">Column 3</td><td>50</td><td colspan="2">42621.51</td><td>852.4301</td><td>3888.898</td></tr>
<tr><th colspan="7">ANOVA Results</th></tr>
<tr><th>Source of Variation</th><th>SS</th><th>df</th><th>MS</th><th>F-value</th><th>P-value</th><th>F-critical</th></tr>
<tr><td>Between Groups</td><td>11487678</td><td>2</td><td>5743839</td><td>197.8499</td><td>3.71E-43</td><td>3.055162</td></tr>
<tr><td>Within Groups</td><td>4441789</td><td>153</td><td>29031.3</td><td></td><td></td><td></td></tr>
<tr><td>Total</td><td>15929467</td><td>155</td><td></td><td></td><td></td><td></td></tr>
</table>

6.3.3 Travel Time Reliability Analysis

Travel time reliability is a critical aspect of transportation systems that directly impacts the convenience and predictability of travel experiences for commuters and travelers. It refers to the consistency and dependability of travel times on a given route, taking into account variations due to factors such as congestion, weather, and unexpected incidents. Measuring travel time reliability is essential for assessing the overall quality of a transportation network and making informed decisions for its improvement.

The Buffer Index (BI) is a specific metric used to quantify travel time reliability. It represents the extra time that a traveler should allocate to their journey to ensure a 95% probability of arriving on time. In essence, it provides a margin for unexpected delays and disruptions. Equation 6.1 represents the formula for BI calculations. Typically, the BI is computed based on the 95th percentile travel time. Table 6.5 summarizes the results for the BI concerning the three transportation modes studied in this project: transit, private car, and micromobility. The origin-destination pair considered in this analysis is the route between the campus HUB and the recreation center.

$$BI = \frac{Travel\ Time95th\ percentile - Average\ Travel\ Time}{Average\ Travel\ Time} \tag{6.1}$$

The BI for transit was 29.3%, with an average travel time of 1514 seconds (approximately 25.2 minutes). This equates to a buffer time of 7.3 minutes. In practical terms, this means that individuals choosing transit for this route should allocate an additional 7 minutes to their planned travel time to ensure punctuality 95% of the time.

For private car travel, the BI was at 13.4%, with an average travel time of 1275 seconds (around 21.3 minutes), resulting in a buffer time of 2.8 minutes. In other words, those opting for a private car should factor in an extra 3 minutes into their planning time to achieve a 95% on-time arrival rate.

Similarly, in the case of micromobility, the BI was 12%, with an average travel time of 852 seconds (approximately 14.2 minutes), translating to a buffer time of 1.7 minutes. Thus, a person selecting micromobility for this route only needs to add 1.7 minutes to their planning time, resulting in a total journey time of 15.9 minutes, ensuring a high probability of arriving on time. As evident from the average travel time and buffer time data, micromobility emerges as the most efficient and reliable mode of transportation for this route when compared to transit and private cars. It's important to emphasize that the buffer time takes into account potential delays along the route, contributing to the overall reliability of the transportation choice.

Table 6.5: Buffer Index Results (HUB-Recreation Center)

Transportation Mode	Average Travel Time (s)	95th Percentile Travel Time (s)	Buffer Index (BI)
Transit	1514	1957	29.3%
Private Car	1275	1446	13.4%
Micromobility	852	955	12.0%

6.4 Summary and Results

The mobility analysis described in this chapter was conducted around the University of Florida (UF) campus in Gainesville. The primary objective was to quantify the mobility benefits associated with choosing micromobility as the preferred mode of transportation for students and other campus users. The study involved a comparative analysis of travel times across three transportation modes: Transit, Private Car, and Micromobility devices. The selected origin-destination (O-D) pair for the study was the route between the HUB and the Recreation Center. This choice was based, not only on the availability of all three transportation options at these locations, but also their demand. The study was conducted for two days, encompassing three distinct time periods: AM Peak, PM Peak, and Off-Peak hours, which is crucial for assessing travel time savings and travel time reliability.

Travel time calculations were derived from various components, including on-route time, walking time, waiting time for buses, and the additional time spent searching for suitable parking spaces for users opting for private cars. The average travel times for micromobility, private cars, and transit were 14.2 minutes, 21.3 minutes, and 25.2 minutes, respectively. The ANOVA test confirmed that there is a significant statistical difference between the mean travel times for the three transportation modes at a 95% confidence interval (p-value = 3.71E-43).

The study also evaluated travel time reliability for the three modes of transportation using the Buffer Index (BI), which was calculated based on the 95th percentile travel time. Micromobility emerged as the most reliable mode of transportation, boasting a BI of 12.0%. This means that users of micromobility services only need to allocate a 1.7-minute buffer time (added to the mean travel time of 14.2 minutes) to ensure that they arrive on time in 95% of their trips. Choosing micromobility guarantees more consistent travel times when navigating the selected route.

In contrast, private cars and transit exhibited higher BIs of 13.4% and 29.3%, respectively. These higher BI values suggest greater variability and inconsistency in travel times at different times throughout the day for these modes of transportation. Consequently, the study's findings strongly indicate that opting for micromobility services as the mode of transportation within the campus offers a more reliable and consistent travel experience compared to private cars and transit.

6.5 User Survey

A survey of E-scooter and E-bike users was conducted in various parts of Florida. The aim of the survey was to gain an in-depth understanding of micromobility devices and user experience. In addition, the survey provided more insights into the micromobility needs in communities with access to micromobility vehicles. The following subsections present the descriptive and inferential analyses on user behavior trends and patterns and an analysis of the factors influencing user adoption and satisfaction.

6.5.1 Surveyed Areas

The survey was conducted in the downtown areas of both Orlando and Tampa, Florida. In Orlando, the surveyed area focused on the downtown area of the city, where e-scooters and e-bikes are commonly used. In Tampa, the surveyed area focused on e-scooters used around the downtown area. E-scooters in Tampa are used for various purposes downtown, most specifically for first and last-mile travel. Figure 6.14 shows the micromobility devices used in the surveyed areas.

(a) E-scooters/E-bikes in downtown Orlando (b) E-scooters in downtown Tampa

Figure 6.10: Micromobility Devices Used in Surveyed Areas

6.5.2 *Survey Methodology*

6.5.2.1 Survey Design

The goal of the survey was to gain more information on the user experience of micromobility devices usage. The survey was conducted in various Florida cities with a large number of micromobility device users. Types of questions included single-choice, multiple-choice, text entry, Likert scale, and open-ended questions. Questions pertained to the following categories:

- Practical Usage: The survey collected information about the current usage of micromobility vehicles, focusing on ownership, frequency of use, time, and distance of use. Additionally, the respondents were also asked about the location where they drive their vehicles.
- Purpose and Benefits: The survey gathered information on the reasons and benefits of using micromobility vehicles from the survey respondents.
- Current services feedback and recommendations: The survey respondents were asked about their view on the current micromobility services, such as what further improvement should be made to improve the micromobility services. Additionally, they were asked if they had any feedback or recommendations to give.
- Background Information: At the end of the survey, basic socio-economic demographics information was obtained. This information included age, gender, marital status, income range, and employment status.

6.5.2.2 Data Collection

The survey was created online using Qualtrics, a Web-based software allowing users to create surveys and generate reports without any previous programming knowledge. This software allows one to capture information, analyze, and act on insights. The research team first tested the survey to ensure it was well created and not too long to bore the respondents, leading them not to finish the survey. Random sampling was used to get survey responses, meaning no specific group was approached. The target group for the survey included all micromobility vehicle users without any age or other restrictions.

The data collection process started in May 2023 and ended in September 2023. The survey was distributed physically, through a Quick Response (QR) code, and using an offline Qualtrics survey. The responses from the physically distributed paper and offline Qualtrics survey were later uploaded online, while the responses answered using a QR code were automatically uploaded online. The initial goal was to have at least 50 responses from e-scooters/e-bike users. Using a 10% margin error at a 95% confidence level, around 45 survey responses would have been sufficient. Despite various hindrances in obtaining survey responses from e-scooters and e-bike users, a total of 26 responses were submitted.

Before the survey was distributed, various regulations were followed, such as submitting the survey document as a measurement tool to the Institute of Review Board (IRB) for an exempt review. This was done to ensure that the survey was anonymous, and that no identifiable information was collected to avoid any risk imposed on the participants.

6.5.2.3 Survey Regulations

The research study conducted was human-based research, and thus, various regulations had to be followed. These regulations are divided into two parts: before data collection and during the field study.

- **Before Data Collection**

  Before data collection, the research team submitted various documents related to the project to the University of North Florida Institute of Review Board (IRB) for review. The submission to the IRB was for an exempt review, since no identifiable information of participants was recorded during research, and thus, no risk imposed on the participants. The documents submitted included:

  - North Florida Protocol Form
  - Attachment B for an exempt review.
  - Informed Consent Document
  - Survey document as a measurement tool
  - CITI Training Certificates of the research team (Principal Investigator and additional personnel)

- **During the Field Study**

  Regulations that were required to be followed during the field study included:

  - The survey must be anonymous, ensuring that no identifiable information is collected.
  - Also, fundamental ethical principles of respect for persons, beneficence, and justice must be followed. Informed consent must be obtained from the volunteers who participate in the research before they start answering the survey with a short introduction to the project (American Association for Public Opinion Research, 2005). The survey must be distributed randomly, ensuring everyone has an equal chance of participating in the research.
  - The video recording must not include identifiable information, such as the road users' features. The collected data for the survey must be stored electronically on a secure server and protected by a strong password. Only authorized personnel may have access to the recordings, thus preventing any information from being made public.

6.5.3 Data Analysis and Results

This section discusses the analysis of the survey and the findings obtained from the study. The analysis was performed in two stages: descriptive analysis and inferential analysis.

6.5.3.1 Descriptive Analysis for E-scooters/E-bikes

Practical Usage of E-scooters/E-bikes

From the survey responses, nine of the responses were from e-scooter users, and 24 of the responses were from e-bike users. The survey was structured so that the experienced users of both e-scooters and e-bikes were directed to the section of e-bike questions. Of the nine respondents on e-scooters, 77.78% ride the e-scooters by using sharing apps, and 11.11% own e-scooters. The remaining respondents tend to ride e-scooters available in their neighborhood. Of the 24 respondents on e-bikes, 66.67% ride e-bikes using sharing apps, and 25% own e-bikes. The rest of the respondents ride e-bikes available in their neighborhood. These results show that e-scooters are the shared vehicles mostly used by people for the first mile and last mile. According to the responses, the e-scooters cost mostly around $200, and the typical app spending ranges from $10 to $50. Also, the range for the cost of e-bikes is from $200 to $1,000, and the expenses for those using sharing apps range from $8 to a maximum of $100. This shows that e-scooters are an efficient and affordable mode of transport.

From the above responses, eight out of nine e-scooter users answered the question on the frequency of use of e-scooters, while all of the e-bike users responded to the question on the frequency of use of e-bikes. From the e-scooter responses, 62.5% use the e-scooter daily, 25% use the e-scooters once a week, and the rest use the e-scooter at least once a year. Also, from the e-bike responses, 50% use e-bikes once a week, 41.67% use e-bikes daily, 4.17% use e-bikes once a month, and 4.17% use e-bikes at least once a year. These results imply that e-scooters are one of the rising modes of transport and should be incorporated into the transportation system, especially since they are often used daily. Based on the survey, the maximum distance the e-scooters and e-bikes are used is 20 miles for both vehicles, and the maximum time for a single ride is 20 minutes for the e-scooter and 1 hour for e-bikes. This can also be due to area restrictions, as the e-scooters are not allowed in all areas of the cities.

The question on the location where the e-scooters/e-bikes can be used was also a multiple-choice question. Fourteen (14) responses were obtained from the e-scooter users, and the responses show that 50% ride their e-scooters on bike lanes, 35.71% ride their scooters on the sidewalk, and 14.29% ride the e-scooters on the right lane of the road. Forty-six (46) survey responses were obtained from e-bikes users, and from their responses, it was found that 50% ride their e-bikes on the bike lanes, 41.30% ride their e-bikes on sidewalks, and 8.7% ride their e-bikes on the right lane of the road. For both e-scooters and e-bikes, none of the users ride their vehicles on the middle/left lanes of the road. Also noticed was that few users ride in the same lane as the other vehicles. This might be because of the presence of a bike lane, reducing interactions between e-scooters/e-bikes and other modes of transport, thus reducing the number of accidents. Figures 6.11 through 6.16

show the various statistics for e-scooters and e-bikes practical usage of micromobility. Figure 6.11 and Figure 6.12 show the statistics for e-scooter and e-bike usage and ownership, respectively. E-scooter and e-bike frequency of use are shown in Figures 6.13 and 6.14, respectively, Figures 6.15 and 6.16 show the statistics for e-scooter and e-bike location usage.

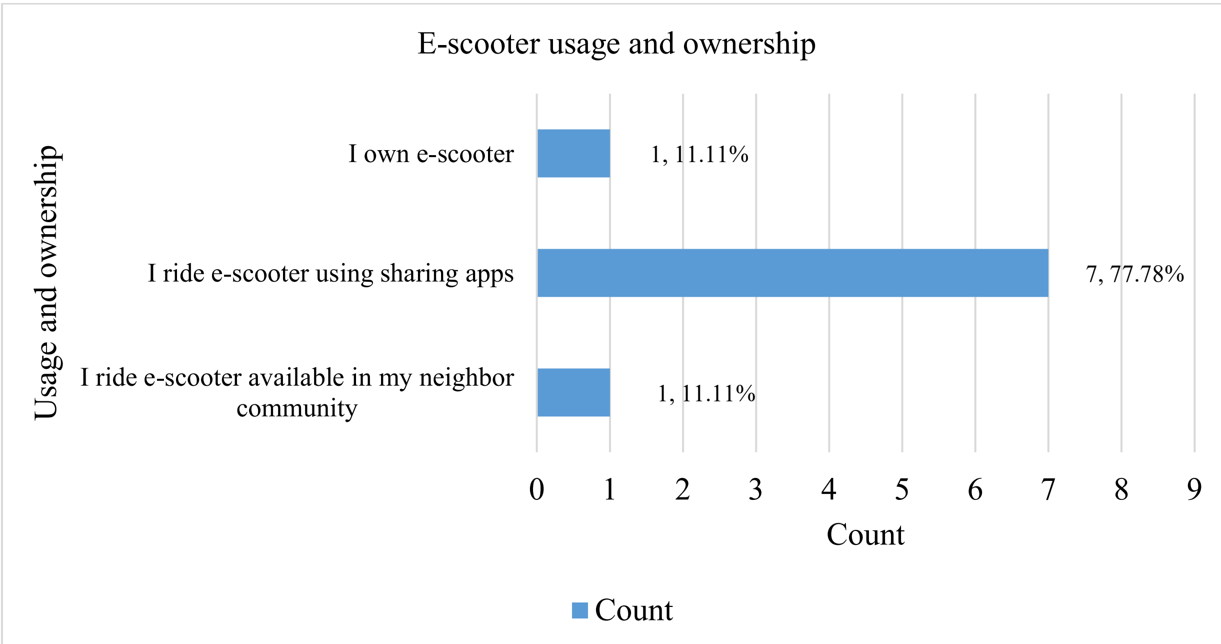


Figure 6.11: E-scooter: Usage and Ownership

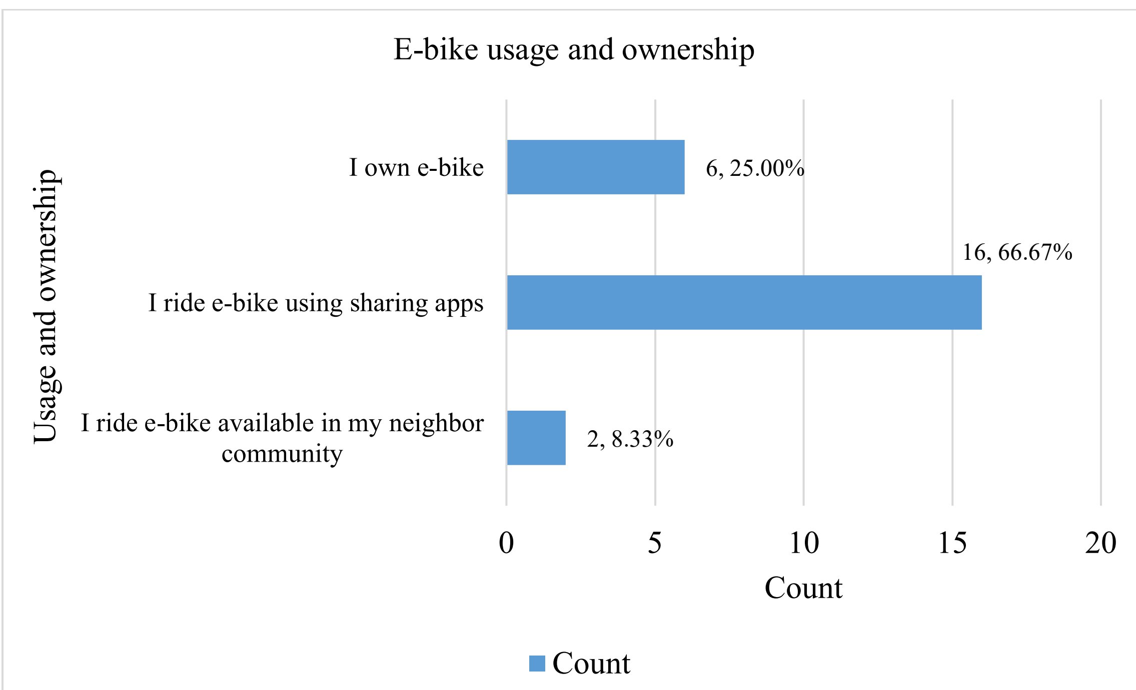


Figure 6.12: E-bike: Usage and Ownership

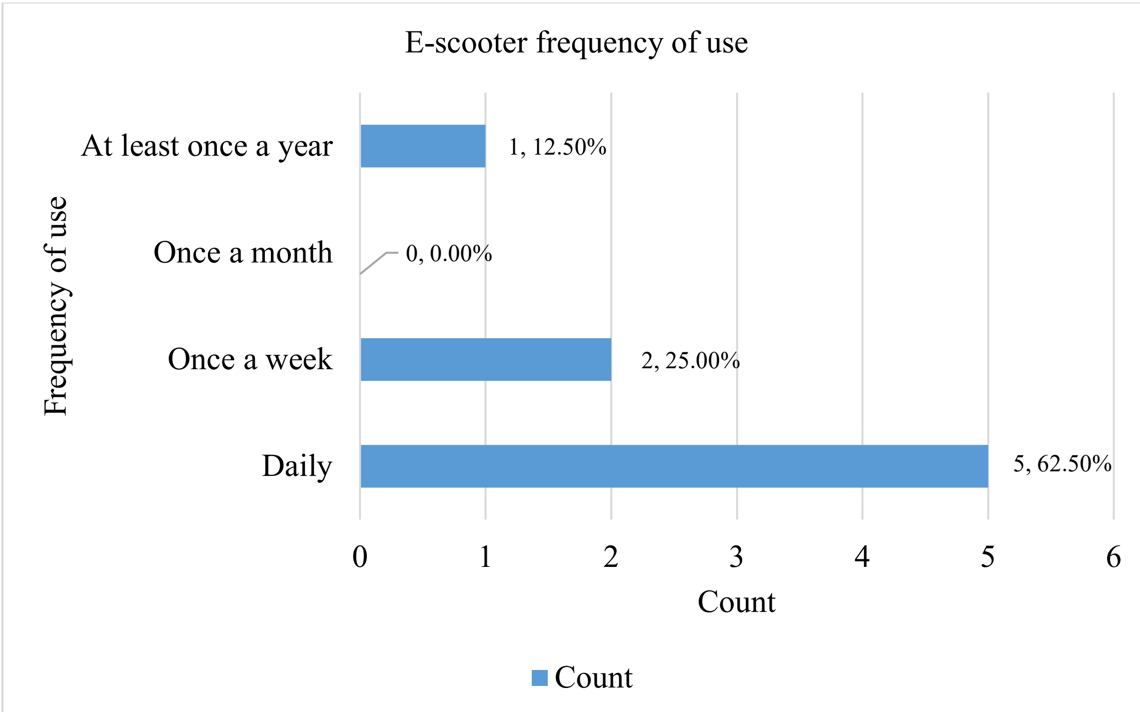


Figure 6.13: E-scooter: Frequency of Use

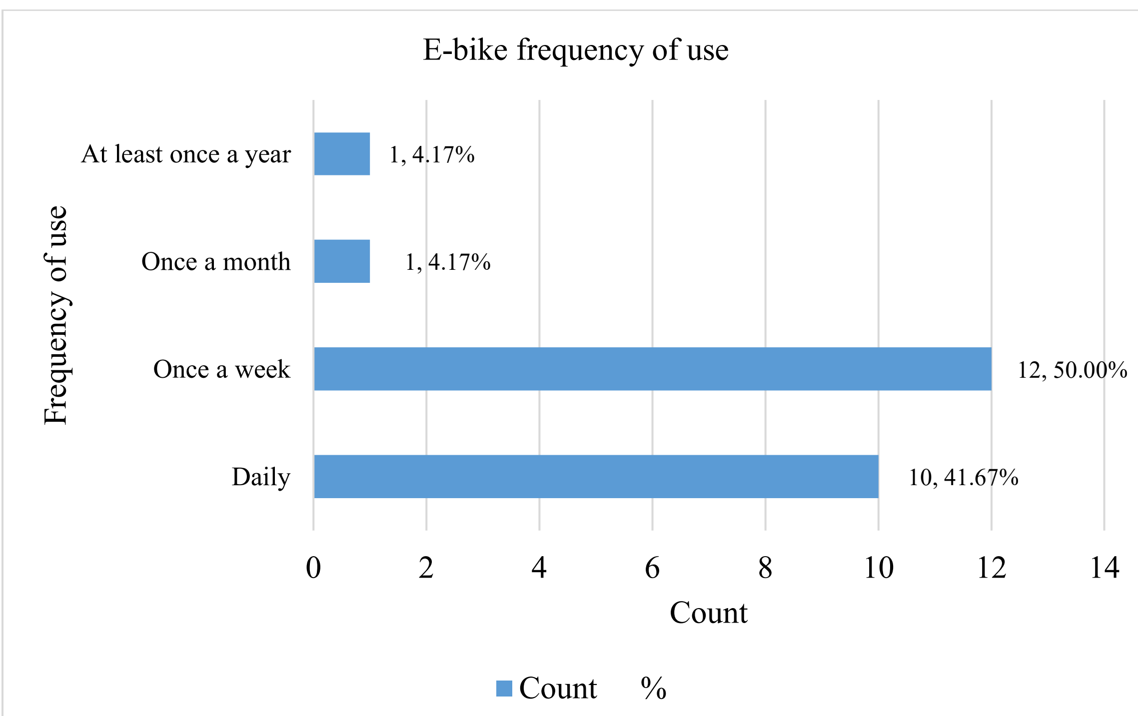


Figure 6.14: E-bike: Frequency of Use

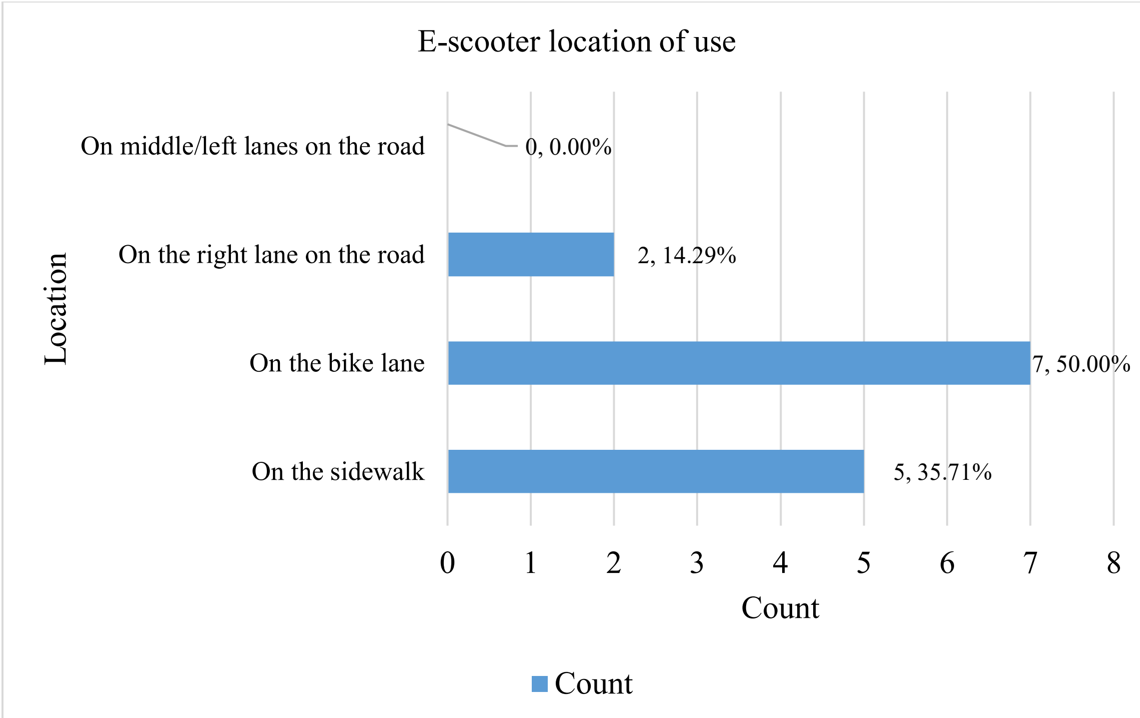


Figure 6.15: E-scooter: Location of Use

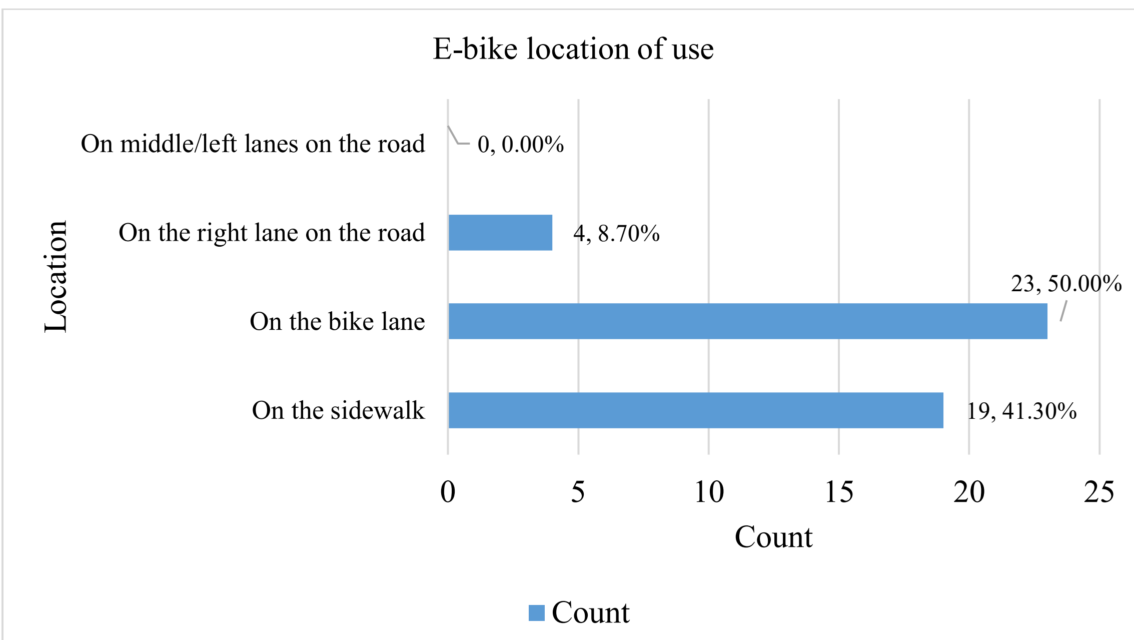


Figure 6.16: E-bike: Location of Use

Purpose and Benefits of Using E-scooters/E-bikes
The respondents were also asked about the purpose and benefits of using e-scooters/e-bikes. The question on the purpose of using scooters had 15 responses. The respondents could also select more than one choice. Most people said they use e-scooters for everyday commuting (40%) and

entertainment and leisure (40%). Just over 13% use them for occasional local outings, and 6.67% use them for everyday errands. Similarly, the respondents could also choose more than one choice for using e-bikes, and 46 responses were obtained. From the responses, it was found that 45.65% use their e-bikes for entertainment/leisure, 32.61% use the e-bikes for everyday commuting, 15.22% use the e-bikes for occasional local outings, and 4.35% use the e-bikes for everyday errands. The rest of the responses show that the e-bikes are used for other purposes, such as going to work.

Survey questions pertaining to the benefits of using e-scooters had 29 responses. The respondents stated that they use e-scooters because they are easy to ride (27.59%), ease of access and availability (24.14%), fun (20.69%), and good for the environment (13.79%). The rest of the responses indicate that e-scooters are used because they are a cheaper mode of transportation (13.79%). In terms of the benefits of using the e-bikes, out of 90 responses, 25.56% stated that they are easy to ride. Other benefits included fun (23.33%), ease of access and availability (20%), cheaper transportation (16.67%), and good for the environment (12.22%). The rest of the responses show that they use e-bikes because they feel safe (2.22%). The results on the purposes and benefits of e-scooters and e-bikes show that despite being a new mode of transport in the transportation system, they have numerous advantages. Figures 6.17 through 6.20 illustrate the statistics for the purpose and benefits of using e-scooters and e-bikes.

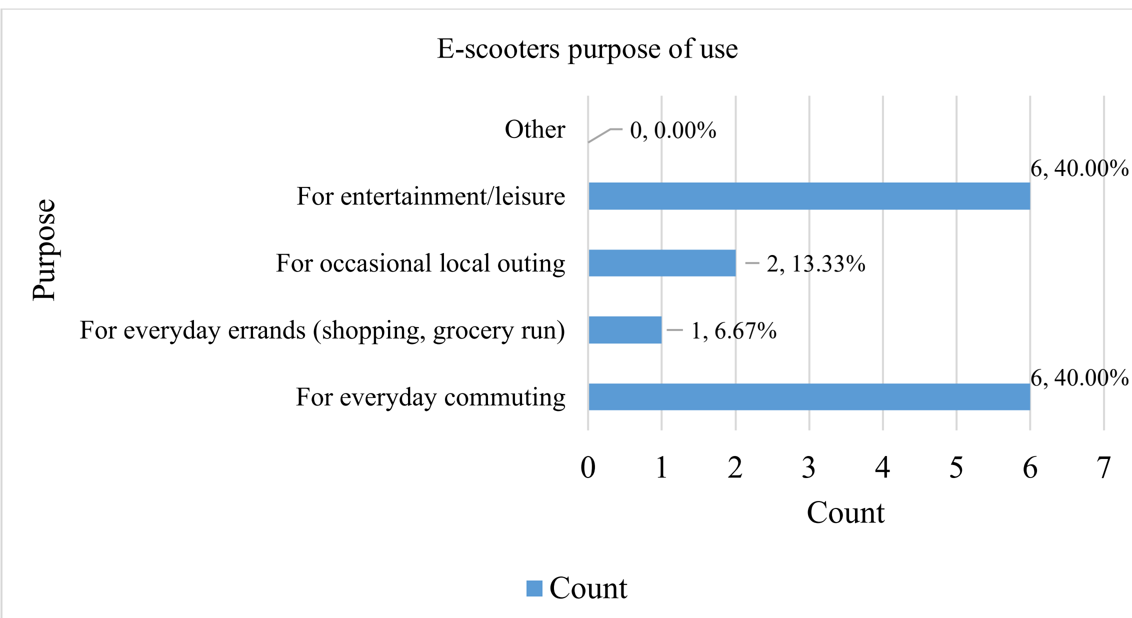


Figure 6.17: E-scooters: Purpose of Use

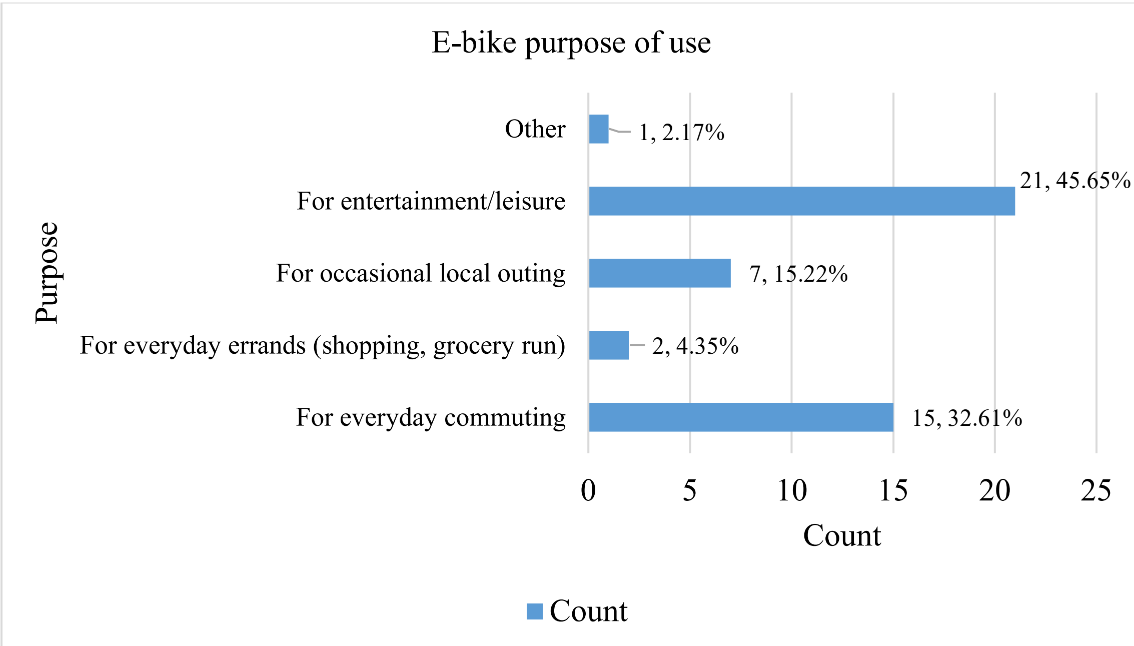


Figure 6.18: E-bike: Purpose of Use

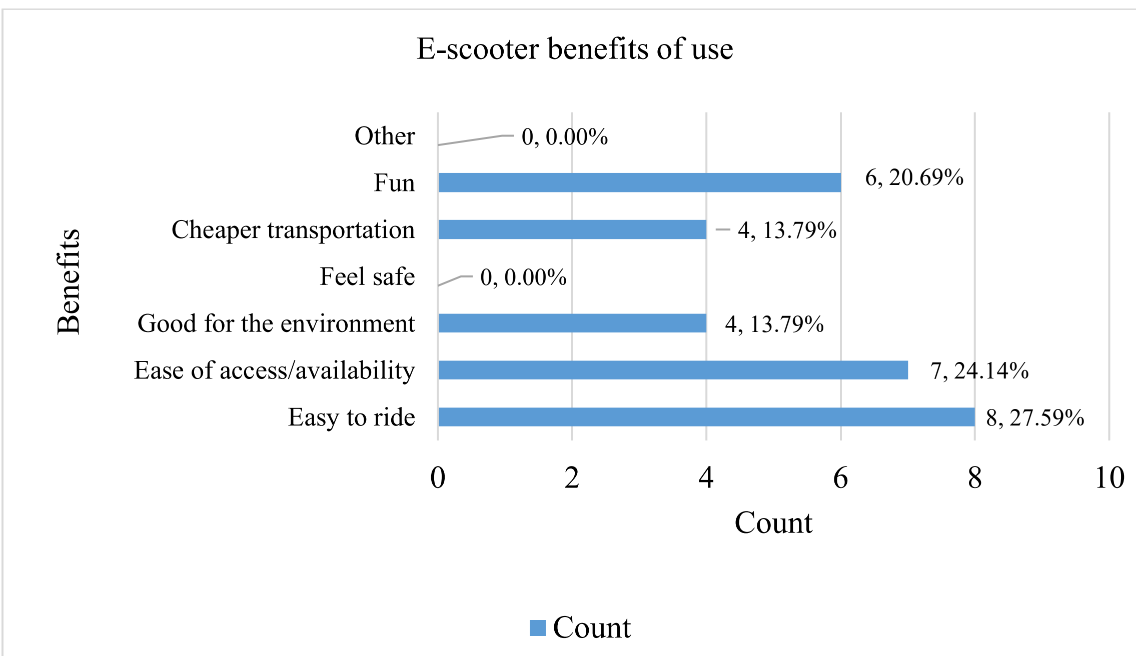


Figure 6.19: E-scooters: Benefits of Use

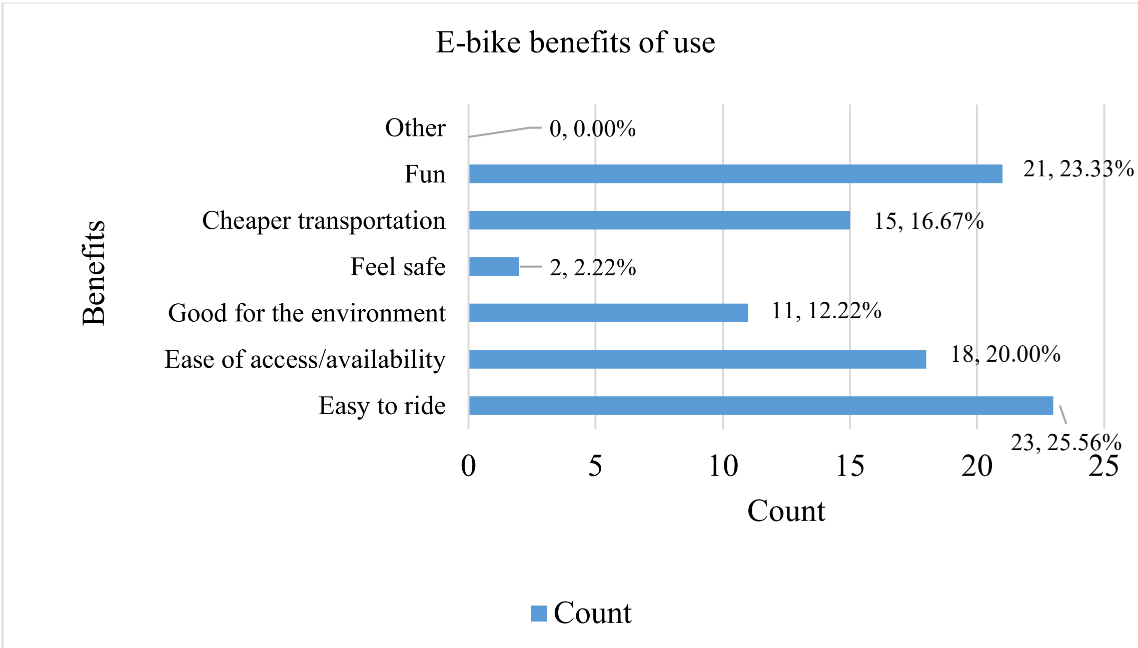


Figure 6.20: E-bike: Benefits of Use

Current E-scooter/E-bike Service Feedback and Recommendations

The respondents were also asked to rate how they would like the e-scooter/e-bike usage and services to be improved. The ratings were also ranked ordinally, with '1' being least important and 5 being very important. Similar to the GC questionnaire, not all factors were intended to be responded to by all respondents. Some were relevant to users, some to owners, and others to both users and owners. On rating scooters' appealing styling, there were eight responses. About 37.5% of the respondents stated that it is important to improve styling, and 62.5% said it is not a must. In terms of e-bike styling, 24 responses were obtained and 45.83% said that it is unnecessary, 37.5% said that it is least important, 8.33% said that it is important.

Regarding e-scooters' better riding comfort, 75% said it is important to improve riding comfort, and 12.5% said it is least important. For e-bikes, 33.33% said it is important to improve riding comfort, while 41.67% said it is not important. The respondents were also asked about improved overall safety. Most of the respondents on e-scooters indicated that improving overall safety is very important (62.50%). From the analysis on e-bikes, 54.17% of the 67 responses suggested that overall safety should be improved, while 4.17% suggested that it is least important, and 16.07% suggested that it is not a must.

Regarding the longer electric range/assist, the responses on e-scooters' driving range show that 75.00% suggested improving it, while 12.5% say it is least important. Regarding the e-bike electric range, 50.00% said it is important to improve the longer electric range/assist, while 12.5% said it is not a must.

Regarding e-scooters' ride availability, most respondents said it is important to improve this factor (42.86%), while 14.29% said that it is not a must. This was also the same case on e-bikes, as 68.75% of 16 responses suggested improving ride availability is important, and 12.5% said it is not a must. Most e-scooters and e-bike owners were also asked about the lower initial cost, lower cost of ownership, customizability, and shorter charge time. From the e-bike owners, there were only 6 responses on each factor. 33.33% of the responses on customizability suggested that it is important to improve customizability, while 33.33% stated that it is least important. Regarding lower initial cost, most respondents suggest that it is very important to ensure that the initial cost is improved (50%), and 33.33% suggest that it is not a must.

Regarding the lower cost of ownership, most respondents did not indicate concerns about a need for improvement in customizability (66.67%). Lastly, out of the 6 responses, 33.33% suggest that there is no need to improve charging/fuel time, while 50% suggest that improving charging/fuel time is important. From the responses on e-scooters, only 1 owned an e-scooter, and the user suggested that it is with least importance to ensure shorter charge time and lower cost of ownership, and it is not a must to have lower initial cost and customizability. Through the responses to this question, various agencies and providers may be able to note what is lacking in the services and, thus, improve on those areas, leading to better user satisfaction. Tables 6.6 and 6.7 shows the statistics on current service feedback.

An open-ended question also asked respondents about their e-scooters and e-bike recommendations. The recommendations for e-scooter services include the installation of brightest lights to be more visible on roads. The recommendations on e-bike services include that there should be more bike stations, the service providers should ensure better pricing subscriptions, and more payment methods should be available. There was no negative feedback from the respondents. This finding shows that LSV/GCs are accepted in the communities and can be used to offer transportation services.

Table 6.6: Statistics for E-Scooter Current Services Feedback

No	Factor (Current Services)	1 (%)		2 (%)		3 (%)		4 (%)		5 (%)		Total
1	Appealing Styling	0.00	0	0.00	0	62.50	5	37.50	3	0.00	0	8
2	Better Ride Comfort	12.50	1	0.00	0	0.00	0	75.00	6	12.50	1	8
3	Improved Overall Safety	0.00	0	0.00	0	0.00	0	37.50	3	62.50	5	8
4	Longer Electric Range/Assist	0.00	0	12.50	1	0.00	0	12.50	1	75.00	6	8
5	Ride Availability	0.00	0	0.00	0	14.29	1	42.86	3	42.86	3	7
6	Shorter Charge Time	100.00	1	0.00	0	0.00	0	0.00	0	0.00	0	1

Table 6.6: Statistics for E-Scooter Current Services Feedback (continued)

No	Factor (Current Services)	1 (%)		2 (%)		3 (%)		4 (%)		5 (%)		Total
7	Lower Initial Cost	0.00	0	0.00	0	100.00	1	0.00	0	0.00	0	1
8	Lower Cost of Ownership	100.00	1	0.00	0	0.00	0	0.00	0	0.0	0	1
9	Customizability	0.00	0	0.00	0	100.00	1	0.00	0	0.00	0	1

Table 6.7: Statistics for E-Bike Current Services Feedback

No	Factor (Current Services)	1 (%)		2 (%)		3 (%)		4 (%)		5 (%)		Total
1	Appealing Styling	37.50	9	0.00	0	45.83	11	8.33	2	8.33	2	24
2	Better Ride Comfort	0.00	0	0.00	0	41.67	10	33.33	8	25.00	6	24
3	Improved Overall Safety	4.17	1	0.00	0	16.67	4	25.00	6	54.17	13	24
4	Longer Electric Range/Assist	0.00	0	4.17	1	20.83	5	25.00	6	50.00	12	24
5	Ride Availability	0.00	0	0.00	0	12.50	2	18.75	3	68.75	11	16
6	Shorter Charge Time	0.00	0	0.00	0	33.33	2	16.67	1	50.00	3	6
7	Lower Initial Cost	0.00	0	0.00	0	33.33	2	16.67	1	50.00	3	6
8	Lower Cost of Ownership	16.67	1	0.00	0	66.67	4	0.00	0	16.67	1	6
9	Customizability	33.33	2	0.00	0	16.67	1	33.33	2	16.67	1	6

6.5.3.2 Inferential Analysis

An inferential analysis was performed to explore whether user characteristics (i.e., age and gender) impact the purpose of using e-scooters or e-bikes.

Background Information for E-scooters/E-bikes

The survey gathered a total of 26 responses from e-scooters/e-bikes users. The distribution of these respondents, according to the demographics, is presented in Table 6.8.

Table 6.8: E-scooter and E-bike Demographics Descriptive Statistics

Variables	Category	Count	%
Gender	Female	7	26.92
	Male	19	73.08
	Other	0	0.00
	Prefer not to answer	0	0.00
Marital Status	Single	1	3.85
	Partnered	12	46.15
	Married	13	50.00
	Other	0	0.00
Household	Living with parents/Guardians	5	19.23
	Living Alone	10	38.46
	Partnered/ Married with no child	8	30.77
	Single/Partnered/Married with one child	3	11.54
	Single/ Partnered/ Married with two children	0	0.00
	Single/Partnered/Married with 2 or more children	0	0.00
Employment Status	Full time employed	16	61.54
	Part-time employed	9	34.62
	Not employed	0	0
	Retired	1	3.85
Household Income	Below $ 50K	10	38.46
	$50K to $100K	14	53.85
	$100K to $150K	2	25.79
	$150K to $200K	0	0.00
	Above $200K	0	0.00
Age	≥ 65 years	0	0.00
	< 65 years	26	100

For this survey, all e-scooter/e-bike users were less than 65 years of age. This shows that the e-scooters/e-bikes are used mainly by middle-aged persons and teenagers. About 26.92% of the respondents were females, and the rest were males (73.08%). Half the respondents are married (50%), and 46.25% are just partnered. The respondents either live with their partners (30.77%), alone (38.46%), with their guardians (19.23%), and the rest live with their partner and have one child (11.54%). As observed from the study, most users of e-scooters/e-bikes are employed (61.54% for full-time employment and 34.62% for part-time employment). This shows that the e-scooters/e-bikes are mostly used for first and last miles, enabling workers to reach their place of employment on time. Over 38.46% of the respondents have a household income below $50,000, 53.85% have a household income of $50,000 to $100,000, and 25.79% have a household income of $100,000 to $150,000. This response on income shows that most users of e-scooters and e-bikes are low to medium-income earners.

Chi-square Test

A chi-square test was also performed to test whether various user characteristics impact the purpose of using the golf carts or e-scooters. These characteristics include age and gender. Equation 3.1 presents the formula for the chi-square test.

$$X^2 = \frac{(O_i - E_i)^2}{E_i} \tag{6.2}$$

where, O_i represents the observed values, and E_i represents the expected values.

The observed values are the values present in the data set. The expected values can be obtained by using Equations 6.3 through 6.6.

$$E(x) = P(x) * n \tag{6.3}$$

$$P(x) = \frac{\sum c_j}{n} * \frac{\sum r_i}{n} \tag{6.4}$$

Substituting the probability of occurrence of an event, $P(x)$, in Equation 6.4, the formula for determining the expected values becomes:

$$E(x) = \frac{\sum c_j}{n} * \frac{\sum r_i}{n} * n \tag{6.5}$$

$$E(x) = \frac{\sum c * \sum r}{n} \tag{6.6}$$

where, E(x) is the expected value, $\sum r$ is the sum of rows in the observed value table for the particular variable, $\sum c$ is the sum of columns in the observed value table for the specific variable, and n is the total number of observed values for the particular variable.

After obtaining the observed values and the expected value, the contribution of each cell for the variables to the chi-square test was later determined, and the chi-square analysis was then performed. The chi-square value obtained from the data analysis was compared to the critical square value at a particular significance level and degree of freedom to determine whether to reject or fail to reject the null hypothesis.

The null hypothesis and alternative hypothesis for the chi-square test between the users' characteristics and purpose were as follows:

Null hypothesis: H_o: Users' characteristics have no impact on the purpose of using low-speed vehicles (GC)/E-scooters.

Alternative Hypothesis: H_a: Users' characteristics have an impact on the purpose of using low-speed vehicles (GC)/E-scooters.

The Chi-square analysis test results were obtained using Minitab Software. For analysis, the degree of freedom was obtained by the formula shown in Equation 6.7.

$$df = (r - 1)(c - 1) \tag{6.7}$$

where, df is the degree of freedom, r is the number of rows for a particular variable, and c is the number of columns for a specific variable in the contingency table.

The Chi-square analysis test was performed at a 95% confidence level ($\alpha = 0.05$). Analysis results indicate that user characteristics impact the purpose of using e-scooters and e-bikes. Only five purposes were included in the analysis test. This is because other purposes (e.g., working and others) were individually tested by the chi-square analysis and found no relation to user characteristics.

6.5.4 Conclusions and Recommendations

A survey was conducted to gain more information on the user experience of micromobility devices in Florida. The study used various descriptive analyses to show trends and user patterns of the micromobility devices. A Chi-square analysis test was employed to test the relationship between user characteristics (i.e., age and gender) and the purpose of use of the micromobility vehicles.

Analysis results for e-scooters and e-bikes indicate that most users get their vehicles by using sharing apps, and they are also mostly used for everyday commuting and entertainment purposes. The e-scooters and e-bikes are mostly operated on bike lanes and sidewalks, reducing the possibility of crashes with other modes of transport. Both e-scooters and e-bikes have numerous advantages, such as being easy to ride, good for the environment, cheaper transportation, and ease of access.

Due to the recommendations provided by the respondents in the survey, transportation agencies may improve micromobility services by providing more multimodal paths for low-speed vehicles and increasing the e-bike/e-scooter stations, as their usage may increase in future years. Also, the providers of e-scooters and e-bikes can make some considerations on the fees/charges per minute. Furthermore, the manufacturers may also install lights on the e-scooters and e-bikes to make them visible on roadways.

In conclusion, since micromobility vehicles are emerging components in the transportation system, various traffic rules and regulations should be considered by transportation agencies to improve the safety and mobility of micromobility device users. This may include speed regulations and age restrictions for using these vehicles. Appropriate locations for their use should also be considered, such as prohibiting locations where extensive interaction with public transport systems may occur to minimize potential crashes.

CHAPTER 7
MICROMOBILITY GUIDELINES AND RECOMMENDATIONS

This chapter presents guidelines and recommendations developed from the safety and mobility analyses of micromobility devices in Florida. One-page summaries are also provided in Appendix C.

7.1 Guidelines for Deploying Shared Micromobility Systems

The following guidelines/recommendations are based on a thorough analysis of responses obtained from a state-of-the-practice survey and a comprehensive review of micromobility policies from around the country.

Guidelines for deploying shared micromobility systems include:

- Initiating pilot programs before transitioning to a permanent program to allow for the development of specific policies and clear guidance for micromobility systems.
- Conducting preliminary studies to understand the needs and concerns of potential users.
- Adopting a hybrid system to effectively maximize user preferences to maximize operational and safety benefits.
- Establish a well-defined relocation plan for emergency weather conditions, prioritizing safety of both users and micromobility devices.
- Strategic infrastructure planning to optimize the system's usability and efficiency.
- Establish clear speed limit policies based on the laws and statutes governing micromobility usage.
- A thorough vendor selection process according to criteria, such as fleet availability, experience, alignment with program objectives, operation plan, and community engagement.
- Establish minimum criteria for vendor selection based on a preliminary study conducted in a specific city or minimum standards set by other cities/agencies with similar requirements.
- Implementing a standard age restriction policy for users.

7.2 Guidelines for AOEMs

The following guidelines are designed to help/assist the automobile original equipment manufacturers (AOEMs) of e-scooters and e-bikes in enhancing the overall quality and safety of their products. These recommendations are based on findings from user experience surveys conducted throughout the State, by device type.

Suggested recommendations for e-scooters/e-bikes include:

- Increase range (battery capacity).
- Improve overall safety.
- Maximize ride comfort.

- Lower initial cost.
- Focus on appealing styling

7.3 Safety Recommendations for E-scooters and E-bikes

Suggested recommendations to improve safety for e-scooters/e-bikes include:

- Provide education programs to inform micromobility users about traffic rules and safety measures.
- Emphasize the importance of wearing safety equipment, such as helmets, for micromobility riders.
- Develop awareness campaigns to promote safe and responsible micromobility use.
- Enforce traffic regulations for micromobility riders to deter violations and ensure safe operation.
- Implement measures to improve compliance with traffic laws by micromobility users.
- Create separate facilities for micromobility riders to reduce conflicts with vehicles and pedestrians.
- Use shared lane pavement markings to indicate the presence of micromobility and their right to use the road.
- Establish colored bike lanes, especially in high-conflict areas.
- Provide standard-width bike lanes for safe micromobility travel.
- Install street lights on roadways to enhance visibility, particularly at night.
- Widen sidewalks to minimize conflicts between micromobility users and pedestrians.

CHAPTER 8
SAFETY ANALYSIS OF GOLF CARTS

This chapter, added as an addendum to the micromobility study, discusses the safety aspects of golf carts operated in Florida.

8.1 Overview

Crashes involving golf carts (GCs) have been on an increasing trend in recent years, particularly in the United States. This study focuses on analyzing GC crashes in the Florida community known as The Villages, one of the largest GC-oriented communities in the nation and worldwide. The objective is to evaluate the injury severity of crashes involving GCs in a retirement community where GCs are a common mode of transportation. The ordinal logistic regression (OLR) model is used to analyze the injury severity of 616 GC-related crashes. The analysis aims to reveal various factors influencing the GC crash severity. The Chi-square test is also used in addition to emphasize on the significant factors affecting GC crash severity. Understanding these factors is vital for transportation agencies to develop effective strategies to reduce the severity of GC crashes, ensuring the safety of GC users.

8.2 Background

Golf carts (GCs) are low-speed vehicles (LSVs), since they are low-powered and operate at relatively lower speeds (maximum of 25 mph). In recent years, the number of golf cart communities have increased in Florida, partly due to the State being a popular retirement destination. Golf carts are available in a variety of styles, with seating capacity from two to six persons. Figure 8.1 shows an example of a 4-person GC.

Figure 8.1: Golf Cart (4-person) Example

Annually, the United States (U.S.) experiences over 18,000 injuries directly associated with GCs (Castaldo et al., 2020). Injuries related to GCs in the U.S. have surged in recent years. This increase can be attributed to a combination of factors, including the enhanced power and versatility of GCs, their growing popularity, and a lack of regulations governing their use (Watson et al., 2008). Over time, GCs have evolved to become faster and more powerful, with newer models capable of reaching speeds up to 25 miles per hour (mph) and covering distances exceeding 40 miles on a single battery charge (NHTSA, 2023; Watson et al., 2008).

Consequently, the increased capabilities of GCs have expanded their range of applications beyond the golf course. They are now commonly employed for transportation purposes at various venues, such as sporting events, airports, hospitals, national parks, college campuses, community businesses, prisons, and military bases (Allen, 2015). Moreover, GCs have become the primary mode of transportation in gated communities and retirement centers (El-Tawab et al., 2020). Approximately 37 States in the U.S. now allow GCs on low-speed roadways (Mitran et al., 2020). In some of these States, laws have been enacted to empower local governments to regulate the usage of GCs on public streets within their specific jurisdictions. Consequently, the spike in GC usage presents a safety issue.

Several studies have explored the safety of GCs. Xue and Xu (2023) used crash data from the Fatality Analysis Reporting System (FARS) database to identify significant contributing factors to fatal crashes involving GCs in the U.S. The study used descriptive statistics and a chi-squared test to investigate the factors related to GC crash fatalities. Florida was found to be one of the States with the highest number of GC fatal crashes. Temporal factors, such as season of the year, day of the week, and time of day, were the dominating factors in determining whether a GC-related crash would turn out to be fatal. Other factors, such as weather conditions, falling from the GC on collision, age, gender, and DUI status, were also found to be significant in causing GC fatal crashes.

One study analyzed every recorded GC crash that occurred in The Villages, Florida, between 2011 and 2019 (Castaldo et al., 2020). A comprehensive data collection was compiled from various sources to ensure a thorough analysis of these incidents. The sources utilized in this study encompassed The Villages Property Owners' Association (POA), The Villages Sun Daily Newspaper, The Villages Public Safety Department (VPSD), Police Dispatch records, and the Sumter County Police database. This study also used descriptive analyses to evaluate how different factors are associated with GC crash injury severity. Factors, such as ejection of one or more occupants from the GC, crash location, and the use of seat belts, were found to be significantly associated with GC crash severity.

In an earlier study, individuals who sought medical treatment for GC-related injuries at participating emergency departments between 2002 and 2005 were identified through the National Electronic Injury Surveillance System (McGwin et al., 2008). Among various age groups, the highest injury rates were observed in individuals between 10 and 19 years of age and those age 80 and over. In addition, male patients exhibited a higher rate of injuries than female patients, and individuals identified as white had a higher injury rate than black or Asian individuals. The most frequent locations where injuries occurred were sporting sites, predominantly golf courses, and residential areas.

Seluga et al. (2009) studied GC vehicle standards to analyze their braking effectiveness and directional stability. Findings from the study affirm that installing brakes solely on the rear wheels of a GC vehicle significantly diminishes its braking effectiveness, compared to a vehicle equipped with brakes on all four wheels. Moreover, having brakes exclusively on the rear axle wheels can potentially result in hazardous yaw instability and subsequent roll-over if the brakes are applied with sufficient force to lock the rear wheels. Another study in Arizona analyzed the factors affecting the injury severity of crashes involving all-terrain vehicles (ATVs) and GCs using police-reported crashes (Russo & Smaglik, 2019). This study used the random parameter ordered logit model to assess the factors contributing to the severity of crashes involving either an ATV or GC. Significant factors in causing severe crashes involving the two vehicle types included age, use of safety devices, roadway grades, road surface, road alignment, and alcohol and drug use.

All previous studies that focused particularly on GC safety used descriptive analysis and proportions to determine factors affecting the severity of GC crashes. None of these studies explicitly studied GC crash injury severity using a predictive model approach. The advantage of the predictive modeling approach over descriptive analysis is its proactive nature and robustness in analyzing and handling traffic safety issues (Williams, 2011). Therefore, this research utilized a modeling approach to understand the factors affecting the severity of crashes involving GCs. Based on the model results, recommendations for providing safer GC movements are provided for different transportation agencies and communities in general.

8.3 Data

This research focused on crashes involving GCs in The Villages, Florida, from January 2018 to February 2023. Situated in central Florida, approximately 60 miles northwest of Orlando, The Villages stands as the largest community worldwide dedicated to GC transportation (Castaldo et al., 2020). It offers a valuable setting to evaluate the safety aspects of GCs employed for transportation within a retirement community for individuals aged 55 and over. With a population of around 140,000 residents and over 50,000 GCs as of 2018, The Villages serves as a significant population center. The entire community has been carefully designed to ensure accessibility for GCs, with options including dedicated GC lanes on streets and parallel GC paths. Currently, there are approximately 70 similar GC-oriented communities throughout the U.S. that have been planned with GC accessibility in mind, mirroring The Villages' approach (Castaldo et al., 2020). Figure 8.2 depicts the studied GC crashes in The Villages, Florida.

Crash data were obtained from Signal Four analytics. Signal Four Analytics is an online system that has been specifically developed to cater to the crash mapping and analysis requirements of various entities in Florida (Signal Four Analytics, 2023). Entities that typically use the system include law enforcement, traffic engineering, transportation planning agencies, and research institutions in Florida. It is an interactive Web-based platform intended to provide support in these areas within the state. The extraction of GC crashes in Signal Four analytics was done by filtering the vehicle style attribute in the dataset using the GC and low-speed vehicles (LSVs) keywords.

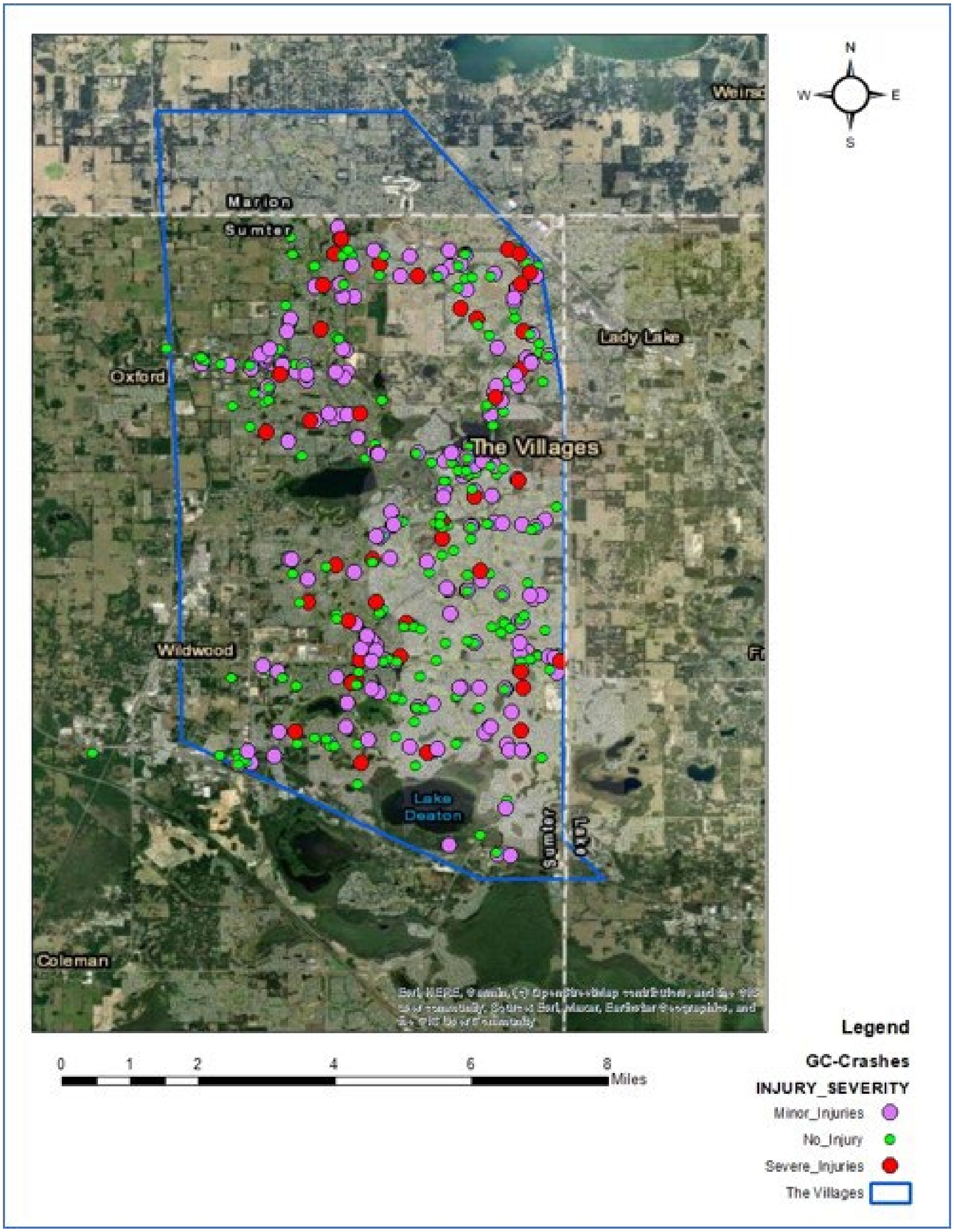


Figure 8.2: GC Crash Incidents in The Villages, Florida (January 2018 to February 2023)

Crash severity was categorized into three groups: no injury, minor injury, and severe injury. The minor injury class includes non-incapacitating and possible injuries, while the severe injury category comprises fatal and incapacitating injuries. The final dataset consists of 616 crashes. Overall, 56% of these crashes resulted in no injuries, 35% resulted in minor injuries, and the remaining 9% resulted in severe injuries. Table 8.1 presents the frequency distribution of the analyzed GC crashes. Variables analyzed included driver attributes, temporal factors, crash attributes, and roadway characteristics.

Table 8.1: Descriptive Statistics for Model Variables Classified by Crash Severity

Variables	Category	No Injury		Minor Injury		Severe Injury	
		Count	%	Count	%	Count	%
Type of Shoulder	Unpaved	55	49.5	36	32.4	20	18
	Paved	85	66.4	37	28.9	6	4.7
	Curbed	205	54.4	143	37.9	29	7.7
Type of Intersection	Not at Intersection	158	53.7	111	37.8	25	8.5
	T-Intersection	86	53.8	57	35.6	17	10.6
	Other	25	65.8	11	28.9	2	5.3
	Four-way Intersection	76	61.3	37	29.8	11	8.9
Road Surface Condition	Dry	320	56.7	198	35.1	46	8.2
	Wet	25	48.1	18	34.6	9	17.3
Roadway Alignment	Straight	311	57.5	186	34.4	44	8.1
	Curve	34	45.3	30	40	11	14.7
Roadway Grade	Level	322	56.4	199	34.9	50	8.8
	Uphill/Downhill	23	51.1	17	37.8	5	11.1
Total Number of Lanes	1	16	61.5	10	38.5	0	0
	2	300	55.8	186	34.6	52	9.7
	3+	29	55.8	20	38.5	3	5.8
Traffic Control Device	No Control	244	51.5	187	39.5	43	9.1
	Traffic Signals/Signs	101	71.1	29	20.4	12	8.5
Crash Location	On Roadway	250	57.9	141	32.6	41	9.5
	Parking zone	37	66.1	18	32.1	1	1.8
	Off Roadway	58	45.3	57	44.5	13	10.2
Trafficway	One-Way/Two-way Undivided	298	54.6	197	36.1	51	9.3
	Two-Way Divided	47	67.1	19	27.1	4	5.7
Estimated GC Speed	Speed ≤15 mph	255	64.4	116	29.3	25	6.3
	Speed >15 mph	90	40.9	100	45.5	30	13.6
Gender of Driver	Female	103	54.5	68	36	18	9.5
	Male	242	56.7	148	34.7	37	8.7
Age of Driver	≤ 65 years	71	55.5	48	37.5	9	7
	> 65 years	274	56.1	168	34.4	46	9.4
Driver's Action	No contributing action	172	57.3	110	36.7	18	6.0
	Contributing action	145	56.6	80	31.3	31	12.1
	Other	28	46.7	26	43.3	6	10

Note: mph = miles per hour; GC = golf cart.

Table 8.1: Descriptive Statistics for Model Variables Classified by Crash Severity (cont'd)

Variables	Category	No Injury		Minor Injury		Severe Injury	
		Count	%	Count	%	Count	%
Vehicle Maneuver	Straight ahead	190	50.5	153	40.7	33	8.8
	Stopped	20	83.3	4	16.7	0	0
	Turning/ Backing/ Other	135	62.5	59	27.3	22	10.2
Manner of Collision	Rear-end/Side-swipe	57	67.1	23	27.1	5	5.9
	Angle	115	58.7	61	31.1	20	10.2
	Roll Over	17	32.1	29	54.7	7	13.2
	Head-On	15	60	8	32	2	8
	Other	141	54.9	95	37	21	8.2
GC Driver Distraction	No	243	83.2	44	15.1	5	1.7
	Yes	102	56.4	68	37.6	11	6.1
Alcohol Use	No	331	56.4	205	34.9	51	8.7
	Yes	14	48.3	11	37.9	4	13.8
Time of the Day	Day	322	57.7	189	33.9	47	8.4
	Night	23	39.7	27	46.6	8	13.8
Speed Related	No	339	56.5	209	34.8	52	8.7
	Yes	6	37.5	7	43.8	3	18.8
GC Tow Damage	No	310	59.8	169	32.6	39	7.5
	Yes	35	35.7	47	48	16	16.3
Estimated GC Vehicle Damage	≤ $500	225	61.6	110	30.1	30	8.2
	> $500	120	47.8	106	42.2	25	10
Disabling Functional Damage to GC	None	32	57.1	21	37.5	3	5.4
	Minor/Functional	244	59.8	131	32.1	33	8.1
	Dysfunctional	69	45.4	64	42.1	19	12.5
Point of Impact	Right front fender	116	60.4	60	31.3	16	8.3
	Front left bumper	162	56.1	99	34.3	28	9.7
	Rear right bumper	23	59	15	38.5	1	2.6
	Overturn	44	45.8	42	43.8	10	10.4
Occupant(s) Ejected	Not ejected	334	67.5	140	28.3	21	4.2
	Ejected	11	9.1	76	62.8	34	28.1
Lighting Condition	Daylight/Dusk	325	57.9	189	33.7	47	8.4
	Dark lighted	12	33.3	19	52.8	5	13.9
	Dark – not lighted	8	42.1	8	42.1	3	15.8
Weather Condition	Clear	277	56.5	172	35.1	41	8.4
	Cloudy	57	59.4	29	30.2	10	10.4
	Rainy	11	36.7	15	50	4	13.3

Note: mph = miles per hour; GC = golf cart.

GC driver attributes involved factors such as the age and gender of GC drivers. Temporal factors included variables that change over time (e.g., time of day and weather conditions). Crash attributes were those involved with the crash occurrence (e.g., estimated GC vehicle damage, crash location, and estimated GC speed prior to impact). Roadway characteristics incorporated features such as the number of lanes and shoulder types. Regarding both crash frequency and crash severity, most crashes occurred during the day (558 crashes), a higher proportion than nighttime crash occurrence (58 crashes). About 14.5% of the severe injury crashes occurred at night. The weather condition variable was grouped into clear, cloudy, and rainy conditions. The proportion of crashes during clear conditions was higher than in cloudy or rainy conditions, reflecting the tendency of most GC users to avoid inclement weather. Consequently, 74.5% of severe injury crashes occurred during clear conditions.

Lighting condition was categorized into daylight, dark-lighted, and dark-not-lighted. The majority of crashes (561 crashes) occurred during daylight conditions, compared to dark conditions. Most severe injury crashes occurred during daylight (85.5%). Three categories were used to describe the crash location variable: on-roadway, parking zone, and off-roadway. Of the 616 crashes, most occurred on the roadway (432 crashes), while the remaining crashes occurred either in a parking zone, on a sidewalk, or on the roadway shoulder. Likewise, 74.5% of severe injury crashes occurred on the roadway. This pattern indicates that most crashes occur when GCs interact with other transport modes.

The type of shoulder variable was also divided into three categories: paved, unpaved, and curbed. The analysis shows that more crashes occur on roadways with curbed shoulders (377 crashes) than on roads with paved or unpaved shoulders. The analysis also showed that 52.7% of severe injury crashes occurred on roadways with curbed shoulders. Based on the type of intersection variable, most GC crashes occur at intersections. Moreover, intersections account for 54.5% of the severe injury crashes. Two categories were analyzed for road surface conditions: wet and dry conditions. A large majority of GC crashes (564) occurred during dry conditions. Also, 83.6% of the severe injury crashes occurred during dry conditions. The trafficway variable was classified into two categories: one-way or two-way undivided trafficway and two-way divided trafficway. The majority of severe injury crashes occurred on one-way or two-way undivided roadways (92.7%), rather than on two-way divided roadways.

Based on roadway alignment, a large majority of GC crashes occurred on straight segments (87.8%) than on curved roadway segments. As a result, 80% of GC severe crashes also occurred on straight roadway segments. Similarly, most GC crashes (93%) and 91% of severe crashes occurred on level roadway segments, compared to sloped segments (uphill or downhill).

The traffic control variable was also divided into two categories: no control and the presence of traffic signals or signs (yield or stop). Of the 616 GC crashes analyzed, 474 crashes and 78% of severe injury crashes occurred in locations with no traffic controls present. Surprisingly, over half (396 of the 616 crashes) of the crashes occurred at GC speeds ≤ 15 mph. Only 16 of GC crashes were speed related. The GC speed is the estimated speed (from Signal Four Analytics) prior to impact/crash. Although most crashes occurred at GC speeds ≤ 15 mph, over half (55%) of the severe injury crashes occurred at GC speeds > 15 mph. Among the 55 severe injury GC crashes, about 6% were speed related. The lower number of speed-related GC crashes could explain the lower number of severe injury speed-related crashes compared to the non-speed-related GC crashes.

Several attributes related to GC drivers were analyzed, including the gender and age of the GC driver. Male drivers were involved in over 69% (427 of 616) of GC crashes and 67% of the severe injury crashes. As expected, since the study area consisted of a retirement community, most of the GC drivers were aged 65 and over. Also, in the majority of GC crash events, neither alcohol use nor driver distraction was a predominant factor. However, GC driver distraction was a factor in 69% of the severe injury crashes.

Three categories were analyzed for the GC driver's action variable: no contributing action, contributing action, and other. No contributing action refers to the GC driver taking no action to initiate the crash, and therefore, not responsible for the crash occurrence. A contributing action refers to the GC driver being responsible for crash by not obeying traffic rules. The category 'Other' refers to an action made by a GC driver as the contributing action that led to the crash, outside of failure to obey traffic rules and regulations. The analysis revealed that over 56% of severe injury GC crashes resulted from the GC driver not obeying traffic rules, such as failure to yield the right-of-way. Additionally, more GC crashes (376) occurred when the GC driver was traveling straight than when stopped, turning, backing, or doing any other maneuver. Around 60% of severe injury crashes occurred when the maneuver during the crash was moving straight ahead. Furthermore, most GC crashes were found to be angle crashes, rather than rear-end, side-swipe, head-on, or roll-over collision types. Among the severe injury GC crashes, 59% were angle collisions.

The estimated GC vehicle damage variable was divided into two categories: ≤ \$500 and > \$500. The dollar amount refers to the GC damage cost that a GC crash has caused. Analysis results indicate that most crashes led to GC vehicle damage equal to or less than \$500. Similarly, 55% of the severe injury crashes led to an estimated vehicle damage equal to or less than \$500. Nearly 20% (121 crashes) of crashes analyzed involved the ejection of at least one occupant from the GC vehicle. Among the severe injury GC crashes, nearly 62% led to the ejection of at least one occupant from the GC vehicle.

8.4 Methodology

This study used the ordinal logistic regression model (OLR) to predict the severity of crashes involving GCs. In contrast to conventional logistic regression models, OLR treats the predicted severity category as an ordinal variable, rather than a nominal one. In this study, the predicted category pertains to crash severity, where the categories are ordered from no injuries to severe injuries. This characteristic makes OLR appropriate for the analysis conducted (Michalaki et al., 2015). Equation 8.1 outlines the probability considerations involved in the classification process for OLR.

$$logit[p(y \leq j)] = \alpha_j - \sum_{i=1}^{M} \beta_i x_i \tag{8.1}$$

where,

p is the probability of a severity category y to be the true category,

y is the ordinal severity category to be predicted,
α_j is an intercept of the ordinal (severity) category to be predicted,
β_i represents a coefficient of an independent variable selected for this study,
x_i represents a selected independent variable for this study,
j = 1,…, J-1 and i = 1,…, M (in this study, J =3 and M = 26),
J is the number of injury severity categories to be predicted, and
M is the number of independent variables used for this study.

In the case of OLR, the coefficients of the independent variables remain consistent across all categories being predicted. The OLR model produces two intercepts corresponding to two out of the three response variable categories. These intercepts define the thresholds at which the underlying variable is divided, creating the three observed groups in the dataset. The probabilities for the two categories were calculated, and by using Equation 8.2, the probability for the third category was also determined. The model predicts the category with the highest probability as the outcome.

$$p(1) + p(2) + p(3) = 1 \tag{8.2}$$

To ensure that the model developed is reliable and consistent in its results, model evaluation was performed on the portion of the dataset that was not used in the model training (test set). Parameters, such as overall accuracy and balanced accuracies, were analyzed. Overall accuracy was used to assess how, in general, the model has performed in prediction, while the balanced accuracy assessed how well each severity category was predicted. Equations 8.3 through 8.6 illustrate the accuracy parameters used in this study.

$$\text{Sensitivity} = \frac{True\ Positives\ (TP)}{True\ Positives\ (TP) + False\ Negatives\ (FN)} \tag{8.3}$$

$$\text{Specificity} = \frac{True\ Negatives\ (TN)}{True\ Negatives\ (TN) + False\ Positives\ (FP)} \tag{8.4}$$

$$\text{Balanced Accuracy} = \frac{1}{2}(Sensitivity + Specificity) \tag{8.5}$$

$$\text{Overall Prediction Accuracy} = \frac{Total\ Correctly\ Predicted\ Classes\ in\ a\ Test\ Set}{Test\ Set\ Sample\ Size} \tag{8.6}$$

In this research, sensitivity refers to the model's ability to predict the correct severity category accurately. Specificity measures the model's capability to identify non-specific severity categories correctly. Balanced accuracy represents the average of sensitivity and specificity, indicating the model's overall performance in predicting severity classes. Overall prediction accuracy reflects the overall effectiveness of the model in predicting all studied injury severity categories. All four parameters have values ranging from 0 to 1, sometimes represented as percentages, where '1' represents the highest accuracy and '0' represents the lowest accuracy in prediction.

True positives represent crashes that are accurately assigned to their true category by the model's prediction. True negatives are crashes that do not belong to a specific category and are correctly identified as such by the model. False positives are crashes predicted as a particular category, but actually belong to a different category. False negatives are crashes that are predicted to be in other categories, but actually belong to the category being considered. The proportional odds assumption (POA) for OLR was also checked and met. POA assumes that the effect of the independent variables on the cumulative odds ratio is constant across the different outcome categories.

8.5 Results

From the model results, out of the 26 factors assessed in this study, eight factors were determined to be significant in affecting the severity of crashes involving GCs. The significant factors were shoulder type, intersection type, presence of traffic control devices, median presence, estimated GC speed, manner of collision, estimated GC vehicle damage, and whether a GC occupant was ejected or not. None of the driver behavioral factors seem to affect crash severity in GCs. However, vehicle, crash, and traffic attributes were found to affect injury severity. From the OLR analysis (Equation 1), a positive parameter indicates a variable increases the probability of a crash being more severe; whereas, a negative parameter indicates a higher probability of less severity. Table 8.2 summarizes the OLR model results. Significant variables have a Z-statistics value greater than or equal to 1.96 (95% Confidence Interval (CI)).

An occupant ejected from the GC during a crash significantly increased the chance of being seriously injured or killed. Most GCs do not have seat belts, and therefore, there is no support to prevent the GC occupants from being ejected during a crash (Miller et al., 2016; Ogundele et al., 2013). Consequently, as in any other motorized vehicle, crashes involving not wearing seatbelts tend to result in more severe injuries.

The extent of damage to the GC significantly correlates with the severity of injuries caused in a crash. The model indicates that the more damage sustained by the GC, the more likely the crash will involve more severe injuries. This finding is consistent with the study by Singleton et al. (2010), in which more serious injuries were linked with severe vehicle damage and vice-versa.

The estimated speed of the GC was positively correlated with injury severity. The higher the GC speed at the time of a crash, the more likely the crash will result in serious injury or fatality. Although the speed of most GCs is typically limited to 20 mph, many are capable of somewhat greater speeds (Xue & Xu, 2023). Based on the model results, GC drivers exceeding 15 mph are more likely to be involved in a serious injury or fatality crash, compared to drivers driving below 15 mph. Higher speeds have been shown to be associated with fatal and serious injury crashes (Zhou & Chin, 2019).

Results from the model also indicate that divided roadways are less likely to involve GC severe injury or fatality crashes. In addition, median barriers help to reduce fatal and injury crashes, especially by lessening the likelihood of head-on crashes (Hosseinpour et al., 2014; Russo &

Savolainen, 2018). The OLR model indicates that roadways with traffic control devices have a lower probability of GC drivers sustaining serious injury or fatality in crashes. Appropriate traffic control devices tend to guide traffic and reduce both crash frequency and severity (Jin & Saito, 2009).

Also, the model shows that GCs are less likely to be involved in severe and fatal crashes on roadways with paved shoulders. Paved shoulders provide additional space for a vehicle maneuver, allowing vehicles to safely move out of the way of oncoming vehicles and potentially avoid dangerous types of crashes that involve high severity, such as head-on crashes (Padmanaban et al., 2010).

GC crashes involving overturning are more likely to cause severe injuries and fatalities than other crash types. In roll-over incidents, the vehicle's structure may become compromised or weakened, especially if it is not designed or equipped to withstand such forces. As the GC rolls, the roof, pillars, and other structural components can collapse or deform, increasing the risk of severe injuries for the occupants.

Finally, GC crashes that occur at T-intersections appeared to be significantly more severe compared to other locations, including four-way intersections and non-intersection areas. Severe conflicts may arise at T-intersections due to the complexity of left-turning movements from both major and minor roads. This complexity arises from the lack of available gaps in traffic flow, making it challenging for vehicles to complete left turns safely (Bonela & Kadali, 2022).

Table 8.2: OLR Model Results

Variables	Category	Coefficient	Z-value
Type of Shoulder	Unpaved[b]		
	Paved	**-0.97669**	**-2.54947**
	Curbed	-0.44491	-1.48433
Type of Intersection	Not at Intersection[b]		
	T-Intersection	**0.63570**	**2.21586**
	Four-way Intersection	-0.37592	-1.07433
	Other	0.37249	0.77118
Road Surface Condition	Dry[b]		
	Wet	0.46436	0.70862
Roadway Alignment	Straight[b]		
	Curve	0.24177	0.66449
Roadway Grade	Level[b]		
	Uphill/Downhill	-0.09817	-0.24683
Total Number of Lanes	1[b]		
	2	0.06724	0.11729
	3+	0.25169	0.37401
Traffic Control Device	No Control[b]		
	Traffic Signals/Signs	**-0.68329**	**-2.06068**

Note: mph = miles per hour; b = base category in the model; bold text = significant factor at 95% CI.

Table 8.2: OLR Model Results (continued)

Variables	Category	Coefficient	Z-value
Crash Location	On Roadway[b]		
	Parking Zone	-0.72153	-1.64115
	Off Roadway	0.16641	0.55444
Trafficway	One-Way/Two-way Undivided Trafficway[b]		
	Two-Way Divided Trafficway	**-0.86920**	**-2.12813**
Estimated GC Speed	Speed ≤15 mph[b]		
	Speed >15 mph	**0.61328**	**2.474150**
Gender of Driver	Female[b]		
	Male	-0.37532	-1.70817
Age of Driver	≤ 65 years[b]		
	> 65 years	0.35566	1.37962
Driver's Action	No Contributing Action[b]		
	Contributing Action	0.46319	1.74809
	Other Actions	0.26515	0.69868
Vehicle Maneuver	Straight Ahead[b]		
	Stopped	-0.64773	-0.90956
	Turning/Backing/ Other	-0.36509	-1.37293
Manner of Collision	Rear-end/Sideswipe[b]		
	Angle	0.42263	1.03651
	Roll Over	**1.13441**	**2.19658**
	Head-On	0.27898	0.43609
	Other	0.44082	1.10982
GC Driver Distraction	No[b]		
	Yes	0.09401	0.41516
Alcohol Use	No[b]		
	Yes	0.32388	0.59172
Time of the Day	Day[b]		
	Night	0.32641	0.63651
Speed Related	No[b]		
	Yes	0.13060	0.21046
GC Tow Damage	No[b]		
	Yes	0.57572	1.71193
Estimated GC Vehicle Damage	≤ $500[b]		
	> $500	**0.47451**	**1.96542**
Disabling Functional Damage to GC	None[b]		
	Minor/Functional	0.60908	1.08067
	Dysfunctional	0.86333	1.76213
Point of Impact	Sides[b]		
	Front	0.89704	1.70577
	Rear	0.19125	0.75914
	Other	0.30003	0.73076

Note: mph = miles per hour; b = base category in the model; bold text = significant factor at 95% CI.

Table 8.2: OLR Model Results (continued)

Variables	Category	Coefficient	Z-value
Occupant(s) Ejected	Not ejected[b]		
	Ejected	**2.65864**	**9.87899**
Lighting Condition	Daylight/Dusk[b]		
	Dark lighted	0.02485	0.04228
	Dark – not lighted	0.18643	0.28641
Weather Condition	Clear[b]		
	Cloudy	-0.34904	-1.05836
	Rainy	0.26357	0.36026

Note: mph = miles per hour; b = base category in the model; bold text = significant factor at 95% CI.

8.5.1 Model Reliability

The model's overall test accuracy was about 71%. The "No Injury" category was predicted with a balanced accuracy of about 79%. Severe and minor injury categories were predicted with an accuracy of about 69% and 60%, respectively. According to the previous studies on predicting crash severity, the accuracy obtained from the model is sufficient (Iranitalab & Khattak, 2017). Table 8.3 presents the overall model accuracy and the balanced accuracy in predicting each injury severity category.

Table 8.3: OLR Model's Overall and Balanced Accuracies

Predicted Severity Category	Balanced Accuracy	Overall Prediction Accuracy (%)
No Injury	0.7910	70.97
Minor Injury	0.6922	
Severe Injury	0.6004	

8.5.2 Chi-Square Analysis Test for Association

After obtaining the model results, the chi-square test for association was used to test the relationship between injury severity and the model's significant factors. The analysis was conducted to determine which factors among the significant factors the test also found to be substantial. Equation 8.7 presents the chi-square statistics:

$$X^2 = \frac{(O_i - E_i)^2}{E_i} \tag{8.7}$$

where, O_i represents the observed values, and E_i represents the expected values.

The observed values are the counts obtained from the data set, while the expected values were later determined and compared with observed values. The expected values can be obtained by Equations 8.8 and 8.11:

$$E(x) = P(x) * n \tag{8.8}$$

$$P(x) = \frac{\sum c_j}{n} * \frac{\sum r_i}{n} \tag{8.9}$$

Substituting the probability of occurrence of an event, $P(x)$ from Equation 8.9, in Equation 8.8, the final formula for expected values becomes:

$$E(x) = \frac{\sum c_j}{n} * \frac{\sum r_i}{n} * n \tag{8.10}$$

$$E(x) = \frac{\sum c * \sum r}{n} \tag{8.11}$$

where,

E (x) is the expected value,
$\sum c$ is the sum of columns in the observed value table,
$\sum r$ is the sum of rows in the observed value table, and
n is the total number of observed values.

After determining the expected and observed values, the contribution of each cell to the chi-square was calculated to perform the analysis. The decision to reject or fail to reject the null hypothesis depended on the comparison between the obtained chi-square value and the critical square value, depending on the significance level and the degrees of freedom. As an example of one of the factors, the study will illustrate the chi-square analysis procedure for injury severity and the estimated GC speed prior to the crash (see Tables 8.4 and 8.5).

For the chi-square analysis test between injury severity and estimated speed, the null hypothesis and alternative hypothesis were as follows:

Null hypothesis: H_o: Injury severity in GC crashes is independent of the estimated speed.
Alternative Hypothesis: H_a: Injury severity in GC crashes is dependent on the estimated speed.

Table 8.4 presents the observed values from the dataset.

Table 8.4: Observed Values for Estimated GC Speed from the Dataset

Estimated Speed	**Injury Severity (Observed Values)**			
	No Injury	**Minor Injury**	**Severe Injury**	**Total**
≤ 15 miles per hour	255	116	25	**396**
> 15 miles per hour	90	100	30	**220**
Total	**345**	**216**	**55**	**616**

The Chi-square test results for association were obtained using the Minitab software. For the analysis, the degree of freedom was obtained using Equation 8.12, as follows:

$$df = (r - 1)(c - 1) \quad (8.12)$$

where,

df is the degrees of freedom,
r represents the number of rows, and
c represents the number of columns in the contingency table.

Table 8.5 summarizes the expected values from the analysis for estimated GC speed and summarizes the contribution of each cell toward the calculated chi-square value. The estimated chi-square value for estimated GC speed (mph) was 32.956. The critical chi-square value for estimated speed (mph) at 95% CI, with two (2) degrees of freedom, was 5.991 (from the chi-square table).

Table 8.5: Expected Values for Estimated GC Speed from the Analysis and Cell Contribution Toward Calculating the Chi-Square Value

Estimated Speed	**Injury Severity (Expected Values)**			
	No Injury	**Minor Injury**	**Severe Injury**	**Total**
≤ 15 miles per hour	221.79	138.86	35.36	**396**
> 15 miles per hour	123.21	77.14	19.64	**220**
Total	**345**	**216**	**55**	**616**
Estimated Speed	**Injury Severity (Chi-Square Cell Contributions)**			
	No Injury	**Minor Injury**	**Severe Injury**	**Total**
≤ 15 miles per hour	4.974	3.762	3.034	**11.77**
> 15 miles per hour	8.953	6.772	5.461	**21.186**
Total	**13.927**	**10.534**	**8.495**	**32.956**

The final chi-square test results were 32.956 with a p-value of 0.00000007. Since the value of α = 0.05 and the p-value (0.00000007) < α (0.05), the null hypothesis was, therefore, rejected. This means that there is enough evidence to suggest injury severity in GC crashes is dependent on the estimated speed (mph) at a 95% CI.

This procedure (chi-square test) was repeated for all of the significant variables, resulting in five variables found to be significant factors affecting the severity of GC crashes: estimated GC speed, occupant(s) ejection from the GC, estimated vehicle damage, traffic control devices, and type of shoulder. The chi-square values for the significant variables were 32.956, 154.214, 11.792, 18.864, and 19.459 respectively. Compared to the OLR model, intersection type, manner of collision, and trafficway features were not found to significantly affect the severity of crashes involving GCs.

The chi-square values for the non-significant variables were 2.367, 4.828, and 3.936 respectively. The slight difference between OLR and chi-square test results may be explained by the fact that the predictive model (OLR) finds the significance of a factor among other factors in affecting severity (Hastie et al., 2008). On the other hand, the chi-square test works with one factor at a time without considering the presence of other factors in the significance of the factor. Therefore, it may be important to consider both statistical approaches to obtain all possible important factors affecting the injury severity.

8.6 Conclusions and Recommendations

This study evaluated GC crash injury severity in The Villages, Florida. Findings revealed that several factors studied were significant in impacting the injury severity of GC crashes. OLR was employed to predict the severity of crashes involving GCs. By treating the predicted severity category as an ordinal variable, OLR accounted for the ordered nature of the severity levels, ranging from no injuries to severe injuries. This modeling approach proved suitable for the analysis conducted. To ensure the reliability and consistency of the developed model, a rigorous evaluation was performed using a separate test set. Parameters, such as overall accuracy and balanced accuracy, were assessed to gauge the model's performance.

Overall accuracy provided an assessment of the model's general predictive capability, while balanced accuracy examined the prediction performance for each severity category. Based on the results, several factors were found to influence GC crash injury severity significantly. Factors found to increase the risk of severe injury in GC crashes include: occupant(s) ejection from the GC, estimated GC vehicle damage, estimated GC speed, median presence, presence of traffic control devices, shoulder type, manner of collision, and intersection type. These findings have important implications for transportation agencies and can guide potential interventions to enhance safety.

The ejection of one or more occupants from the GC was identified by the model as a critical factor contributing to the increased severity of injuries. Therefore, it is recommended that transportation agencies promote and enforce the use of seat belts in GCs to minimize the risk of serious injuries or fatalities in the event of a crash. This can be achieved through public awareness campaigns, regulatory measures, and ensuring that GC manufacturers prioritize the inclusion of seat belts in their vehicles.

The extent of damage to the GC was found to correlate with the severity of injuries sustained in a crash. Transportation agencies should emphasize the importance of regular maintenance and inspection of GCs to ensure their structural integrity. Additionally, promoting safe driving practices and adhering to speed limits can help prevent high-speed collisions that often result in severe injuries and fatalities.

Divided roadways, the presence of traffic control devices, and paved shoulders were identified as mitigating factors associated with lower severity and fatality rates in GC crashes. Transportation agencies should consider the implementation of appropriate traffic control measures, such as traffic signals and signage, to guide GC drivers and reduce the frequency and severity of crashes. Furthermore, maintaining and improving the road infrastructure, including providing divided roadways and paved shoulders, can enhance safety and provide additional space for maneuvering and avoiding potential hazards.

Transportation agencies should collaborate with GC manufacturers to improve vehicle design and safety standards, specifically focusing on enhancing the structural integrity of GCs to better withstand roll-over forces. This can involve reinforcing the roof, pillars, and other critical components to minimize the risk of collapse or deformation during an overturning event. Speed management and enhanced road infrastructures could also help alleviate the impacts of these kinds of crashes.

Lastly, T-intersections were found to be associated with an increased GC crash severity. Transportation agencies should prioritize intersection design improvements at T-intersections to minimize conflicts and enhance safety. This can involve measures such as improving visibility, optimizing signal timings, and providing dedicated turning lanes to facilitate safe and efficient traffic flow.

In terms of model reliability, the overall test accuracy of approximately 71% obtained from the OLR model is considered sufficient based on previous studies on crash severity prediction. However, continuous refinement and validation of the model should be pursued to improve its accuracy and applicability.

It is important to note that the findings from the OLR model and the chi-square test for association complement each other in identifying significant factors affecting injury severity. The Chi-square test identified estimated speed, occupant(s) ejection from the GC, estimated GC vehicle damage, traffic control devices, and type of shoulder as significant factors influencing GC crash severity While the OLR model considers the significance of factors in the presence of other factors, the chi-square test examines factors individually. Thus, both statistical approaches provide valuable insights into the factors influencing injury severity and should be considered when evaluating the significance of these factors.

In conclusion, transportation agencies should focus on implementing measures, such as seat belt enforcement, regular maintenance and inspection of GCs, speed limit enforcement, improved roadway infrastructure, appropriate traffic control devices, and intersection design improvements, to improve GC safety. These actions can collectively contribute to reducing the severity and fatality rates associated with GC crashes, thereby enhancing the overall safety of GC users and the communities they operate in.

CHAPTER 9
MOBILITY ANALYSIS OF GOLF CARTS

This chapter presents the findings obtained from a mobility analysis of golf carts, also referred to as low-speed vehicles (LSVs), since they are low-powered and operate at relatively lower speeds (maximum of 25 mph). The study was conducted in Jacksonville, within the Nocatee Community. The following sections discuss the data collection process, analysis methodology, and results obtained from the analysis of the mobility benefits of golf carts.

9.1 Study Site

The mobility study was conducted in Jacksonville, in the Nocatee community, where golf carts (GCs) are used as the primary mode of transport. The study concentrated on the area around the Pine Island Academy, where children are dropped off and picked up from school using GCs. This school is both for elementary and middle school students. The Pine Island Academy is located at 805 Pine Island Road, near the southern edge of the Nocatee Community. Since Nocatee is a golf cart community, various provisions were made to ensure that parents can pick up and drop off their children using both private cars and GCs. Figure 9.1 shows the school location.

Figure 9.1: Pine Island Academy, Nocatee

9.2 Data Collection

Data required to evaluate the mobility benefits of micromobility devices included the following:

- **Traffic flow:** Traffic counts were obtained using video analysis to obtain the total number of different classes of vehicles during the study period. This included the total number of both micromobility devices and other vehicles. The traffic flow pattern was also obtained by identifying the number of vehicles doing various maneuvers on the road, such as left turns, through movements, and right turns.

- **Parking behavior:** Parking behaviors for all the vehicles within the traffic network were collected. This included parking routes and parking time for various vehicles.

- **Traffic control timing:** The timing patterns observed by the traffic officer controlling the traffic in the study area were recorded and analyzed. This is when the vehicles in a particular direction are either allowed to move or stop.

9.3 Methodology

The methodology for this research study consisted of the following steps:

1. Developing a VISSIM microsimulation model to reflect the existing field conditions.
2. Calibrating and validating the Base VISSIM model to present the model's ability to replicate field conditions.
3. Scenario management and integration within the Base VISSIM microsimulation model.
4. Analysis of data and conducting statistical tests of the network performance to document and evaluate the network's performance in different scenarios.
5. Developing mobility and safety benefits from the analysis.

9.4 VISSIM Microscopic Simulation

Microscopic simulation refers to a simulation approach that models the movement and behavior of vehicles in a detailed manner, taking into account various factors, such as driver behavior, traffic rule signal timings, vehicle characteristics, and road geometry. The microscopic traffic simulation model replicates real-world traffic network dynamics by simulating individual vehicles' movement in the network (Lu et al., 2016). Through VISSIM microscopic simulation, various traffic performance measures, such as vehicle speed, delay, queue length, and travel times, can be evaluated (Yun & Ji, 2013). The VISSIM Microscopic simulation was used in this study to establish the mobility and safety performance metrics. The use of VISSIM for the study was due to its ability to reflect the existing condition during simulation to obtain traffic performance measures. Also, the VISSIM software is easy to use, flexible, and does not require cumbersome coding (Nyame-Baafi et al., 2018).

9.4.1 VISSIM Model Development

The VISSIM model was created as the first step to reflect the existing traffic characteristics of the site. For a model to be created, various data have to be collected. For this study, the data collected included traffic flow parameters, parking behavior, and traffic control timing. The data collection process was performed through video recordings, using drones to record the school pick-up and drop-off activities. Collection times included the morning peak hours from 7:00 to 8:00 a.m., when parents bring their kids to school, and the afternoon peak hours from 2:00 to 3:00 p.m. when parents pick up their kids from school. The existing school zone model was created in VISSIM with the help of an aerial image (base map) of the site incorporated in VISSIM. The link connectors were later drawn to fit the lane width on site. Parking lots were also drawn to fit the parking alignment present on site. For parking time and queue time, an average time was used in the model after observations of the parking time of the cars, buses, and golf carts from the drone video output. The parking time considered was the time that the vehicles were in the parking lot for pick up and drop off, and the queue time considered was the time that all vehicles were in the queue. The analysis period was 1.5 hours, with the first 30 minutes used as a warm-up period. Figure 9.2 shows the drone used for data collection, and Figure 9.3 illustrates the VISSIM model used for analysis.

Figure 9.2: Drone Camera

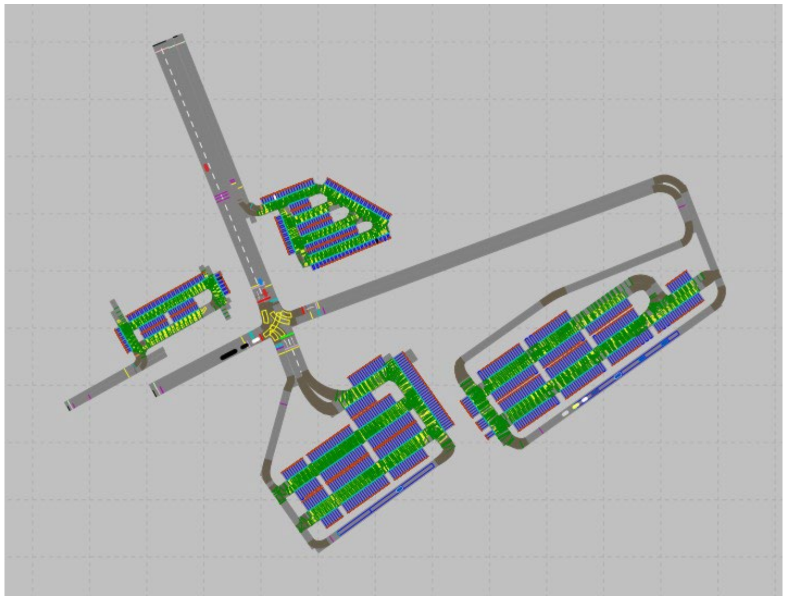


Figure 9.3: VISSIM Model – Plan View

9.4.2 Number of Simulation Runs

For VISSIM microscopic simulation, determining the number of simulations runs in VISSIM is very useful in improving statistical confidence and variability analysis. For the performance of simulation runs in VISSIM, the random seed number should be used to reflect the stochastic nature of traffic flow. The random seed value initiates a random number generator that assigns a unique seed number to a simulation run. Random seeding facilitates the replication of stochastic behavior and patterns observed in the real-world traffic flow in the VISSIM simulation model, leading to the variation of results from the simulation (Russo, 2008; Soloka, 2019). From the simulation results, VISSIM creates more meaningful values for results attributes in evaluation, such as means, maximum, and minimum values.

As recommended by the FDOT Traffic Analysis Handbook (FDOT, 2021) the formula in Equation 9.1 can be used to determine the number of simulation runs to be carried out for our study.

$$n = \left[\frac{s * t_{\alpha/2}}{\mu * \varepsilon}\right]^2 \tag{9.1}$$

where,

n - the required number of simulations runs,

s - the standard deviation of the traffic performance measure,

$t_{\alpha/2}$ - the critical value of a two-sided Student's t-statistic, at the level of confidence α and n-1 degrees of freedom,

ε - the tolerable error, specified as a fraction of the μ, and

μ - the mean of the system performance measure.

A performance measure was selected to determine the sample standard deviation and mean. This study used speed to determine the sample standard deviation and mean. Ten preliminary simulation runs were carried out at different seed numbers for each run to determine the number of simulation runs to be used. The road performance measure (Speed) average was then evaluated, as shown in Table 9.1. The road segment of Cross water NB (outbound) near Pine Island Academy was selected for the analysis. The analysis involved the selection of a segment that reflects the movement of vehicles without delay. The Crosswater NB (outbound) segment was selected for analysis since the vehicle on this route travel at a uniform speed without any stops and delays. Furthermore, the average speed obtained from the simulation was 26.25 mi/h, which is within the range of the observed speeds around the school.

Table 9.1: Average Performance Measures from Preliminary Simulation Runs

Simulation Run	Seed Number	Average		
		Density (Veh/mi/ln)	Volume (veh/h)	Speed (mph)
1	10	6.34	165.76	26.16
2	15	6.31	163.04	25.83
3	20	6.13	160.13	26.13
4	25	5.37	144.07	26.84
5	30	5.81	156.31	26.93
6	35	5.82	150.56	25.88
7	40	6.45	156.21	24.23
8	45	5.41	143.00	26.42
9	50	6.14	163.98	26.71
10	55	5.18	142.04	27.41
Average		5.89	154.51	26.25
Standard deviation		0.45	9.06	0.87
Maximum		5.18	142.04	24.23
Minimum		6.45	165.76	27.41

At 95% confidence level (α =0.05), degree of freedom of 9, and standard deviation of 0.87, as shown in Table 9.1, the critical value obtained from the statistical table was 2.262. Using a value of 10% as the error tolerance, the number of simulation runs obtained using Equation 9.1 was less than 5 (0.56). Since the required number of simulation runs obtained was low, the number of simulation runs used in the analysis was 10, corresponding to the recommended value in the Traffic Analysis Handbook (FDOT, 2021).

9.4.3 VISSIM Model Verification

Model verification was performed to ensure that the model, after calibration, does not contain errors. The base model verification process follows the checklist shown in Table 9.2, as recommended in the Traffic Analysis Handbook (FDOT, 2021).

Table 9.2: Model Verification (Error Checking) Process Checklist

Error Type	Description	Check
Software	Verify no runtime or syntax error occurs in the Protocol Window.	
	Review the error file (.err) for any errors or runtime warnings that affect simulation results.	
	Review RBC errors or warnings.	
Model Run Parameters	Review the temporal boundary limit to confirm it matches the approved methodology.	
	Verify initialization period is at least equal to twice the time to travel the entire network.	
Network	Verify the spatial boundary limit against the approved methodology.	
	Check basic network connectivity.	
	Verify the background image has been properly scaled.	
	Verify link geometry matches lane schematics.	
	Check link types for appropriate behavior parameters.	
	Check for prohibited turns, lane closures and lane restrictions at intersections and on links.	
	Check and verify traffic characteristics on special use lanes against general use lanes.	
Demand and Routing	Verify coded volume and vehicle mix/traffic composition.	
	Check HOV vehicle type and occupancy distribution as appropriate.	
	Check routing decision including connector look back distances.	
	Verify O-D matrices and their placement in the network.	
Control	Check and verify the intersection control type and data are properly coded. Verify vehicles are reacting properly to the controls.	
	Check ramp meter control type and data.	
	Check conflict area settings.	
Traffic Operations and Management Data	Verify bus operations—routes, dwell time.	
	Check parking operations.	
	Verify pedestrian operations and delays.	
Driver and Vehicle Characteristics	Check if driver behavior adjustments are necessary in saturated conditions.	
	Verify no lane changes occur in unrealistic locations and vehicles make necessary lane changes upstream in the appropriate location.	
	Verify average travel speed reasonably match field conditions	
Animation	Review network animation with the model run at low demand levels—check for unrealistic operational characteristics such as congestion and erratic vehicle behaviors.	
	Review reasonableness of the model against data coding, route assignment, and lane utilization.	
	Compare model animation to field characteristics.	
	Verify all turn bays are fully utilized and they are not blocked by through vehicles.	
	Verify there are no vehicles turning at inappropriate time or locations.	

Note: O-D = Origin-Destination.

The study's base model verification process was completed according to the following categories:

- ***Software Errors***
  The VISSIM software was checked, and no software errors were obtained after review. From the verification process, no errors related to the network and scenario were found that could affect the simulation results.

- ***Network and Model Parameters***
  The network used for the study was checked to ensure that it reflected the site conditions. The background image was verified to ensure that it had properly been scaled. The links on the network were also checked for the appropriate behavior parameters and to ensure that they match the lanes' schematics. The traffic demand volume, vehicle traffic composition, vehicle type, occupancy distribution, and routing decisions were also checked. Traffic signals were carefully reviewed, including signal timing to match the field conditions. Furthermore, parking operations, driver behaviors, and lane changes were checked and verified. In addition, the average travel speed was verified to ensure that it matched the field condition.

- ***Animation Errors***
  The simulation animation was run to observe any unrealistic movements of the vehicles and to ensure that vehicles traveled smoothly over the network. Few errors were obtained from this step and were fixed accordingly.

After adjusting all errors, the revised model was run with actual input data, and after reviewing the model again, it was concluded that the model was working.

9.4.4 VISSIM Model Calibration and Validation

Any model created in VISSIM must be calibrated to sufficiently represent field conditions (Siddharth & Ramadurai, 2013). The VISSIM model calibration process was performed in accordance with the Traffic Analysis Handbook guidelines (FDOT, 2021). The calibration targets for this study are shown in Table 9.3, per the Handbook, and were achieved by varying the various model parameters. The calibration process for this study focused on adjusting the model parameters related to the study objective and more likely to influence the traffic performance measures. This involved calibrating the driving behavior parameters: car following and lane change behavior.

Table 9.3: Model Calibration Targets

Calibration Item	Calibration Target/Goal
Capacity	Simulated capacity to be within 10% of the field measurements.
Traffic Volume	Simulated and measured link volumes for more than 85% of the links to be: Within 100 vph for volumes less than 700 vph Within 15% for volumes between 700 vph and 2700 vph Within 400 vph for volumes greater than 2700 vph.
	Simulated and measured link volumes for more than 85% of links to have a GEH* statistic value of five (5) or lower.
	Sum of link volumes within the calibration area to be within 5%.
	Sum of link volumes to have a GEH* statistic value of five (5) or lower.
Travel Time (includes Transit)	Simulated travel time within ±1 minute for routes with observed travel times less than seven (7) minutes for the routes identified in the data collection plan.
	Simulated travel time within ±15% for routes with observed travel times greater than seven (7) minutes for the routes identified in the data collection plan.
Speed	Modeled average link speeds to be within the ±10 mph of field-measured speeds on at least 85% of the network links.
Intersection Delay	Simulated and field-measured link delay times to be within 15% for more than 85% of cases.
Queue Length	The difference between simulated and observed queue lengths to be within 20%.
Visualization	Check consistency with field conditions of the following: on-ramp and off-ramp queuing; weaving maneuvers; patterns and extent of queue at intersection and congested links; lane utilization/choice; locations of bottlenecks; etc.
	Verify there are no unrealistic U-turns or vehicles exiting and reentering the network.

Note: *GEH is an empirical formula expressed as $\sqrt{2 * \frac{(M-C)^2}{M+C}}$ where M is the simulation model volume, and C is the field counted volume; vph = vehicles per hour.

9.4.4.1 Car Following Parameters Calibration

The major parameters considered in this category include look ahead distance, look back distance, number of interaction objects, number of interaction vehicles, and stand still distance. Two possible car following models can be used in VISSIM: Wiedemann 99 and Wiedemann 74. The Wiedemann 99 is suitable for freeways, while the Wiedemann 74 is suitable for surface streets (Lu et al., 2016). The Wiedemann 74 car following model was appropriate for this study.

Look ahead distance: This is the distance that a driver can see ahead of their current position, while driving, to other objects or adjacent vehicles. This study used a minimum and maximum value of 0.0 ft and 820.21 ft, respectively. These distances were found to be consistent with field conditions.

Look back distance: This is the distance that a driver can see behind when driving and adjust their behavior. The calibrated value used for this parameter was the default value of 492.13 ft.

Number of Interaction Objects and Vehicles: This refers to the number of objects or vehicles that a vehicle can observe ahead. This includes signal heads, stop signs, reduced speed areas, parking lots, and priority rules. The calibrated value of 6 objects was used for this study.

9.4.4.2 Lane Change behavior

Two possible lane change behaviors can be used in VISSIM: free lane selection and slow lane rule. Free lane selection behavior refers to the ability of vehicles to freely choose any lane within the available options when navigating through a road network. The slow lane rule behavior refers to when vehicles on a multilane road choose a slower lane compared to other available lanes. The free lane selection behavior was used for this study. In this category, other considerations included the maximum and accepted deceleration of the vehicle and the trailing vehicle, the waiting time before diffusion, safety distance reduction factor, and front and rear minimum clearance. Other parameters for calibration related to lane change behavior included advance merging and vehicle decision routing ahead.

9.4.4.3 Unmet Demand at the Entry Links Check

This process ensures that the vehicle input in all links can enter the network. According to the FDOT Traffic Analysis Handbook (FDOT, 2021), if all traffic demand cannot enter the network, the unmet demand can be corrected by extending the spatial and temporal limits. The length of the entry links with unmet demand can be extended to store more vehicles. After simulation, unmet demand was seen in one of the links due to high vehicle input. Once corrected, a review after calibration showed that this issue was solved.

9.4.4.4 Calibration Results

The calibration results for the AM Peak and PM peak periods are summarized in Table 9.4. The volume calibration criteria were used to check if results from the existing model was within satisfactory limits. The check was performed on all entry links for both golf carts and public vehicles.

Table 9.4: Model Calibration Results

Location	Demand Volume	Model Volume	GEH	Demand Volume	Model Volume	GEH
	AM Peak			PM Peak		
Pine Island EB Inbound	39	36.31	0.4	66	61.98	0.5
Cross water SB Inbound	278	277	0.06	127	118.06	0.81
Golf Cart Cross water SB Inbound	80	76.73	0.37	75	71.29	0.43
Golf Cart Pine Island EB Inbound	34	24.08	1.84	48	34.61	1.47

According to the FDOT Traffic Analysis Handbook (FDOT, 2021), the simulated and the measured link volumes should have a GEH statistical value of 5 or lower. When all the input volumes were compared, all GEH values were observed to be lower than 5. This shows that the created VISSIM model satisfies the volume calibration criteria. GEH values can be determined by using Equation 9.2, where *M* is the simulation model volume, and C is the field counted volume (demand volume).

$$\sqrt{2 * \frac{(M-C)^2}{M+C}} \tag{9.2}$$

The calibration parameters used for the study are shown in Table 9.5.

Table 9.5: Model Calibration Parameters

Lane Change Parameters	Default	Road Calibration Parameters
Necessary Lane Change (Route)		
Maximum deceleration	-13.12 ft/s2 (Own) -9.84 ft/s2 (Trail)	-13.12 ft/s2 -9.84 ft/s2
-1 ft/s2 per distance	200 ft (Freeway)	100 ft
Accepted deceleration	-3.28 ft/s2 (Own) -1.64 ft/s2 (Trail)	-3.28 ft/s2 -3.28 ft/s2
Waiting time before diffusion	60 s	300
Min. headway (front/rear)	1.64 ft	1.64 ft
To Slower Lane if Collision Time Above (seconds)	0.00	0.00
Safety distance reduction factor	0.6	0.6
Max. deceleration for cooperative braking	-9.84 ft/s2	-29.99 and -31.99 ft/s2
Overtake reduced speed areas.	Uncheck	Checked
Advanced Merging	Checked	Checked
Cooperative lane change	Unchecked	Unchecked

9.4.5 Link Evaluation

The traffic performance measures were evaluated by using link evaluation. The link evaluation was configured by defining the link segment to be evaluated. The Pine Island Inbound and Crosswater Inbound were the entry links for private vehicles, and Golf Cart SB inbound and Golf

Cart EB Inbound were entry links for GCs. For vehicle travel time, both the start and end points for evaluation were defined. Data collection points were also created to measure queue delay, and data collection points were created for each lane. Tables 9.6 through 9.8 summarize the link evaluation simulation results, i.e., relative delay, travel time, and queue delay. Equation 9.3 computed the relative delay results from the simulation.

$$Relative\ delay\ = \frac{Total\ Delay}{Total\ travel\ time\ for\ all\ vehicles\ for\ the\ link} \tag{9.3}$$

Table 9.6: Simulation Results for Relative Delay for Entry Links for AM and PM Peak

Golf Cart vehicle composition (%)	**Pine Island EB Inbound (seconds)**	**Percent Change (%)**	**Crosswater SB Inbound (seconds)**	**Percent Change (%)**	**Golf Cart SB Inbound (seconds)**	**Percent Change (%)**	**Golf Cart EB Inbound (seconds)**	**Percent Change (%)**
AM Peak								
0	93.78	0	97.27	0	0	-100	0	-100
10	92.52	-1.34	96.32	-0.98	0.98	-98.93	1.83	-87.79
20	91.84	-0.73	94.28	-3.07	2.72	-97.03	2.52	-83.19
30	91.69	-2.23	85.36	-12.24	3.85	-95.80	4.93	-67.11
40	91.09	-2.87	79.64	-18.12	15.15	-83.48	6.45	-56.97
50	90.90	-0.03	77.98	-19.83	25.41	-72.29	9.75	-34.96
60	90.13	-3.89	77.13	-20.71	11.73	-87.21	12.22	-18.48
70	89.99	-4.04	77.82	-20.00	22.90	-75.03	12.29	-18.01
80	88.68	-5.44	76.59	-21.26	49.81	-45.70	11.54	-23.02
90	73.19	-21.96	76.32	-21.54	66.05	-27.99	13.45	-10.27
100	0	-100	0	-100	91.72	0	14.99	0
PM Peak								
0	93.64	0	98.72	0	0	-100	0	-100
10	92.61	-1.1	98.57	-0.15	0.55	-97.49	1.26	-90.13
20	92.31	-1.42	97.65	-1.08	1.61	-92.65	3.60	-71.81
30	92.69	-0.01	95.60	-3.16	2.84	-87.03	6.39	-49.96
40	90.82	-3.01	88.27	-10.59	3.42	-84.38	7.64	-40.17
50	91.08	-2.73	81.07	-17.88	11.05	-49.54	8.57	-32.89
60	90.92	-2.90	77.66	-21.33	14.80	-32.42	10.02	-21.53
70	90.75	-3.09	75.92	-23.10	14.59	-33.38	10.98	-14.02
80	88.59	-0.05	78.22	-20.77	15.13	-30.91	12.06	-5.56
90	87.28	-6.79	74.34	-24.70	10.45	-52.28	12.52	-1.96
100	0	-100	0	-100	21.90	0	12.77	0

Table 9.7: Simulation Results for Travel Times for Entry Links for AM and PM Peak

Golf Cart vehicle composition (%)	Pine Island EB Inbound (seconds)	Crosswater SB Inbound (seconds)	Golf Cart SB Inbound (seconds)	Golf Cart EB Inbound (seconds)
AM Peak				
0	894.18	1453.91	0	0
10	690.98	1366.91	210.38	201.67
20	677.86	1263.68	213.55	202.60
30	627.91	1108.81	216.06	203.34
40	594.44	918.64	220.65	204.12
50	512.73	727.94	226.34	205.82
60	417.51	528.83	239.12	206.54
70	426.00	501.01	278.83	207.39
80	315.60	362.4	338.28	208.41
90	310.2	323.08	430.66	209.36
100	0	0	489.99	212.19
PM Peak				
0	925.18	1344.39	0	0
10	932.97	1238.37	209.14	201.77
20	842.12	1080.68	211.36	202.70
30	835.07	934.57	213.78	203.23
40	689.11	714.04	215.71	204.00
50	620.91	517.27	217.18	204.99
60	455.54	428.49	219.57	205.98
70	383.43	380.19	223.47	207.04
80	338.02	355.08	227.96	208.16
90	327.3	328.78	235.60	208.51
100	0	0	252.68	212.19

Table 9.8: Simulation Results for Queue Delay for Entry Links for AM and PM Peak

Golf Cart vehicle composition (%)	Pine Island EB Inbound (seconds)	Crosswater SB Inbound (seconds)	Golf Cart SB Inbound (seconds)	Golf Cart EB Inbound (seconds)
AM Peak				
0	23.65	325.74	0	0
10	22.17	230.30	0	0
20	20.82	145.42	0	0
30	17.83	55.70	0	0
40	11.93	30.39	0.01	0
50	11.84	23.47	0.07	0
60	9.16	20.14	0.38	0.01
70	3.91	18.17	0.9	0.01
80	2.74	12.94	3.17	0.01
90	0.94	7.22	25.17	0.01
100	0	0	54.85	0.02
PM Peak				
0	47.79	802.71	0	0
10	37.09	734.40	0	0
20	33.25	741.40	0	0
30	35.69	383.73	0	0
40	22.04	145.27	0	0
50	22.14	28.40	0.01	0
60	19.72	15.83	0.06	0
70	14.38	12.18	0.04	0
80	7.76	10.39	0.05	0
90	3.38	4.69	0.32	0.01
100	0	0	0.34	0.01

9.5 Discussion of Simulation Results

9.5.1 Relative Delay

Simulation results of the relative delay for each of the entry links were evaluated and summarized in Table 9.6. The simulation results showed that the relative delay on the links used by private vehicles is very high. It was also observed that as the vehicle composition of GCs increases, the relative delay of the links for the private vehicles decreases, and the relative delay for the GCs increases. The percentage decrease in the relative delay of private vehicles was from 0 to 21.96% as the GC composition increased in the network (0 to 90%). Despite the decrease in the relative delay for private vehicles as the GC composition increases, the relative delay for private vehicles was still high compared to GCs at the higher composition of GCs. This might be because vehicles in one direction have to wait for vehicles from other approaches to pass through, as there is only one exit point for all vehicles.

9.5.2 Travel Times

Simulation results of the travel time for each entry link were evaluated and summarized in Table 9.7. The travel time measured was the time it took for the vehicles to enter and leave the school zone considering the waiting time during the queue and the parking time while waiting for the kids. The travel time in the model was determined by identifying the start point for evaluation, which was the entry of the school zone, and the endpoint for evaluation, which was the exit of the school zone. In VISSIM, data collection points were placed at the entry and exit of the school zones to capture travel time for each vehicle. The simulation results showed that as the vehicle composition of GCs increases, the travel time for other vehicle paths decreases while the travel time for GCs increases. When there was no GCs in the system, the delay for other vehicles was high, up to 1453.91 seconds (24 minutes) during the morning and 1344.39 (22 minutes) during the afternoon.

9.5.3 Queue Delay

Simulation results of the queue delay for each entry link were evaluated and summarized in Table 9.8. The queue delay was the delay that occurs when vehicles wait in a queue before being allowed to go ahead. In the model, queue delay was determined by adding a data collection point on each entry link to obtain the queue delay results. The simulation results showed that the queue delay for vehicles decreases as the vehicle composition of GCs increases. Also, despite the increasing queue delay for GCs, as the vehicle composition of the GCs increases, it was almost zero most of the time.

From the simulation results, it was observed that the entry links for other vehicles have a higher relative delay, queue delay, and longer travel times than the entry links for the GCs. This might be because there was only one entry point (Intersection) in the study area for all vehicles for pick up and drop off of the children at the school, leading to congestion and, thus, causing higher delays and longer travel times. The results also show that the delays and travel times decrease as the vehicle composition of GCs increases in the system. Also, even though the increase in delay and travel times for the GCs as their vehicle composition increased, the change was still small. This shows that GCs are a good alternative mode of transportation to be used for picking up and dropping off children at school, leading to a decrease in congestion and delay and, thus, time savings.

Also, since the GCs in the study area have their own path for the drop-off and pick-up of the kids at the school, there are no interaction between the GCs and other vehicles, thus reducing the possibility of conflicts that may lead to accidents. Furthermore, the relative delay for GCs at 100% GC composition for the AM Peak appeared to be high; however, this scenario rarely occurs.

9.6 Statistical Analysis

In this study, statistical analysis was performed using the analysis of variance (ANOVA) comparisons of means. The ANOVA test was used to compare the travel times means for private vehicles and GCs for both AM and PM Peak at different GC compositions. This analysis was conducted to determine if there was a significant difference in travel times between GCs and other vehicles for pick-up and drop-off activity. The null hypothesis was that the travel time means at different GC compositions are equal, and the alternative hypothesis was that the mean for travel time at different GC compositions is not equal, as follows:

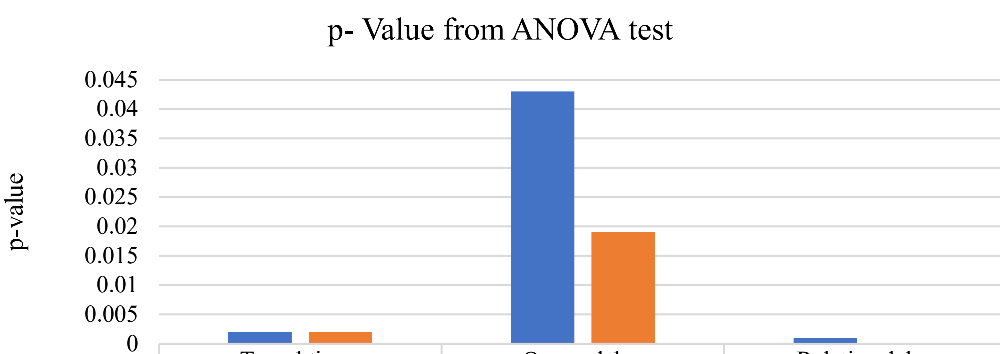
Null Hypothesis: H_0: $\mu 1 = \mu 2 = \mu 3 = \mu 4 = \mu 5$

Alternative hypothesis: H_1: $\mu 1 \neq \mu 2 \neq \mu 3 \neq \mu 4 \neq \mu 5$

where, $\mu 1, \mu 2, \mu 3, \mu 4, \mu 5 =$ meanTravel times at different GC compositions.

The study considered a 95% Confidence level ($\alpha = 0.05$). The p-value obtained from the ANOVA test was 0.001 for both AM and PM Peak. Since the p-value obtained was less than the α-value, i.e., (0.001) < α (0.05), the null hypothesis was therefore rejected. This indicates that there is enough evidence to suggest a significant difference between the travel times of GCs and other vehicles. This further supports the simulation results that GCs take a shorter time to pick up and drop off kids at school, leading to time savings and decreased delay and congestion.

The same procedure was repeated for the relative delay and queue delay, and the p-values obtained from the results were less than the α-value, showing a significant difference between the delay of the GCs and other vehicles, with GCs having a shorter delay than private vehicles for pick-up and drop-off activity at the school. Figure 9.4 shows the ANOVA analysis p-value results.



	Travel times	Queue delay	Relative delay
AM Peak	0.002	0.043	0.001
PM Peak	0.002	0.019	0.00000011

Figure 9.4: P-values from the ANOVA Test of Significance for AM and PM Peak

9.7 Conclusions and Recommendations

This study used a VISSIM model to evaluate the mobility benefits of GCs. The study used the Nocatee Community, a GC community in Jacksonville, Florida, as the study area. The simulation results presented in this study provide valuable insights into the potential benefits of integrating golf carts into the transportation system for school pick-up and drop-off of children. The analysis of relative delay, travel times, and queue delay revealed significant advantages for using golf carts as an alternative mode of transportation in a school zone.

The results demonstrate that the relative delay experienced by private vehicles is considerably high. However, as the proportion of GCs in the system increases, the relative delay for personal vehicles decreases while the relative delay for GCs increases. Despite this trade-off, it is evident that the overall traffic operation will greatly benefit from including GCs, as congestion and delay for private vehicles are reduced with increasing golf cart usage.

Similarly, travel times for other vehicle paths decrease as the number of GCs in the system increases. Conversely, the travel time for GCs increases, but this increase remains relatively small compared to the time saved for other vehicles. Consequently, implementing GCs as a transportation option will lead to considerable time savings for commuters, making it an attractive proposition for parents and students.

One of the key advantages of introducing GCs is the reduction in queue delay for all vehicles. As the GC composition increases, the queue delay for vehicles decreases substantially. The increase of GC in the network indicates the modal shift by parents from private vehicles to GC, thus reducing congestion on the route used by other cars and hence leading to a decrease in delay of the private vehicles. Additionally, GCs experience minimal queue delay most of the time, making it a highly efficient mode of transportation during school pick-up and drop-off hours.

While it is acknowledged that reaching a 100% GC penetration rate may be unrealistic, the observed patterns in the results indicate that even partial adoption of golf carts can significantly improve traffic operation in a school zone. This is further supported by the ANOVA test of significance. The reduction in congestion, relative delay, and queue delay, along with the time savings for commuters, makes golf carts a viable alternative for transporting children to and from school.

9.8 Recommendations to Transportation Agencies

Based on the study's findings, the following recommendations are suggested for transportation agencies responsible for school transportation management:

1. **Promote Golf Cart Usage**: Encourage parents and guardians to consider using golf carts for transporting their children to and from school, especially for short distances. Public awareness campaigns and incentives can be employed to promote the adoption of golf carts as a viable transportation option.

2. **Designated Golf Cart Paths**: Establish dedicated paths or lanes for golf carts in the school zone to ensure smooth traffic flow and minimal interaction with other vehicles. This separation would help avoid conflicts and potential accidents, ensuring the safety of both the students and commuters.

3. **Incentives for Schools**: Collaborate with schools to develop initiatives that promote golf cart usage. Provide support for implementing golf cart infrastructure and offer incentives to schools that actively encourage and facilitate golf cart transportation.

4. **Data Monitoring and Analysis**: Continuously monitor traffic patterns and vehicle compositions in the school zone to assess the effectiveness of integrating golf carts. Periodic data analysis would help identify areas for improvement and potential adjustments in transportation strategies.

5. **Multi-Modal Approach**: Implement a multi-modal transportation approach that includes golf carts, traditional vehicles, walking, and cycling. This approach would offer flexibility to parents and cater to the diverse needs of the students and their families.

6. **Safety Measures**: Emphasize safety training and awareness for golf cart users. Ensure that all drivers, especially parents, and guardians operating the golf carts, adhere to traffic regulations and safety guidelines.

In summary, the simulation results clearly indicate that integrating GCs into the transportation system for school pick-up and drop-off can positively impact traffic operations. While reaching full GC penetration may not be feasible, even partial adoption of GCs can lead to reduced congestion, delay, and travel times, resulting in significant time savings for commuters. Transportation agencies should consider the recommendations provided to promote and facilitate the use of GCs, ultimately contributing to a more efficient and safer school transportation system. The findings of this study shed light on the potential benefits of incorporating GCs into transportation systems, particularly in school zones. However, the implications of these results extend beyond educational settings and highlight the importance of GCs in various areas of transportation.

9.9 User Survey

This section discusses and presents the findings obtained from a survey administered to users of golf carts in Florida. The survey was conducted in Jacksonville within the Nocatee community, in Miami around the Brightline station, and in The Villages community northwest of Orlando, Descriptive and inferential analyses were performed to better understand user behavior trends and patterns and to analyze the factors influencing user adoption and satisfaction.

9.9.1 Surveyed Areas

Jacksonville: The survey in Jacksonville focused on golf carts (GCs). GCs in the Nocatee community in Jacksonville were introduced in the early 2010s (Burmeister, 2017). They are used as the primary mode of transport for various purposes within the community. This mode is used to drop students at schools within the community, attend events, and do shopping activities. The GCs have dedicated lanes on one side of the road, with a speed limit of 25 mph, and are allowed on other roads with a 35-mph speed limit (Castaldo et al., 2020; Xue & Xu, 2023).

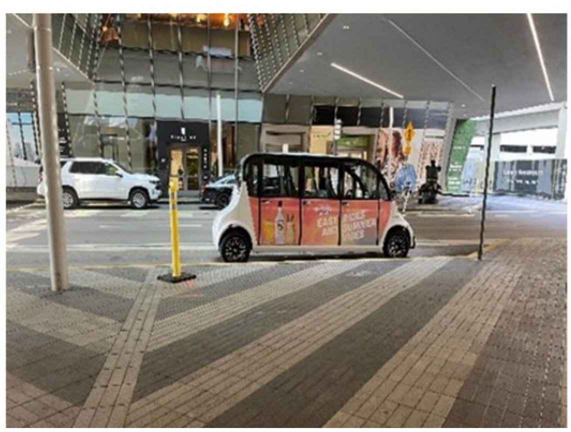
Orlando: The Orlando study area consisted of The Villages community and downtown areas. The Villages is a retirement community using GCs as their primary transportation mode (Castaldo et al., 2020), and most of the GCs are privately owned. The GCs usually operate in the GC dedicated lanes and use shared lanes in various road sections.

Miami: In Miami, the survey focused on GCs used to pick up passengers from the Brightline train station. GCs tend to share the roadway with other vehicles in this surveyed area, as they do not have designated lanes. The GCs in this area have a maximum set speed of 30 mph (FLHSMV). These GCs are not privately owned and are generally shared by passengers. Passengers arrange for the GC when booking a trip before they arrive at the station.

Figure 9.5 shows examples of typical GCs operating in the surveyed areas.

(a) GC in Nocatee Community, Jacksonville

(b) GC in The Villages, Northwest of Orlando



(c) GC at Brightline Station, Miami

Figure 9.5: Golf Cart Examples at Surveyed Locations

9.9.2 *Survey Design*

The goal of the survey was to gain more information on the user experience of golf cart usage. Types of questions included single-choice, multiple-choice, text entry, Likert scale, and open-ended questions. Questions pertained to the following categories:

- Practical Usage: The survey collected information about the current usage of micromobility vehicles, focusing on ownership, frequency of use, time, and distance of use. Additionally, the respondents were also asked about the location where they drive their vehicles.
- Purpose and Benefits: The survey gathered information on the reasons and benefits of using micromobility vehicles from the survey respondents.
- Current services feedback and recommendations: The survey respondents were asked about their view on the current micromobility services, such as what further improvement should be made to improve the micromobility services. Additionally, they were asked if they had any feedback or recommendations to give.
- Background Information: At the end of the survey, basic socio-economic demographics information was obtained. This information included age, gender, marital status, income range, and employment status.

9.9.3 *Data Collection*

The survey was created online using Qualtrics, a Web-based software allowing users to create surveys and generate reports without any previous programming knowledge. This software allows one to capture information, analyze, and act on insights. The research team first tested the survey to ensure it was well created and not too long to bore the respondents, leading them not to finish the survey. Random sampling was used to get survey responses, meaning no specific group was approached. The target group for the survey included all golf cart users, without any age or other restrictions.

The data collection process started in May 2023 and ended in September 2023. The survey was distributed physically, through a Quick Response (QR) code, and using an offline Qualtrics survey. The responses from the physically distributed paper and offline Qualtrics survey were later uploaded online, while the responses answered using a QR code were automatically uploaded online. The initial goal was to have at least 50 responses from GC users. Using a 10% margin error at a 95% confidence level, around 45 survey responses would have been sufficient. A total of 72 responses were submitted from GC users.

Before the survey was distributed, various regulations were followed, such as submitting the survey document as a measurement tool to the Institute of Review Board (IRB) for an exempt review. This was done to ensure that the survey was anonymous, and that no identifiable information was collected to avoid any risk imposed on the participants. Survey regulations are presented in detail in Chapter 6 of this report.

9.9.4 Data Analysis and Results

This section discusses the analysis of the survey responses obtained from golf cart users. The analysis was performed in two stages: descriptive analysis and inferential analysis.

9.9.4.1 Descriptive Analysis for Golf Carts

Practical Usage of Golf Carts
The survey involved respondents who were micromobility users. Out of all survey responses, 72 of the responses were from Golf cart (GC) users. Of the 72 respondents, 64% were owners of GCs and primary drivers. About 7% of the respondents were owners, but not primary drivers of the GC vehicle. The remaining respondents use GCs as passengers (29%), and 7% use sharing apps to obtain their services. This shows that most GCs are privately owned. According to the responses, the cost of a GC ranges from $4,000 to $30,000. Due to the cost range of GCs indicated in the responses, primarily middle- and high-income earners could afford to buy a GC.

Out of the 72 respondents, only 69 answered the question on the frequency of use of the GCs, and 96% of the responses showed that they use the GCs daily. From this analysis, it is worth noting that GCs, like micromobility vehicles (e-bikes, e-scooters), are also used daily (Stenner et al., 2020). Using GCs as a mode of transport may save time and space, since they can carry more than one passenger. Based on the survey, the maximum distance the GC is used for is 30 miles, and the maximum time for a single ride is one hour. This is because, in most of the communities where they are present, GCs are restricted within geographical boundaries (Mitran et al., 2020). In Miami, the GCs are allowed only in some parts of the downtown area. In the Nocatee Community, Jacksonville, the GCs have a designated path and are permitted only within the community.

In the survey, the location of where the GCs can be used was a multiple-choice question, and 82 responses were obtained. Some respondents chose more than one location. Of the 82 responses, 52% show that the GCs are primarily driven on the specified GC lanes or bike lanes, and 44% show that the drivers use a shared right lane of the road. The provision of lanes on the sidewalk prevents much interaction between GCs and other transport modes, leading to fewer GC crashes. The presence of shared lanes in various areas is due to insufficient facilities for GCs. Figures 9.6 through 9.8 show the various statistics for the practical usage of GCs. Figure 9.6 shows the statistics for GC usage and ownership, Figure 9.7 shows the statistics for GC frequency of use, and Figure 9.8 shows statistics for GC location.

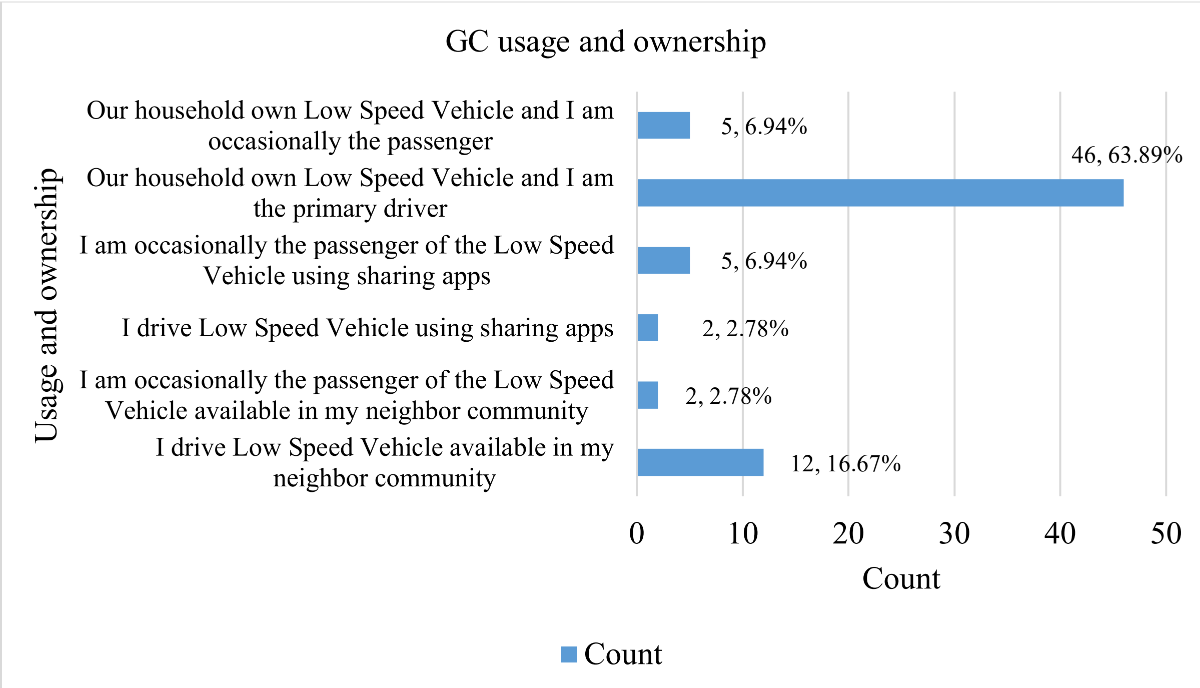


Figure 9.6: Golf Cart Usage and Ownership

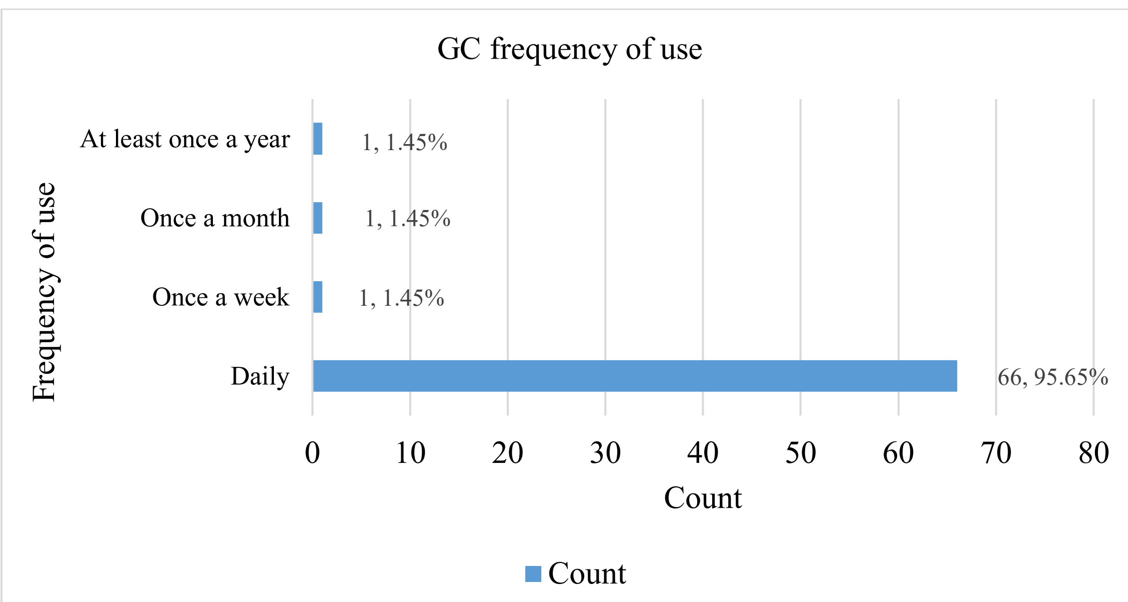


Figure 9.7: Golf Cart Frequency of Use

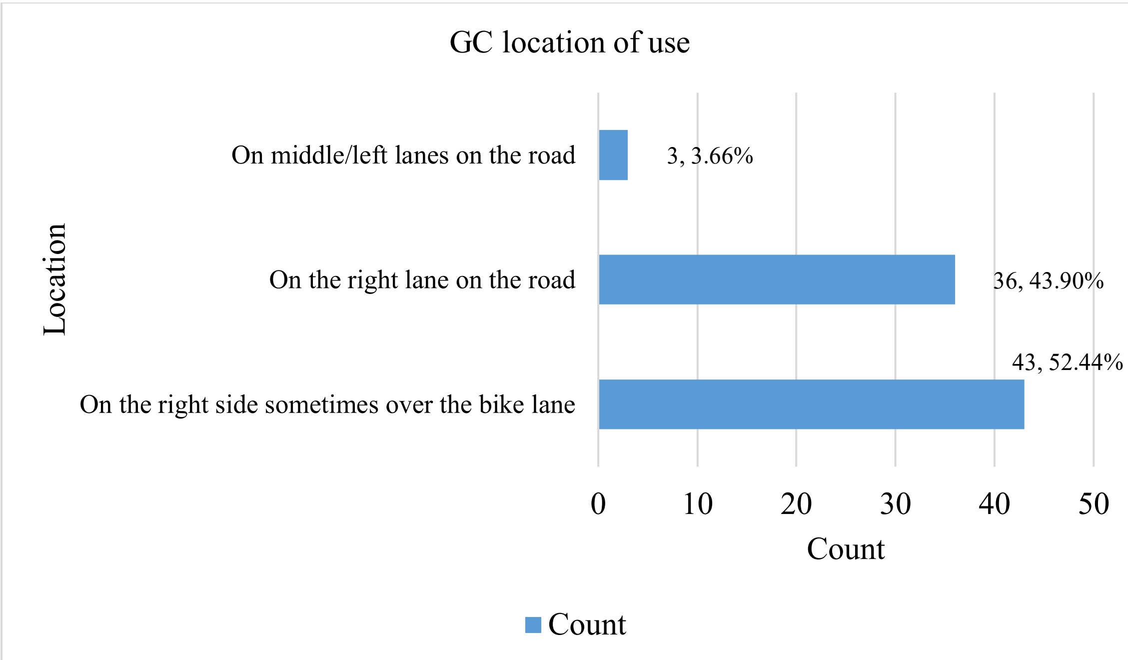


Figure 9.8: Golf Cart Location of Use

Purpose and Benefits of GCs

The respondents who were GC users were also asked about the purpose and benefits of using a low-speed vehicle (LSV), i.e., GC. The question on the purpose of using LSV/GCs had 186 responses. In this question, the respondents could provide multiple answers. Most people stated that they use low-speed vehicles (GCs) for everyday errands, such as shopping and grocery runs (25.3%) and entertainment and leisure (25.3%). Around 17.2% indicated using LSV/GCs for everyday commuting, while 19.9% use them for occasional local outings. About 7.5% use LSV/GCs to transport kids to school. The remaining responses included working by transporting passengers and large items and golfing. These responses show that LSV/GCs are mainly used for daily regular trips within a community, replacing automobiles.

The part of the survey on GC benefits had 386 responses. Respondents said they use the LSV because it is easy to drive with good acceleration and handling (13.2%) and ease of access and availability (13.5%). About 13.5% of respondents indicated that GCs are easy to operate (i.e., switch and control). Others state the benefits of GCs as a fun mode of travel (13.7%), cheaper transportation (12.4%), easy to find parking (11.4%), good for the environment (8.6%), can carry multiple people/items (6.7%), feel safe (5.7%), and other (1.3%). Other GC benefits included that pick-up/drop-off of their children is easier using a golf cart due to the absence of a school bus. Also, since most GCs are open, it is nice to use them to enjoy the weather. By observing the distribution of the responses on the choices, it can be observed that the LSV/GCs have numerous advantages and benefits in society. Figures 9.9 and 9.10 illustrate the statistics for the purpose and benefits of using LSV/GCs.

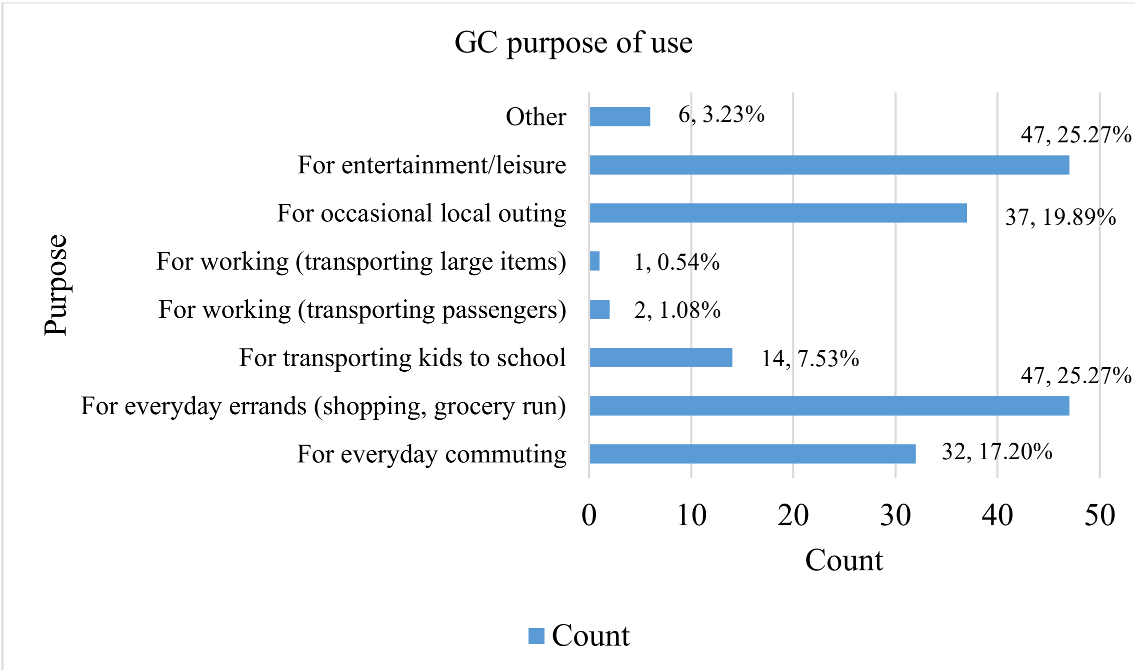


Figure 9.9: Golf Cart Purpose of Use

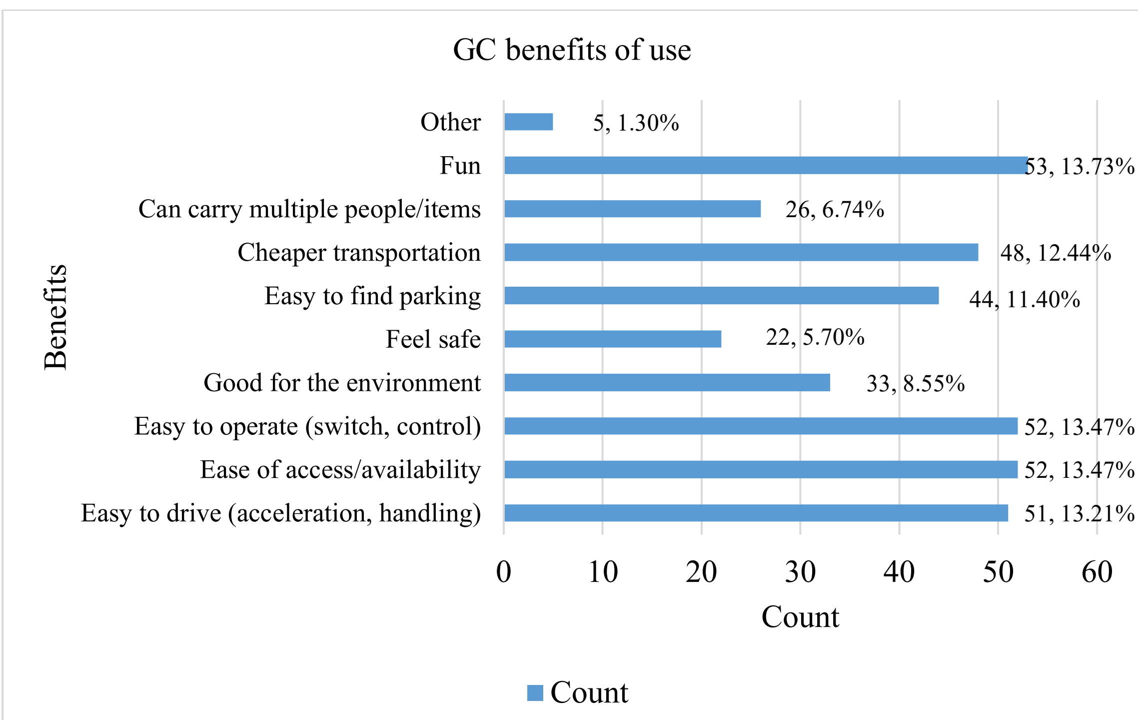


Figure 9.10: Golf Cart Benefits of Use

Current Golf Carts Services Feedback and Recommendations
GC users were asked to rate how they would like the GC usage and services to be improved. The ratings were ranked ordinally, with '1' being least important and '5' being very important. Not all factors were intended to be responded to by all respondents. Some factors were more relevant to users, some to owners, and others to both users and owners. On rating GC's appealing styling, there were 67 responses. About 31.4% of the respondents stated that it is important to improve styling, and 16.4% said it is least important.

Regarding better riding comfort, 32.84% stated that it is important to improve riding comfort, and only 3% said that it is least important. The respondents were also asked about improved overall safety and longer driving range. Most of the respondents indicated that improving overall safety and longer driving range is very important. From the analysis, 43.28% of the 67 responses on safety suggested that overall safety should be improved, while 4.48% suggested that it is least important. Regarding the longer driving range, 31.88% suggested improving it, while 8.5% say it is least important. When asked to comment on more seating and cargo space, most of the respondents indicated that these improvements were not necessary (41.79% on seating, and 49.25% on cargo space).

Regarding ride availability, most respondents said it is not important to improve this factor (50%). Most owners of the LSV/GCs were asked about overall durability, lower initial cost, lower cost of ownership, customizability, and shorter charge/fuel time. There were 50 responses on each of the factors. 38% of the responses on durability suggested that it is important to improve overall durability, and only 8% suggested that it is least important. Regarding lower initial cost and lower cost of ownership, most respondents suggest that it is very important to ensure that both initial cost and cost of ownership are improved (38% on lower initial cost and 36% on lower cost of ownership).

Regarding customizability, most respondents did not indicate concerns about a need for improvement in customizability (32%). Lastly, out of the 50 responses, 32% suggest that there is no need to improve charging/fuel time, while 30% suggest that improving charging/fuel time is important. Through the responses to this question, various agencies and providers may be able to note what is lacking in the services and, thus, improve on those areas, leading to better user satisfaction. Table 14 shows the statistics on current service feedback.

Respondents were also asked an open-ended question about low-speed vehicle (GC) recommendations. Recommendations included providing better batteries for LSV/GCs, keeping the GC speed low to avoid accidents, making it quieter and more comfortable, if needed, adding sun visors on the LSV/GCs, and adding or providing a multimodal path that is not directly adjacent to regular roads, as it is dangerous. Making more roads accessible to LSVs and increasing LSVs at train stations for last-mile services can benefit the communities in which they serve. Furthermore, additional feedback on services noted that LSV/GCs are easy to service and that they are an "evolving form of transport." There was no negative feedback from the respondents. This finding shows that LSV/GCs are accepted in the communities and can be used to offer transportation services.

Table 9.9: Statistics for Current Golf Cart Services Feedback

No	Factor (Current Services)	1 (%)		2 (%)		3 (%)		4 (%)		5 (%)		Total
1	Appealing Styling	16.42	11	13.43	9	31.34	21	19.4	13	19.4	13	67
2	Better Ride Comfort	2.99	2	8.96	6	22.39	15	32.84	22	32.84	22	67
3	Improved Overall Safety	4.48	3	4.48	3	20.9	14	26.87	18	43.28	29	67
4	Longer Driving Range	8.7	6	1.45	1	26.09	18	31.88	22	31.88	22	69
5	More Seating	11.94	8	11.94	8	41.79	28	22.39	15	11.94	8	67
6	More Cargo Space	8.96	6	8.96	6	49.25	33	23.88	16	8.96	6	67
7	Ride Availability	50	3	0	0	16.67	1	0	0	33.33	2	6
8	More Overall Durability	8	4	0	0	28	14	38	19	26	13	50
9	Shorter Charge/Fuel Time	14	7	2	1	32	16	22	11	30	15	50
10	Lower Initial Cost	6	3	6	3	26	13	24	12	38	19	50
11	Lower Cost of Ownership	8	4	6	3	24	12	26	13	36	18	50
12	Customizability	12	6	4	2	32	16	26	13	26	13	50

9.9.4.2 Inferential analysis

An inferential analysis was performed to explore whether user characteristics (i.e., age and gender) impact the purpose of golf carts. The following subsections discuss the analysis findings.

Background Information for Golf Carts

The survey gathered a total of 72 responses from GC users. The distribution of these respondents, according to the demographics, is presented in Table 9.10.

For this survey, 55.24% of the GC users were either equal to or above 65 years of age, while 44.76% were less than 65 years of age. This shows that aged people mostly use LSVs. About 40.58% of the respondents were females, 56.52% were males, and the rest preferred not to answer. Most survey respondents are married (86.51%), and most live with their partners or spouse (71.93%). As observed from the study, most users of LSVs are retired since the survey shows that 59.09% of the responses were from retirees. This might also be due to the location where the survey was conducted. Over 39% of the respondents have a household income of $50,000 to $100,000, while 25.79% have a household income of $100,000 to $150,000. This response on income shows that most users of LSV/GCs are middle to high-income earners.

Table 9.10: GC Demographics Descriptive Statistics

Variables	Category	Count	%
Gender	Female	28	40.58
	Male	39	56.52
	Other	0	0.00
	Prefer not to answer	2	2.90
Marital Status	Single	6	8.70
	Partnered	2	2.90
	Married	59	85.51
	Other	2	2.90
Household	Living with parents/Guardians	1	1.75
	Living Alone	5	8.77
	Partnered/ Married with no child	41	71.93
	Single/Partnered/Married with one child	6	10.53
	Single/ Partnered/ Married with two children	2	3.51
	Single/Partnered/Married with 2 or more children	2	3.51
Employment Status	Full time employed	21	31.82
	Part-time employed	2	3.03
	Not employed	4	6.06
	Retired	39	59.09
Household Income	Below $ 50K	7	10.61
	$50K to $100K	26	39.39
	$100K to $150K	17	25.79
	$150K to $200K	10	15.15
	Above $200K	6	9.09
Age	≥ 65 years	37	55.24
	< 65 years	30	44.76

Chi-square Test

A chi-square test, described in Chapter 8 of this report, was performed to test whether various user characteristics impact the purpose of using the golf carts. These characteristics include age and gender. The Chi-square analysis test results were obtained using Minitab Software.

The null hypothesis and alternative hypothesis for the chi-square test between the users' characteristics and purpose were as follows:

Null hypothesis: H_o: Users' characteristics have no impact on the purpose of using low-speed vehicles (GCs).

Alternative Hypothesis: H_a: Users' characteristics have an impact on the purpose of using low-speed vehicles (GCs).

Table 9.11 shows the observed values from the data set of GC users.

Table 9.11: Observed Values from the Data Set of GC Users

	Purpose	Everyday Commuting	Everyday Errands	Transporting kids to school	Occasional local outing	Entertainment/ Leisure	Total
Driver Characteristics	**Age**						
	≥ 65 years	21	29	2	21	23	**96**
	< 65 years	10	16	11	15	22	**74**
	Total	**31**	**45**	**13**	**36**	**45**	**170**
	Gender						
	Female	9	25	10	17	22	**83**
	Male	22	20	3	19	23	**87**
	Total	**31**	**45**	**13**	**36**	**45**	**170**

Table 9.12 shows expected values, contribution to the chi-square, and the chi-square value obtained from the analysis by using the variable GC purpose of use.

Table 9.12: Chi-square Analysis for GCs

Purpose (Variable)	Expected value and contribution to Chi-square	Age		Gender	
		≥ 65 years	< 65 years	Female	Male
Everyday commuting	Expected value	17.51	13.49	15.14	15.86
	Contribution to Chi-square	0.6974	0.9048	2.48702	2.37268
Everyday Errands	Expected value	25.41	19.59	21.97	23.03
	Contribution to Chi-square	0.5067	0.6573	0.41771	0.39850
Transporting kids to school	Expected value	7.34	5.66	6.35	6.65
	Contribution to Chi-square	3.8860	5.0414	2.10239	2.00573
Occasional Local Outing	Expected value	20.33	15.67	17.58	18.42
	Contribution to Chi-square	0.0221	0.0287	0.01891	0.01804
Entertainment and leisure	Expected value	25.41	19.59	21.97	23.03
	Contribution to Chi-square	0.2289	0.2969	0.00004	0.00004
Degree of freedom		4		4	
Chi-square statistics value		12.270		9.821	
P-value		0.015		0.015	

The Chi-square analysis test was performed at a 95% confidence level ($\alpha = 0.05$), and it was observed that the p-values from the analysis for both age and gender were less than the α value. Thus, the null hypothesis is therefore rejected. This indicates that there is enough evidence to suggest that the users' characteristics impact the purpose of using LSV/GCs. Only five purposes were included in the analysis test. This is because other purposes (e.g., working and others) were individually tested by the chi-square analysis and found no relation to driver characteristics.

9.9.5 Conclusions and Recommendations

A survey was administered to gain more information on the user experience of golf carts in Florida. Analyses of the survey responses included both descriptive and inferential analyses. A Chi-square analysis test was employed to test the relationship between user characteristics (age and gender) and the purpose of use of the low-speed vehicles, i.e., golf carts.

Results from the study indicate that most LSVs are privately owned, and they are used daily for various purposes, such as everyday commuting, everyday errands, and transporting children to school. The LSVs are mainly driven on the right-hand side of the road or in a shared road lane, depending on the presence of infrastructure designed to accommodate the LSVs. LSVs/GCs have numerous benefits, such as being easy to operate (switch, control), easy to drive (acceleration and handling), with good acceleration and handling, and ease of access. Also, the chi-square analysis test found that the user characteristics (i.e., age and gender) impact the purpose of using low-speed vehicles.

Due to the recommendations provided by the respondents in the survey, transportation agencies may improve LSV services by providing more multimodal paths for LSV/GCs, as their usage may increase in future years. Manufacturers can make further provisions, such as sun visors, since these are not present on some LSV/GCs, forcing users to find other means to cover the GCs.

In conclusion, since GC usage is emerging in the transportation system, various traffic rules and regulations should be considered by transportation agencies to improve the safety and mobility of LSV users. This may include speed regulations and age restrictions for using these vehicles. Appropriate locations for their use should also be considered, such as prohibiting locations where extensive interaction with public transport systems may occur to minimize potential crashes.

CHAPTER 10
CONCLUSIONS

The use of micromobility devices, such as e-scooters and e-bikes, are gaining in popularity nationwide, and in Florida. As a result, transportation agencies and cities are seeking to gain a better understanding of micromobility systems. The Florida Department of Transportation (FDOT), through its Connected and Automated Vehicle (CAV) Program, has expanded the agency's CAV initiatives to include electric and shared-use vehicles, leading to the term ACES (*Automated, Connected, Electric, and Shared-use* vehicles).

The goal of this research was to examine micromobility systems currently operating in Florida to develop resources to assist agencies in considering the deployment of shared micromobility systems. Research objectives included exploring the state-of-the-practice of micromobility systems, developing performance metrics for evaluating the mobility and safety benefits of micromobility systems, examining human factors related to the use of various shared micromobility systems, and presenting guidelines and recommendations for micromobility deployments.

To explore the existing state-of-the-practice of micromobility systems, existing guidelines and processes for deploying micromobility services, from various agencies in the U.S., were reviewed. Findings reveal that different approaches have been adopted by States in the regulation of micromobility services, with shared micromobility systems commonly regulated at the local level. Successful implementation of micromobility services, such as bike-sharing and scooter-sharing, requires a well-defined engineering process. The five key stages undertaken in establishing micromobility services include the inception stage, the procurement stage, the design stage, the deployment stage, and the operation stage.

A survey questionnaire was also distributed to local agencies in Florida currently operating shared-micromobility systems to assess the current state of the practice across the five stages of the engineering process for implementing micromobility services. Seven cities responded to the survey. Key findings include:

- Most of the agencies started their micromobility system with a pilot program before moving on to a permanent program.
- Few agencies conducted a preliminary study before the micromobility system was established.
- Dockless versus docked systems vary among the agencies.
- Factors considered when selecting vendors during the procurement process varied among the agencies.
- Most of the agencies implemented design modifications to existing infrastructure, such as adding bicycle lanes, signage and striping, and parking corrals, whenever necessary, to deploy micromobility systems.
- Payment methods for micromobility services varied among the agencies.

- An age restriction of 18 years or older was imposed by the vendor(s) across all cities.
- Speed restrictions imposed on micromobility devices varying depending on the travel location, with a typical speed limit of 15 mph for travel lanes and 12 mph for sidewalks.

A safety analysis of micromobility systems deployed in Florida was conducted. Analysis results of user injury severity resulting from micromobility-related crashes are shown in Table E.1. The majority of fatal and incapacitating injuries occurred at or within 50 ft of an intersection (46.5%), along a roadway segment (46.5%), during daylight hours (65.1%), in clear weather conditions (83.7%), on a Friday (30.2%), and during the months of February (14%) and August (14%). The majority of non-incapacitating and possible injury micromobility-related crashes occurred during the month of March (13.2%) over the study period (December 2018 and June 2022).

Crash statistics also indicate that the majority of fatal and incapacitating injuries to the micromobility users involved users between the ages of 20-39 (46.5%), not wearing safety equipment (76.7%), and not impaired by alcohol (79.1%). Based on Police Reports, the majority of fatal and incapacitating injuries occurred on roadways with no on-street parking (65.1%) and no presence of a bike lane (67.4%).

Crash modification factors (CMFs) were developed for micromobility-related crashes in Florida. The objective involved developing CMFs for both roadway segments and signalized intersections. The CMFs were developed based on data from Miami Beach and Miami Downtown regions, both of which have defined service areas for shared micromobility services. A cross-sectional analysis was used to develop the CMFs

A mobility analysis of micromobility systems deployed in Gainesville, Florida was conducted to evaluate the travel time of different modes of transport used in the areas around the University of Florida (UF) campus. A comparative analysis of travel times was performed across three transportation modes: Transit, Private Car, and Micromobility devices, using a common origin-destination (O-D) route on the UF campus. Results show that the average travel times for micromobility, private cars, and transit were 14.2 minutes, 21.3 minutes, and 25.2 minutes, respectively, revealing the travel time benefits of using micromobility devices around campus.

A survey was also conducted to gain more information on the user experience of micromobility devices in Florida. Analysis results for e-scooters and e-bikes indicate that most users get their vehicles by using sharing apps, and they are also mostly used for everyday commuting and entertainment purposes. The e-scooters and e-bikes are mostly operated on bike lanes and sidewalks, reducing the possibility of crashes with other modes of transport.

Guidelines and recommendations were developed from the safety and mobility analyses of micromobility devices in Florida. Suggested recommendations for the automobile original equipment manufacturers (AOEMs) of e-scooters and e-bikes were also identified, based on findings from user experience surveys.

In addition to the study of micromobility systems in Florida, the safety and mobility of golf carts (GCs), also low-speed vehicles, was explored. Of the 26 factors analyzed, eight factors were found to be significant in increasing the risk of severe injury in GC crashes. The significant factors were shoulder type, intersection type, presence of traffic control devices, median presence, estimated GC speed, manner of collision, estimated GC vehicle damage, and whether a GC occupant was ejected or not.

A mobility study of golf carts was conducted in Jacksonville, in the Nocatee community, where golf carts (GCs) are used as the primary mode of transport. The analysis of relative delay, travel times, and queue delay revealed significant advantages for using golf carts as an alternative mode of transportation in a school zone.

In addition, a survey questionnaire was administered to GC users in the Nocatee community, in Jacksonville, in Miami around the Brightline station, and in The Villages community northwest of Orlando to gain more information on the user experience. Results from the study indicate that most GCs are privately owned, used daily for various purposes, and have numerous benefits, such as being easy to operate (switch, control), easy to drive (acceleration and handling), with good acceleration and handling, and ease of access.

Micromobility vehicles and the use of golf carts are emerging components in the transportation system. Shared micromobility can revolutionize the conventional project development process for urban and suburban transportation projects, which are primarily considering only the traditional transportation modes. It could improve connectivity to other modes to provide efficient last-mile access improving mobility, safety, and public health by reducing congestion and emissions. Agencies can leverage the already existing provisions for non-motorized modes to promote shared micromobility, potentially leading to a modal shift to environmentally friendly and efficient means of transportation for urban areas. Guidance on deploying these systems and the operational and safety performance metrics developed from this research can assist Florida agencies in the deployment evaluation process.

REFERENCES

Abegaz, T., Berhane, Y., Worku, A., Assrat, A., & Assefa, A. (2014). Effects of excessive speeding and falling asleep while driving on crash injury severity in Ethiopia: A generalized ordered logit model analysis. *Accident Analysis & Prevention*, *71*, 15–21. https://doi.org/10.1016/J.AAP.2014.05.003.

Allen, P. E. (2015). "Golf Carts Utility Carts--They Are Not Just for Golf Anymore." Paper presented at the ASSE Professional Development Conference and Exposition, Dallas, TX, June 2015 (Paper No. ASSE-15-642). OnePetro. https://onepetro.org/ASSPPDCE/proceedings-abstract/ASSE15/All-ASSE15/ASSE-15-642/78238.

Alter, C., Buonocore, J., Chang, C., and Arunachalam, S. (2021). Transportation emissions generate air pollution that has a large death toll. Harvard T. H. *Chan School of Public Health, Center for Climate, Health, and The Global Environment (C-CHANGE).* Boston, MA. Retrieved July 31, 2022 from https://www.hsph.harvard.edu/c-change/news/trechsources/.

Austin Transportation Department. (2019). *Director Rules for Deployment and Operation of Shared Small Vehicle Mobility Systems*. Austin Transportation and Public Works, Austin, TX. http://austintexas.gov/sites/default/files/files/Transportation/Dockless_Final_Accepted_Searchable.pdf.

Bai, S., & Jiao, J. (2020). Dockless e-scooter usage patterns and urban built environments: A comparison study of Austin, TX, and Minneapolis, MN. *Travel Behaviour and Society*, *20*, 264–272. https://doi.org/10.1016/j.tbs.2020.04.005.

Bieliński, T., & Ważna, A. (2020). Electric scooter sharing and bike sharing user behavior and characteristics. *Sustainability (Switzerland)*, *12*(22), 1–13. https://doi.org/10.3390/su12229640.

Billstein, L., & Svernlöv, C. (2021). Evaluating the Safety and Performance of Electric Micro-Mobility Vehicles. Comparing E-bike, E-scooter, and Segway based on Objective and Subjective Data from a Field Experiment. *Masters Thesis,* Chalmers University of Technology, Gothenburg, Sweden. https://hdl.handle.net/20.500.12380/303657.

Bonela, S. R., & Kadali, B. R. (2022). Review of traffic safety evaluation at T-intersections using surrogate safety measures in developing countries context. *IATSS Research*, *46*(3), 307–321. https://doi.org/10.1016/J.IATSSR.2022.03.001.

Burmeister, C. (2017). "*Golf carts get go-ahead in all of Nocatee*." (09/17/2017). Jacksonville Daily Record. Retrieved July 26, 2023, from https://www.jaxdailyrecord.com/news/2017/jun/09/golf-carts-get-go-ahead-all-nocatee/.

Cai, Q., Abdel-Aty, M., & Lee, J. (2017). Macro-level vulnerable road users crash analysis: A Bayesian joint modeling approach of frequency and proportion. *Accident Analysis & Prevention*, *107*, 11–19. https://doi.org/10.1016/J.AAP.2017.07.020.

Campbell, K. B., & Brakewood, C. (2017). Sharing riders: How bike-sharing impacts bus ridership in New York City. *Transportation Research Part A: Policy and Practice*, *100*, 264–282. https://doi.org/10.1016/J.TRA.2017.04.017.

Castaldo, J. E., Raquet, B., Roberts, M., & VandeWeerd, C. (2020). Analysis of death and disability due to golf cart crashes in The Villages, Florida: 2011-2019. *Traffic Injury Prevention*, *21*(7), 437–441. https://doi.org/10.1080/15389588.2020.1799995/SUPPL_FILE/GCPI_A_1799995_SM1263.

DOCX.
Chapman, J., & Noyce, D. (2012). Observations of driver behavior during overtaking of bicycles on rural roads. *Transportation Research Record*, *2321*, 38–45. https://doi.org/10.3141/2321-06.
Cicchino, J. B., Kulie, P. E., & McCarthy, M. L. (2021). Severity of e-scooter rider injuries associated with trip characteristics. *Journal of Safety Research*, *76*, 256–261. https://doi.org/10.1016/J.JSR.2020.12.016.
City of Baltimore. (2022). *Code of Baltimore Regulations Annotated*, Title 14 Department of Transportation. Baltimore City Department of Legislative Reference, City of Baltimore, MD. https://legislativereference.baltimorecity.gov/sites/default/files/TITLE%2014%20-%20DEPT%20OF%20TRANSPORTATION%20Hanna%20Naugle.pdf.
City of Chicago. (2023). *Scooter Sharing Business Rules*. City of Chicago, IL. https://www.chicago.gov/content/dam/city/depts/dol/rulesandregs/CDOT-BACP-Scooter-Rules.pdf.
City of Santa Monica. (n.d.). Shared Mobility (webpage). Santa Monica, CA. Retrieved August 28, 2023 from https://www.santamonica.gov/programs/shared-mobility.
District of Columbia Municipal Regulations (DCRegs). (2023). Washington, D.C. Retrieved August 28, 2023 from https://dcregs.dc.gov/Common/DCMR/SectionList.aspx?SectionNumber=24-3314.
El-Tawab, S. S., Sprague, N., Stewart, M., Pareek, M., & Zubov, P. (2020). *Enhanced Interface for Autonomously Driven Golf Cart in a Networked Controlled Environment*. In Proceedings of the 9th International Conference on Software and Information Engineering (ICSIE '20). Association for Computing Machinery, New York, NY. Pp. 174–179. https://doi.org/10.1145/3436829.3436875.
Fang, K. (2022). Micromobility injury events: Motor vehicle crashes and other transportation systems factors. *Transportation Research Interdisciplinary Perspectives*, *14*, 100574. https://doi.org/10.1016/J.TRIP.2022.100574.
Federal Highway Administration (FHWA). (2014). *The FHWA 2015 R&T Story: Improving The Mobility of People and Goods* (Publication No. FHWA-HRT-14-091). U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. https://www.fhwa.dot.gov/publications/research/general/14091/003.cfm.
Federal Highway Administration (FHWA). (2023). *Pedestrian and Bicycle Crash Analysis Tool (PBCAT, Version 3).* U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. Retrieved May 18, 2023, from https://highways.dot.gov/research/pbcat/overview.
Fitt, H., & Curl, A. (2020). The early days of shared micromobility: A social practices approach. *Journal of Transport Geography*, *86* (June), 102779. https://doi.org/10.1016/j.jtrangeo.2020.102779.
Florida Department of Transportation (FDOT). (2021). *Traffic Analysis Handbook*. Florida Department of Transportation, Systems Implementation Office, Tallahassee, FL. Available at https://www.fdot.gov/planning/systems/systems-management/systems-management-documents.
Florida Department of Transportation (FDOT). (2023). *Roadway Characteristics Inventory (RCI) Handbook*. Florida Department of Transportation, Transportation Data and Analytics

(TDA) Office, Tallahassee, FL. Available at https://ftp.fdot.gov/public/file/LA_R9yJQLUmsRqSrO2ZgEQ/FDOT_RCI_Handbook.pdf.

Florida Statutes. (2023a). *2023 Florida Statutes (Title XXIII, Chapter 316, Section 2065 – Bicycle Regulations).* The Florida Senate, Tallahassee, FL. https://www.flsenate.gov/Laws/Statutes/2023/Chapter316.

Florida Statutes. (2023b). *2023 Florida Statutes (Title XXIII, Chapter 316, Section 008 – Powers of local authorities).* The Florida Senate, Tallahassee, FL. https://www.flsenate.gov/Laws/Statutes/2023/0316.008.

Hastie, T., Tibshirani, R., & Friedman, J. (2008). *The Elements of Statistical Learning: Data Mining, Inference, and Prediction,* Second Edition. Springer Series in Statistics (SSS) Book Series. Springer, New York, NY.

Haworth, N., Schramm, A., & Twisk, D. (2021). Changes in shared and private e-scooter use in Brisbane, Australia and their safety implications. *Accident Analysis & Prevention*, *163*, 106451. https://doi.org/10.1016/J.AAP.2021.106451.

Hertach, P., Uhr, A., Niemann, S., & Cavegn, M. (2018). Characteristics of single-vehicle crashes with e-bikes in Switzerland. *Accident Analysis & Prevention*, *117*, 232–238. https://doi.org/10.1016/J.AAP.2018.04.021.

Hosseinpour, M., Yahaya, A. S., & Sadullah, A. F. (2014). Exploring the effects of roadway characteristics on the frequency and severity of head-on crashes: Case studies from Malaysian Federal Roads. *Accident Analysis & Prevention*, *62*, 209–222. https://doi.org/10.1016/J.AAP.2013.10.001.

Iranitalab, A., & Khattak, A. (2017). Comparison of four statistical and machine learning methods for crash severity prediction. *Accident Analysis & Prevention*, *108*, 27–36. https://doi.org/10.1016/J.AAP.2017.08.008.

Jang, K., Park, S., Kang, S., Song, K., Kang, S., & Chung, S. (2013). Evaluation of pedestrian safety. *Transportation Research Record*, *2393*, 104–116. https://doi.org/10.3141/2393-12.

Ji, Y., Ma, X., He, M., Jin, Y., & Yuan, Y. (2020). Comparison of usage regularity and its determinants between docked and dockless bike-sharing systems: A case study in Nanjing, China. *Journal of Cleaner Production*, *255*, 120110. https://doi.org/10.1016/j.jclepro.2020.120110.

Jin, T. & Saito, M. (2009). Spatial and Temporal Analyses of Crashes at Two Work Zones with Different Traffic Control Devices: Drums and Jersey Barriers. *Compendium of Technical Papers*. ITE 2009 Annual Meeting and Exhibit, San Antonio, TX. Institute of Transportation Engineers (ITE), 17p. https://trid.trb.org/Results?q=&serial=%22ITE%202009%20Annual%20Meeting%20and%20Exhibit%22.

Karpinski, E., Bayles, E., & Sanders, T. (2022). Safety Analysis for Micromobility: Recommendations on Risk Metrics and Data Collection. *Transportation Research Record: Journal of the Transportation Research Board*, *2676* (12), 420-435. https://doi.org/10.1177/03611981221095523.

Kim, J. K., Ulfarsson, G. F., Shankar, V. N., & Kim, S. (2008a). Age and pedestrian injury severity in motor-vehicle crashes: A heteroskedastic logit analysis. *Accident Analysis & Prevention*, *40*(5), 1695–1702. https://doi.org/10.1016/J.AAP.2008.06.005.

Kim, K., Brunner, I. M., & Yamashita, E. (2008b). Modeling fault among accident—Involved pedestrians and motorists in Hawaii. *Accident Analysis & Prevention*, *40*(6), 2043–2049. https://doi.org/10.1016/J.AAP.2008.08.021.

Kruschke, J. K. (2013). Bayesian estimation supersedes the t-test. *Journal of Experimental Psychology: General*, *142*(2), 573–603. https://doi.org/10.1037/a0029146.

Los Angeles Department of Transportation (LADOT). (2020). *LADOT Year One Snapshot: A Review of the 2019-2020 Dockless Vehicle Pilot Program (July 2020)*. City of Los Angeles, Department of Transportation, Los Angeles, CA. Retrieved August 28, 2023, from https://ladot.lacity.gov/sites/default/files/documents/ladot-dockless-year-one-report.pdf.

Lu, Z., Fu, T., Fu, L., Shiravi, S., & Jiang, C. (2016). A video-based approach to calibrating car-following parameters in VISSIM for urban traffic. *International Journal of Transportation Science and Technology*, *5*(1), 1–9. https://doi.org/10.1016/j.ijtst.2016.06.001.

Ma, Q., Yang, H., Mayhue, A., Sun, Y., Huang, Z., & Ma, Y. (2021). E-Scooter safety: The riding risk analysis based on mobile sensing data. *Accident Analysis & Prevention*, *151*, 105954. https://doi.org/10.1016/J.AAP.2020.105954.

McGuckin, N., & Fucci, A. (2018). *Summary of Travel Trends: 2017 National Household Travel Survey*. 148. https://nhts.ornl.gov/assets/2017_nhts_summary_travel_trends.pdf.

McGwin, G., Zoghby, J. T., Griffin, R., & Rue, L. W. (2008). Incidence of golf cart-related injury in the United States. *Journal of Trauma - Injury, Infection and Critical Care*, *64*(6), 1562–1566. https://doi.org/10.1097/TA.0B013E3181238D39.

Meng, S., & Brown, A. (2021). Docked vs. dockless equity: Comparing three micromobility service geographies. *Journal of Transport Geography*, *96*(August), 103185. https://doi.org/10.1016/j.jtrangeo.2021.103185.

Michalaki, P., Quddus, M. A., Pitfield, D., & Huetson, A. (2015). Exploring the factors affecting motorway accident severity in England using the generalized ordered logistic regression model. *Journal of Safety Research*, *55*, 89–97. https://doi.org/10.1016/J.JSR.2015.09.004.

Miller, B., Yelverton, E., Monico, J., Replogle, W., & Jordan, J. R. (2016). Pediatric head and neck injuries due to golf cart trauma. *International Journal of Pediatric Otorhinolaryngology*, *88*, 38–41. https://doi.org/10.1016/J.IJPORL.2016.06.041.

Mitran, E., Codjoe, J., and Ofori-Addo, H. (2020). *Golf Carts on Public Roads – Literature Review of Legislation and State of the Practice in the United States*. Louisiana Transportation Research Center (LTRC), Project No. 19-02TA-SA (FHWA Publication No. FHWA/LA.17/19-02TA-SA). Baton Rouge, LA. https://rosap.ntl.bts.gov/view/dot/63072.

National Association of City Transportation Officials (NACTO). (2019). *Guidelines for Regulating Shared Micromobility*. National Association of City Transportation Officials, New York, NY. Retrieved August 25, 2023, from https://nacto.org/wp-content/uploads/2019/09/NACTO_Shared_Micromobility Guidelines Web.pdf.

National Cooperative Highway Research Program (NCHRP). (2020). *Guidence to Improve Pedestrian and Bicyclist Safety at Intersections*, NCHRP Research Report 926. The National Academies of Sciences, Engineering, and Medicine, Transportation Research Board, Washington, D.C. https://nap.nationalacademies.org/read/25808/chapter/5#33

National Highway Traffic Safety Administration (NHTSA). (2023). Federal Motor Vehicle Safety Standards. *Code of Federal Regulation (CFR) 49 CFR Part 571, § 571.3*. https://www.ecfr.gov/current/title-49/subtitle-B/chapter-V/part-571

Ntzoufras, I. (2009). *Bayesian Modeling Using WinBUGS*. John Wiley & Sons, Inc. ISBN: 9780470141144. https://doi.org/10.1002/9780470434567.

Nyame-Baafi, E., Adams, C. A., & Osei, K. K. (2018). Volume warrants for major and minor roads left-turning traffic lanes at unsignalized T-intersections: A case study using VISSIM modeling. *Journal of Traffic and Transportation Engineering (English Edition)*, *5*(5), 417–428. https://doi.org/10.1016/j.jtte.2018.01.005.

Oeschger, G., Carroll, P., & Caulfield, B. (2020). Micromobility and public transport integration: The current state of knowledge. *Transportation Research Part D: Transport and Environment*, *89*(November). https://doi.org/10.1016/j.trd.2020.102628.

Ogundele, O. J., Ifesanya, A. O., Adeyanju, S. A., & Ogunlade, S. O. (2013). The impact of seat-belts in limiting the severity of injuries in patients presenting to a university hospital in the developing world. *Nigerian Medical Journal : Journal of the Nigeria Medical Association*, *54*(1), 17. https://doi.org/10.4103/0300-1652.108888.

Padmanaban, J., Rajaraman, R., Stadter, G., Narayan, S., & Ramesh, B. (2010). "Analysis of In-Depth Crash Data on Indian National Highways and Impact of Road Design on Crashes and Injury Severity." *Semantic Scholar.* https://www.semanticscholar.org/paper/Analysis-of-In-Depth-Crash-Data-on-Indian-National-Padmanaban-Rajaraman/db7531193ce24fc8ddc5a25306bbd52aec654eb6.

Peng, H., Ma, X., & Chen, F. (2020). Examining injury severity of pedestrians in vehicle-pedestrian crashes at mid-blocks using path analysis. *International Journal of Environmental Research and Public Health*, *17*(17), 1–16. https://doi.org/10.3390/ijerph17176170

Prabu, A., Shen, D., Tian, R., Chien, S., Li, L., Chen, Y., & Sherony, R. (2022). *A Wearable Data Collection System for Studying Micro-Level E-Scooter Behavior in Naturalistic Road Environment*. https://arxiv.org/abs/2212.11979v1.

Price, J., Blackshear, D., Blount Jr., W., and Sandt, L. (2021). Micromobility: A Travel Mode Innovation. *Public Roads – Spring 2021*, *85* (1). FHWA Publication No. FHWA-HRT-21-003. Federal Highway Administration, Washington, D.C. Retrieved from https://highways.dot.gov/public-roads/spring-2021/02.

Ross, S. (2021). *"Veo bikes, electric scooters now available for rent in Birmingham." Yellowhammer News, Lifestyle News* (April 16, 2021). YHN Media Group, LLC. Birmingham, AL. Retrieved February 28, 2023, from https://yellowhammernews.com/veo-bikes-electric-scooters-now-available-for-rent-in-birmingham/.

Russo, C. (2008). "The Calibration and Verification of Simulation Models for Toll Plazas." Masters Thesis, University of Central Florida, *Electronic Theses and Dissertations*. 3480. https://stars.library.ucf.edu/etd/3480.

Russo, B. J., & Savolainen, P. T. (2018). A comparison of freeway median crash frequency, severity, and barrier strike outcomes by median barrier type. *Accident Analysis & Prevention*, *127*, 216-224. https://doi.org/10.1016/j.aap.2018.04.023.

Russo, B. J., & Smaglik, E. J. (2019). Analysis of factors affecting injury severity for riders or occupants of all-terrain vehicles and golf carts involved in police-reported crashes. *Accident Analysis & Prevention*, *133*, 105289. https://doi.org/10.1016/j.aap.2019.105289

Sanders, T. and Karpinski, E. (2022). Implications for Interactions between Micromobility and Autonomous Vehicles. *SAE International, Journal of Connected and Automated Vehicles*, *6*(2), 185-197. https://saemobilus.sae.org/content/12-06-02-0012/.

Seattle Department of Transportation (Seattle DOT). (2024). *Free-Floating Shared Micromobility Permit Requirements (Version 4.5)*. Seattle Department of Transportation, Seattle, WA.

https://www.seattle.gov/documents/departments/sdot/bikeprogram/shared_micromobility_permit_requirements_combined_4.5_2024.pdf.
Seluga, K. J., Baker, L. L., & Ojalvo, I. U. (2009). A parametric study of golf car and personal transport vehicle braking stability and their deficiencies. *Accident Analysis & Prevention*, *41*(4), 839–848. https://doi.org/10.1016/J.AAP.2009.04.017.
Shah, N. R., Aryal, S., Wen, Y., & Cherry, C. R. (2021). Comparison of motor vehicle-involved e-scooter and bicycle crashes using standardized crash typology. *Journal of Safety Research*, *77*, 217–228. https://doi.org/10.1016/J.JSR.2021.03.005.
Siddharth, S. M. P., & Ramadurai, G. (2013). Calibration of VISSIM for Indian Heterogeneous Traffic Conditions. *Procedia - Social and Behavioral Sciences*, *104*, 380–389. https://doi.org/10.1016/j.sbspro.2013.11.131.
Signal Four Analytics. (2023). *Florida Traffic Safety Dashboard*. 2022–2024.
Singleton, M., Qin, H., & Luan, J. (2010). Factors Associated with Higher Levels of Injury Severity in Occupants of Motor Vehicles That Were Severely Damaged in Traffic Crashes in Kentucky, 2000-2001. *Traffic Injury Prevention*, *5*(2), 144–150. Taylor & Francis. https://doi.org/10.1080/15389580490435169.
St. Petersburg Code of Ordinances. (2019). *Municipal Code, Chapter 26 – Traffic and Vehicles, Article VIII – Micromobility (Ord. No. 395-H, § 1, 10-17-2019).* City of St. Petersburg, FL. https://library.municode.com/fl/st._petersburg/codes/code_of_ordinances?nodeId=PTIISTPECO_CH26TRVE_ARTVIIIMI.
Stenner, H. T., Boyen, J., Hein, M., Protte, G., Kück, M., Finkel, A., Hanke, A. A., & Tegtbur, U. (2020). Everyday Pedelec Use and Its Effect on Meeting Physical Activity Guidelines. *International Journal of Environmental Research and Public Health*, *17*(13). https://doi.org/10.3390/ijerph17134807.
Soloka, M. A. (2019). “Simulation Exploration of the Potential of Connected Vehicles in Mitigating Secondary Crashes.” *University of North Florida Graduate Theses and Dissertations*, UNF Digital Commons. https://digitalcommons.unf.edu/cgi/viewcontent.cgi?article=1982&context=etd.
Sze, N. N., & Wong, S. C. (2007). Diagnostic analysis of the logistic model for pedestrian injury severity in traffic crashes. *Accident Analysis and Prevention*, *39*(6), 1267–1278. https://doi.org/10.1016/J.AAP.2007.03.017.
Tay, R., Choi, J., Kattan, L., & Khan, A. (2011). A multinomial logit model of pedestrian-vehicle crash severity. *International Journal of Sustainable Transportation*, *5*(4), 233–249. https://doi.org/10.1080/15568318.2010.497547.
Thomas, L., Levitt, D., Vann, M., Blank, K., Nordback, K., and West, A. (2021). *Pedestrian and Bicycle Crash Analysis Tool (PBCAT): Version 3 User Guide.* U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. https://pbcat3.org/PBCAT_UserGuide.pdf.
Tian, D., Ryan, A. D., Craig, C. M., Sievert, K., & Morris, N. L. (2022). Characteristics and Risk Factors for Electric Scooter-Related Crashes and Injury Crashes among Scooter Riders: A Two-Phase Survey Study. *International Journal of Environmental Research and Public Health 2022, Vol. 19, Page 10129*, *19*(16), 10129. https://doi.org/10.3390/IJERPH191610129.
Turoń, K., & Sierpiński, G. (2018). Bike-sharing as a possibility to support Vision Zero. *MATEC Web of Conferences*, *231*. https://doi.org/10.1051/matecconf/201823103005.

Watson, D. S., Mehan, T. J., Smith, G. A., & McKenzie, L. B. (2008). Golf Cart–Related Injuries in the U.S. *American Journal of Preventive Medicine*, *35*(1), 55–59. https://doi.org/10.1016/J.AMEPRE.2008.03.029.

White, E., Guo, F., Han, S., Mollenhauer, M., Broaddus, A., Sweeney, T., Robinson, S., Novotny, A., & Buehler, R. (2023). What factors contribute to e-scooter crashes: A first look using a naturalistic riding approach. *Journal of Safety Research*, *85*, 182–191. https://doi.org/10.1016/J.JSR.2023.02.002.

Williams, G. (2011). *Descriptive and Predictive Analytics*. In: *Data Mining with Rattle and R*. *Use R*, 171–177. Springer, New York, NY. https://doi.org/10.1007/978-1-4419-9890-3_8

Xue, C., & Xu, D. (2023). How Much Do We Know about Low-Speed Vehicle and Golf Cart Communities and Crashes: A Case Study in Nocatee, Florida. *Journal of Transportation Engineering, Part A: Systems*, *149*(8), 05023006. https://doi.org/10.1061/JTEPBS.TEENG-7742.

Yang, H., Ma, Q., Wang, Z., Cai, Q., Xie, K., & Yang, D. (2020). Safety of micro-mobility: Analysis of E-Scooter crashes by mining news reports. *Accident Analysis & Prevention*, *143*, 105608. https://doi.org/10.1016/J.AAP.2020.105608.

Younes, H., & Baiocchi, G. (2022). Analyzing the spatial determinants of dockless E-Scooter & E-Bike trips across four U.S. Cities. *International Journal of Sustainable Transportation*, *17*(8), 870-882. https://www.tandfonline.com/doi/abs/10.1080/15568318.2022.2119623#:~:text=Bai%20and%20Jiao%20(2020)%20used,more%20trips%20only%20in%20Austin.

Yun, M., & Ji, J. (2013). Delay Analysis of Stop Sign Intersection and Yield Sign Intersection based on VISSIM. *Procedia - Social and Behavioral Sciences*, *96*, 2024–2031. https://doi.org/10.1016/j.sbspro.2013.08.228.

Zhou, M., & Chin, H. C. (2019). Factors affecting the injury severity of out-of-control single-vehicle crashes in Singapore. *Accident Analysis & Prevention*, *124*, 104–112. https://doi.org/10.1016/J.AAP.2019.01.009.

APPENDIX A: SURVEY QUESTIONS

Invitation Email

State-of-the-Practice Survey on the Establishment of Micromobility Services in Florida

Dear Transportation official:

The Florida Department of Transportation (FDOT) is sponsoring research to develop guidelines and best practices for shared micromobility projects in Florida. To develop these guidelines, the University of North Florida (UNF) and Florida International University (FIU) are conducting a brief survey to obtain information on conception, procurement, deployment, operation, lessons learned, and related information on the implementation of shared micromobility projects in your area. The survey is estimated to take approximately 15 minutes. Please use the link below to complete the survey. If needed, PLEASE FORWARD THIS SURVEY INVITATION TO THE APPROPRIATE PERSON(S) in your department to complete.

Your participation is greatly appreciated and important for developing the FDOT shared micromobility guidelines.

Link to the Survey

https://unf.co1.qualtrics.com/jfe/form/SV_0T9oIHsaKnJRFbw

Survey Questions: Micromobility Services in Florida

Introduction

- ◯ Name of the city ____
- ◯ Name of the respondent ____
- ◯ Title of the respondent ____

Inception

Q2 When did the micromobility services start?

____

Q3 What were the reasons/objectives for the start of the micromobility system?

____
____
____

Q4 How was the establishment of the micromobility services initiated?

- ☐ The city introduced a pilot program
- ☐ The city introduced a permanent micromobility program
- ☐ Vendors applied for permits (state the department issuing the permit)

  ____
- ☐ Vendors rolled in without permits
- ☐ Other (Specify) ____

Q5 What type of micromobility system is established in the city?

- ◯ Docked
- ◯ Dockless
- ◯ Hybrid

Q6 Was any study done before the micromobility system was established? If yes, please provide the link to the study.

- ◯ Yes ____
- ◯ No

Q7 Were there any ordinances at the local level governing the establishment and operation of the micromobility services during the start period? Please provide the link to the city ordinances

- ◯ Yes ____
- ◯ Maybe
- ◯ No

Q8 Were any amendments to the local level ordinances established to govern the establishment and operation of the micromobility? If yes, please provide the link to the previous versions of the ordinances (and reasons why the amendments were affected)

- ◯ Yes ____
- ◯ Maybe
- ◯ No

Procurement

Q9 How does the city procure the micromobility services?

____
____
____
____

Q10 What were the important factors in consideration for the selected vendors?

____
____
____
____

Q11 What was the requirement for the experience of the vendors?

____
____
____
____

Q12 What was the requirement for the maintenance, recharging and sustainability plan?

____
____
____
____

Q13 What was the requirement of the data-sharing plan between the vendor and the city?

____
____
____
____

Q14 In light of the weather condition in FL, was there any requirement on the relocation plan in emergency weather conditions?

____
____
____
____

Q15 How did the bidding process go about?

____
____
____
____

Design

Q16 What procedures were followed during the design of the micromobility network and parking areas?

____
____
____
____
____

Q17 Is there any information on the design of the micromobility network and parking areas? If yes, please provide the link to the document.

○ Yes ____

○ No

Q18 What were the important factors considered during the design of the micromobility network and parking areas?

____
____
____
____

Q19 What design modification was done to promote the safety of those using micromobility systems and others in public using the right of way?

____
____
____
____

Deployment

Q20 Name the vendors currently operating in the city

____
____
____
____
____

Q21 How many vendors were allowed to operate in the city at the beginning of the services?

____
____
____
____
____

Q22 How many vendors are currently allowed to operate in the city (Any reason for the change)

____
____
____
____
____

Q23 How many micromobility devices are allowed?

- ☐ In Total ____
- ☐ Per vendor ____

Q24 What type of micromobility devices are operating currently?

- ☐ e-scooters
- ☐ e-bikes
- ☐ Other (Specify) ____

Q25 Do the vendors have to pay for the permits?

- ○ Yes
- ○ No

Q26 What are the conditions for the permits?

- [ ] Fees ____

- [ ] Time/Duration for the permits
____

Q27 How does the city collect revenue?

____
____
____
____
____

Q28 What are the challenges faced during the deployment of micromobility services?

____
____
____
____
____

Operation

Q29 How do the micromobility users pay for the services? (mobile apps, cash, electronic card)

____

Q30 What are the rates that micromobility users pay for the services per trip per vendor?

____
____
____
____
____

Q31 Are micromobility services accessible and being utilized by a broad segment of the population? If not, how are the disadvantaged population getting access.?

- ◯ Yes ____
- ◯ No

Q32 How is the redistribution and charging of micromobility services managed after using the micromobility devices?

____
____
____
____
____

Q33 How many dedicated staff work on the micromobility program? How many of those are full-time employees (FTE)? (Please specify those who are city employees)

- ☐ Total ____
- ☐ FTE ____

Q34 What were the benefits of introducing and using micromobility services?

____
____
____
____
____

Q35 What are the challenges faced during the operation of micromobility services?

____
____
____
____
____

Q36 What are the age regulations for one to use micromobility devices?

____
____
____
____

Q37 What are the speed regulations to be followed by micromobility users when using micromobility devices?

- [ ] On sidewalks ____
- [ ] On travel lanes ____

Q38 What are the parking regulations to be followed in parking areas?

____
____
____
____
____

Q39 Who enforces the parking regulations?

- [ ] The city (city parking agencies, staff, etc.)
- [ ] The local law enforcement
- [ ] Vendors
- [ ] Other (Specify) ____

Q40 Who is responsible for repossessing illegally parked vehicles?

____
____
____
____

Q41 What are the regulations pertaining to the use of safety equipment such as helmets?

____
____
____
____
____

Q42 What are the consequences incurred when regulations are not adhered to? (Fines, Ticket, etc.)

____
____
____
____

Q43 Has the city prohibited any areas/corridors from being used by the micromobility devices?

- ◯ Yes
- ◯ Maybe
- ◯ No

Q44 Name those areas and the reasons for the prohibitions? (If applicable)

____
____
____
____
____

General questions

Q45 Does the city store any trip related data involving micromobility devices? If yes, please provide the link to the data.

- ◯ Yes ____
- ◯ No

Q46 Does the city store any crash data involving micromobility devices? If yes, please provide the link to the data.

- ◯ Yes ____
- ◯ No

Q47 Have any measures been taken to ensure the safety of riders and others using public space and mitigate the potential for crashes? (Please mention if any)

____
____
____

Q48 Did the applied measures result in any improvement as far as safety is concerned? (Please list the improvements)

____
____
____
____
____

Q49 Have there been any studies conducted on the perception of users/non-users on micromobility services? (Please provide the link if any)

○ Yes ____

○ No

Q50 Is there anything that you would have done differently? (List if any)

____
____
____
____

APPENDIX B: SURVEY RESPONSES

Inception Stage

Table B-1: Reasons for Establishing Micromobility Services

Agency	Reasons for Establishing Micromobility Systems
City of Miami	As a pilot program to explore providing alternative methods of transportation in the downtown core area.
City of St. Augustine	Traffic congestion, many pedestrians, limited parking, etc.
Fort Lauderdale	We wanted to gage the response for this type of transportation alternative in the beach and downtown areas. We operate a tram at the beach area, but its ridership was very low and yielded a high cost per passenger to operate.
Gainesville	Complement the range of transportation options available; close the first mile / last mile gap.
Pensacola	Provide alternative transportation options.
St. Petersburg	Enhance mobility options for residents and visitors; Help replace car trips and time savings over what could be a walking trip; Provide additional first-/last-mile solution to increase transit viability; Increase equity and access to a low-cost transportation option; allow users to expand their trip range to visit different areas and connect adjacent business districts to provide for trips that they otherwise would not have made (induced spending at local businesses).
Tampa	To respond to demand from resident who live in and workers in the CBD and vicinities.

Table B-2: Methods of Initiating Micromobility Services

Agency	Methods of Initiating Micromobility Services
City of Miami	The city introduced a pilot program
City of St. Augustine	Other (Specify); **A**
Fort Lauderdale	The city introduced a pilot program
Gainesville	The city introduced a permanent micromobility program, Vendors applied for permits
Pensacola	The city introduced a pilot program
St. Petersburg	The city introduced a pilot program, Vendors applied for permits
Tampa	The city introduced a pilot program, The city introduced a permanent micromobility program, Other (Specify); **B**

A - Private rental businesses on private property.

B - For shared bicycle systems, the city issued an RFP. For E-scooter the city issued a RFA for a pilot program. For Citywide the city issued an RFP.

Table B-3: Types of Micromobility System

Agency	Types of Micromobility System
City of Miami	Dockless
City of St. Augustine	Docked
Fort Lauderdale	Hybrid
Gainesville	Dockless
Pensacola	Dockless
St. Petersburg	Hybrid
Tampa	Hybrid

Table B-4: Preliminary Study(s) Prior to the Establishment of Micromobility System

Agency	Preliminary Study(s) Prior to the Establishment of Micromobility System
City of Miami	No
City of St. Augustine	No
Fort Lauderdale	No
Gainesville	No
Pensacola	No
St. Petersburg	Yes
Tampa	No

Table B-5: Presence of Local Level Ordinances during the Start Period

Agency	Presence of Local Level Ordinances During the Start Period
City of Miami	Yes
City of St. Augustine	No
Fort Lauderdale	No
Gainesville	Yes
Pensacola	Yes
St. Petersburg	Yes
Tampa	Yes

Procurement Stage

Table B-6: Procurement Methods

Agency	Procurement Methods
City of Miami	Companies applied to a pilot program. All which met criteria and insurance eligibility were selected
City of St. Augustine	Solicitation of bids
Fort Lauderdale	As a pilot, we piggybacked off of a contract that Circuit had with the City of Hollywood
Gainesville	Permits available; Vendors reach out to the city.
Pensacola	RFQ
St. Petersburg	Ordinance requires license to operators; City issues RFP for services to determine which operator(s) will enter into license agreements for services.
Tampa	Request for Proposal and Request for Application

Table B-7: Factors Considered in Selecting Vendors

Agency	Factors Considered in Selection of Vendors
City of Miami	Fleet availability and insurance requirements
City of St. Augustine	Reputable business
Fort Lauderdale	Cost per hour
Gainesville	-
Pensacola	Ability to geofence, shut vehicles off, local crew.
St. Petersburg	**A**
Tampa	**B**

A
Experience and past performance on similar contracts.
Qualifications and technical competence.
Responsiveness to scope requirements and program goals, including equity.
Quality and quantity of proposed vehicles.
Demonstrated operations readiness and proposed schedule.

Demonstrated financial viability and stability.
Fiscal impact to the city

B

1. Firm's Program Vision, Experience and Project Team	5		points
2. Proposed System Equipment	45		points
a. Micromobility Vehicles		28	points
b. Docking Stations	17		points
3. Operational Plan		10	points
4. Program Safety Compliance Plan	8		points
5. System Data Capabilities		7	points
6. Community Engagement and Marketing Program	5		points
7. WMBE/SLBE Participation	20 points		

Table B-8: Requirement of the Data Sharing Plan

Agency	Requirement of the Data-Sharing Plan Between the Vendor and the City
City of Miami	Permittees were required to share data, such as location, number and length of trips, number of deployed devices, etc.
City of St. Augustine	Companies must provide the city with monthly reports.
Fort Lauderdale	Yes, they provide us with monthly data on ridership, high volume pick and drop off locations, number of trips, number of passengers transported, etc.
Gainesville	See ordinance and permit.
Pensacola	Pilot required month reports with data such as average mile per ride, average distance, total miles, number of crashes, etc. With the permanent program we have a 3rd party data aggregator call Populus.
St. Petersburg	Required to be shared, exclusive of personally identifiable information, and in MDS format. GBFS feeds are required as well. City uses a data aggregator to collate the information across all operators.
Tampa	**A**

A

REPORTING

Operator must provide accurate weekly summaries to the city describing customer or staff incidents, injuries, system operation, system use, reported complaints, customer service responses, and system maintenance.

Operator shall assist and participate in the formal evaluation of the program, including provision of data and information to inform subsequent city ordinances and programs.

Operator shall provide both GBFS and MDS data to the City of Tampa or a third party provider for monitoring and data collection.

Operator shall provide device communications system with method to communicate with real-time application Program Interface (API) data at a rate of 30 seconds or less to third party mobility manager platform for on-line vehicles.

Program Interface (API) data at a rate of 30 seconds or less to third party mobility manager platform for off-line vehicles.

Operator shall provide on a monthly basis anonymized data reports to the city for the following municipal-level data:

- Monthly revenue data of the system
- Total users in system by month
- Trip number by day, week and month
- Detailed, aggregate trip origin/destination information
- Trip length and time
- Hourly fleet utilization with trip origin or destination within the areas
- Hourly device quantities within the areas.
- Heat maps of usage trip showing top pick-up spots and drop-off spots
- Number and nature of complaints logged by operator users and the general public

Operator will also provide additional data and information, at the request of the city, to assist with city oversight and transportation planning and to inform the city's potential future RFP process for the program.
Operator will provide city desktop access to GPS map location for all vehicles deployed.

Table B-9: Requirements for Relocation Plan during Emergency Weather Conditions

Agency	Requirements for a relocation plan during emergency weather conditions?
City of Miami	In case inclement weather advisories, our department issues notification to all vendors for immediate removal of devices from the right of way.
City of St. Augustine	During hurricane events, private companies were responsible for temporarily removing equipment from flood prone areas. Move to their warehouse.
Fort Lauderdale	Yes, we use our community shuttle program currently to provide transportation for relocation during weather events.
Gainesville	See ordinance and permit.
Pensacola	We have not had this situation arise, but we've incorporated the micromobility FL statute language about emergency weather into our contract. The plan is if the weather service issues a tropical storm warning we are going to start engaging the operators and getting them to remove the vehicles.
St. Petersburg	Yes, each operator is required to have a plan for emergencies including inclement weather and public health emergencies. The plans are to be provided to the city upon request. Further, the city can require operators to remove equipment from the ROW when needed and has the authority to remove equipment if the operators fail to do so in a timely manner.
Tampa	Yes, in the event a hurricane watch for the Tampa area is issued, or upon request of the director of mobility or the director's designee, operator shall pick up all vehicles located within the city within twelve (12) hours of the issuance of the watch or notification by the city.

Table B-10: Requirements for Maintenance, Recharging, and Sustainability Plan

Agency	Requirements for maintenance, recharging and sustainability plan
City of Miami	Permitted companies must maintain fleets in a safe and secure running condition at all times.
City of St. Augustine	Private companies' responsibility to the satisfaction of city officials.
Fort Lauderdale	This was dictated by the piggyback contract with Hollywood.
Gainesville	See ordinance and permit.
Pensacola	Vehicles must be maintained to keep requirements of a bicycle such as lighting, functional brakes, etc. No recharging requirements.
St. Petersburg	The RFP asked operators for their plans associated with maintenance, recharging, and sustainability, which were evaluated as a part of determining whether they should be issued a license agreement. For operators who did enter into agreement with the city, the responses to the RFP were incorporated within their scope of services to hold them accountable to their plans.
Tampa	**A**

A

MAINTENANCE AND SAFETY

Every operator vehicle shall be inspected for safety, with a recorded inspection history, at least once per month.

Vehicles requiring charging are picked up by operator local operations team as a part of its daily responsibilities or are brought in by a member of the operator charger network.

Operators local operations team shall be trained by professional mechanics and inspect the following:

Once a vehicle has been repaired and/or cleaned, it will go through a quality assurance check before being processed for redeployment back into the field.

Table B-11: Bidding Process Procedure

Agency	Bidding Process Procedure
City of Miami	N/A
City of St. Augustine	Normal city bid processing procedure through our city procurement department.
Fort Lauderdale	There was no bidding process for the pilot. In this year's budget we did put in for funding to do a solicitation for the City of Fort Lauderdale. We also have some grant funding from FDOT to do a micro-transit in NW communities.
Gainesville	Permits issued to first 3 applicants that fulfilled all ordinance requirements in the order in which permit applications were received.
Pensacola	RFQ
St. Petersburg	An RFP was issued for both bike share and e-scooter services. The evaluation committee would make a recommendation as to which operator(s) would be permitted to enter into a license agreement with the city to deploy vehicles in the ROW. City ordinance requires the license agreement; rogue deployments can be removed by the city if required. The evaluation committee was made of up staff from various departments including transportation; economic development; urban affairs; and sustainability. Also included outside stakeholders such as the chamber of commerce.
Tampa	Competitive bidding with either a RFA or RFP.

Design Stage

Table B-12: Factors Considered while Designing Micromobility Network and Parking Areas

Agency	Factors Considered During the Design of the Micromobility Network and Parking Areas
City of Miami	Right of way availability to ensure parked scooters meet ADA guidelines at all times.
City of St. Augustine	Determining locations for supply and demand. Providing visibility of the product while not inhibiting safety.
Fort Lauderdale	-
Gainesville	No restrictions: units allowed to circulate and park anywhere with very few restrictions based on local knowledge; University of Florida implemented more restrictive deployment and parking zones. Program also includes areas where speeds are restricted or where the units are not allowed to circulate to avoid conflicts with pedestrians.
Pensacola	Try to get residential areas that surrounding the downtown to use scooters instead of cars. Parking areas should be near areas of demand.
St. Petersburg	Access to desired destinations (1 per block, or 1/8-mile was desired); minimizing disruption to existing motor vehicle parking; identifying street-level (not curb level) areas, since sidewalk riding is prohibited by city ordinance; collaboration with adjacent businesses, chamber, and stakeholders throughout design; language in operator agreements to ensure compliance with capacity and improper parking; avoidance of locations near fire hydrants.
Tampa	Population density and bicycle network

Table B-13: Design Modifications Implemented to Promote Safety of Road Users

Agency	Design Modifications Implemented to Promote Safety of Road Users
City of Miami	Parking corrals were identified with sidewalk stickers and were available on all operators' applications.
City of St. Augustine	Signage and striping.
Fort Lauderdale	As a pilot this project is allowing us to determine these parameters.
Gainesville	None
Pensacola	No design modifications have been made. We prohibit riding on sidewalks, but that is an enforcement issue sometimes. It has taken a while for people to learn properly riding behavior. We have slow streets downtown so scooters are expected to ride in bike lane when one is provided or use the street.
St. Petersburg	Reduced capacity of parking areas where necessary and desired by emergency services.
Tampa	Adding bicycle lanes

Deployment Stage

Table B-14: Names of Vendors Operating in the City

Agency	Vendors Currently Operating in the City.
City of Miami	N/A. The program has been paused over the past 13 months
City of St. Augustine	Our City's Bike Share program is operated by Gotcha Bikes, transitioned to Bolt, currently transitioning to a new owner.
Fort Lauderdale	Circuit
Gainesville	Bird, Spin, Veo
Pensacola	VEO
St. Petersburg	Razor and VeoRide (e-scooters); CycleHop's license for bike share expires in Feb 2023. The city has active solicitation for bike share services now and expects new operator(s) for bike share in spring 2023.
Tampa	Bird, Lime, Spin, HOPR and Razor

Table B-15: Number of Vendors Allowed to Operate at Start of Micromobility Services

Agency	Vendors Allowed to Operate in the City at the Beginning of the Services
City of Miami	7
City of St. Augustine	Only one city bike share company, but several private rental businesses are allowed to operate from an established business operating on private property.
Fort Lauderdale	Circuit was providing service for Brightline
Gainesville	3
Pensacola	We had 2 vendors in the pilot but went to one in the permanent program. We do plan to put out an RFQ to seek another vendor so there is more variety.
St. Petersburg	1 for bike share; 2 for e-scooters.
Tampa	One shared bicycle vendor, four e-scooters vendor in the pilot program and in the citywide program, two e-scooter vendor, two e-bicycle vendor, one vendor for e-scooter with seat and one vendor for e-bicycle with two seat/e-cargo.

No. = Number

Table B-16: Number of Micromobility Devices Allowed

Agency	Number of Micromobility Devices Allowed?
City of Miami	-
City of St. Augustine	100 bikes for city bike share company
Fort Lauderdale	Currently the pilot has 6 cars dedicated to the downtown area and 2 vehicles dedicated to the beach area
Gainesville	600
Pensacola	500
St. Petersburg	1100 for e-scooters; 400 for bikes, since city owns most of the equipment (prior business model)
Tampa	6900

Table B-17: Type of Micromobility Devices

Agency	Type of Micromobility Devices
City of Miami	N/A
City of St. Augustine	e-bikes, Other (specify); City only allows pedal assist e-bikes, but private businesses rent a variety of devices.
Fort Lauderdale	Electric vehicles Golf cars
Gainesville	e-scooters, Other (specify); seated scooters
Pensacola	e-scooters
St. Petersburg	e-scooters, e-bikes, Other (specify); pedal bikes
Tampa	e-scooters, e-bikes, Other (specify); bicycles and e-scooters with seat

Operation Stage

Table B-18: Payment Methods

Agency	Payment Methods
City of Miami	Mobile apps
City of St. Augustine	Mobile apps
Fort Lauderdale	The service is free, but the ride is hailed through on mobile app
Gainesville	Mobile apps Electronic cards
Pensacola	Mobile apps
St. Petersburg	Mobile apps.
Tampa	Mobile apps Cash Electronic cards

Table B-19: Micromobility Service Accessibility

Agency	Micromobility Services Accessibility
City of Miami	Operators were required to rebalance their fleets daily to ensure fair distribution throughout the operating area.
City of St. Augustine	Yes
Fort Lauderdale	The service is free, but the ride is hailed through on mobile app
Gainesville	Yes, the current accessibility is accommodated through an additional ADA compliant vehicle
Pensacola	VEO has a reduced fee for qualifying individuals.
St. Petersburg	Services are accessible though usage varies. We've found that education of equity-based pricing is challenging, especially when the equity programs vary by operator.
Tampa	Yes, at one time some of the highest ridership existed in the disadvantage community.

Table B-20: Benefits of Micromobility Services

Agency	Benefits of Micromobility Services
City of Miami	Wider range of options for residents and visitors in the urban core area.
City of St. Augustine	assists mobility of pedestrians
Fort Lauderdale	It provides another alternative for short trips in a designated area
Gainesville	expansion of mobility options particularly to those that are transit dependent or low income who may benefit from riding incentives provided by the vendors.
Pensacola	Offering transportation options that reduce car dependency, parking demand, and reduces carbon emissions.
St. Petersburg	Enhances mobility options for residents and visitors; Helps replace car trips â€ "also provides time savings over what could be a walking trip; Provides additional first-/last-mile solution to increase transit viability; Increases equity and access to a low-cost transportation option; Allows users to expand their trip range to visit different areas and that they otherwise would not have made (induced spending at local businesses)
Tampa	Reduce automobile trips and provide access to short trip users

Table B-21: Challenges Faced with the Operation of Micromobility Services

Agency	Challenges Faced with the Operation of Micromobility Services
City of Miami	Operational safety and obstruction of the right of way.
City of St. Augustine	-
Fort Lauderdale	The demand is higher than the supply
Gainesville	Potential blockage of row (has not been a problem in Gainesville; level of complaints is minimal since inception of the program); potential safety issue (also has not been an issue in Gainesville; the city offers a variety of dedicated bike facilities that accommodates safe use)
Pensacola	Many downtown businesses and residents did not like them because they felt people were just using them for joy riding and not as a proper mode of transportation. They felt they were littering the downtown.
St. Petersburg	Monitoring compliance; communications related to special events, etc. that impact vendor operations; turnover in operator staff (young industry) at the project management level (consistent communications) and employee level (training).
Tampa	Adequacy of bike lanes and parking spaces, vandalism and theft.

Table B-22: Age Restrictions

Agency	Age Restrictions
City of Miami	Only 18 years old and older are allowed
City of St. Augustine	None
Fort Lauderdale	To ride Circuit vehicles children must be accompanied by a parent but otherwise no restrictions
Gainesville	None specified in city regulations; mirror state restrictions, and encourage use of helmets
Pensacola	We do not have age restriction, but vendor requires 18 and up.
St. Petersburg	18+ for renting from the vendors in the ROW; 16+ for privately-owned motorized devices.
Tampa	City of Tampa is 16 years old and vendor is 18 years old.

Table B-23: Parking Regulations

Agency	What are the parking regulations to be followed in parking areas?
City of Miami	Must not obstruct sidewalks/ pedestrian ramps/building entrances/driveways, fire hydrants/transit facilities.
City of St. Augustine	Micromobility devices must abide by all normal parking regulations.
Fort Lauderdale	N/A
Gainesville	None in the city
Pensacola	In the downtown area, riders have to end their ride is a designated parking corral or the ride won't end.
St. Petersburg	Shared scooters/bikes are required to park in city-provided parking corrals; privately owned scooters must be upright and outside of pedestrian paths.
Tampa	Lock the devices to a rack or store neatly in the docking area

Table B-24: Parking Regulations Enforcers

Agency	Parking Regulation Enforcer
City of Miami	The city (city parking agencies, staff etc.) Vendors
City of St. Augustine	The city (city parking agencies, staff etc.) The local law enforcement
Fort Lauderdale	The city (city parking agencies, staff etc.)
Gainesville	Vendors
Pensacola	The city (city parking agencies, staff etc.) Vendors
St. Petersburg	The city (city parking agencies, staff etc.) The local law enforcement Vendors
Tampa	Vendors

Table B-25: Party Responsible for Retrieving Illegally Parked Devices

Agency	Who is responsible for retrieving illegally parked shared micromobility devices?
City of Miami	If operators don't respond promptly, city's Miami parking authority can impound scooters.
City of St. Augustine	Micromobility companies are responsible for retrieving all their equipment and devices.
Fort Lauderdale	N/A
Gainesville	Vendors; if non-compliant, city can remove and store the units at a cost stipulated in the ordinance
Pensacola	The vendor.
St. Petersburg	Vendors, though the city may if needed.
Tampa	Vendors

Table B-26: Regulations Regarding Safety Equipment

Agency	Regulations Pertaining the Use of Safety Equipment (e.g. Helmets)
City of Miami	Use of helmets is required
City of St. Augustine	If a renter desires a helmet, then they contact the business and they are provided with a helmet.
Fort Lauderdale	N/A
Gainesville	Encouraged but not required
Pensacola	Helmets are encouraged.
St. Petersburg	Recommended, not required. Vendors are required to host an educational event at least once every 6 months and often include a helmet giveaway as a part of the event.
Tampa	Florida statute

APPENDIX C: ONE-PAGE SUMMARIES

FLORIDA MICROMOBILITY SERVICES

Micromobility Guidelines

Guidelines For AOEMs

The following guidelines are designed to help/assist the automobile original equipment manufacturers (AOEMs) of e-scooters, e-bikes, and golf carts in enhancing the overall quality and safety of their products. These recommendations are based on findings from user experience surveys conducted throughout the State, by device type.

E-Scooter & E-Bike

- Increase range (battery capacity).
- Improve overall safety.
- Maximize ride comfort.
- Lower initial cost.
- Focus on appealing styling.

Golf Cart

- Increase range (driving range).
- Install additional safety features, such as sun visors.
- Maximize ride comfort.
- Lower initial cost.
- Improve durability.
- Focus on appealing styling.

Guidelines for Deploying Shared Micromobility Systems

Safety is a top priority for agencies and communities when introducing shared micromobility systems. The following guidelines/recommendations are based on a thorough analysis of responses obtained from a state-of-practice survey and a comprehensive review of micromobility policies from around the country.

Guidelines for deploying shared micromobility systems include:

- Initiating pilot programs before transitioning to a permanent program to allow for the development of specific policies and clear guidance for micromobility systems.
- Conducting preliminary studies to understand the needs and concerns of potential users.
- Adopting a hybrid system to effectively maximize user preferences to maximize operational and safety benefits.
- Establish a well-defined relocation plan for emergency weather conditions, prioritizing safety of both users and micromobility devices.
- Strategic infrastructure planning to optimize the system's usability and efficiency.
- Establish clear speed limit policies based on the laws and statutes governing micromobility usage.
- A thorough vendor selection process according to criteria, such as fleet availability, experience, alignment with program objectives, operation plan, and community engagement.
- Establish minimum criteria for vendor selection based on a preliminary study conducted in a specific city or minimum standards set by other cities/agencies with similar requirements.
- Implementing a standard age restriction policy for users.

FLORIDA MICROMOBILITY SERVICES

E-scooters & E-bikes

South Beach Miami Bike Rack

An e-scooter is an electric powered low-speed two-wheeled personal mobility device, without a seat or pedals, and designed for a single driver. An e-bike is a motorized bicycle with an integrated electric motor used to assist propulsion. In Florida, the design speed for these devices is limited to 20 mph.

E-scooters & e-bikes are typically used for short trips and first- and last-mile travel, and are stationed in designated corrals located near office buildings, train stations, bus stations, and school campuses.

E-scooter Parking Zone
Downtown, Orlando

Mobility Benefits

- Easy to ride/operate.
- Low operating costs.
- Less noise pollution.
- Relatively eco-friendly.
- Provides mobility for persons with health issues.
- Significantly lower travel times compared to
- E-scooter users experience 423 seconds less travel time than personal vehicle users (approximately 33% reduction), and 662 seconds less travel time than transit users (approximately 44% reduction).[a]
- For travel time reliability, e-scooters have a Buffer Index (BI) of 12%, meaning users need to allocate only 1.7 minutes (above the mean travel time) to ensure on-time arrival in 95% of their trips.[a]

Performance Metrics

- Travel time
- Travel time reliability (Buffer Index)
- Crash frequency and severity

Data Limitations/Constraints

- Limited data for analysis.
- Analysis results are site-specific.
- E-scooter and E-bike maximum design speed (15 – 20 mph) may influence travel time.

Safety Recommendations

- Provide education programs to inform micromobility users about traffic rules and safety measures.
- Emphasize the importance of wearing safety equipment, such as helmets, for micromobility riders.
- Develop awareness campaigns to promote safe and responsible micromobility use.
- Enforce traffic regulations for micromobility riders to deter violations and ensure safe operation.
- Implement measures to improve compliance with traffic laws by micromobility users.
- Create separate facilities for micromobility riders to reduce conflicts with vehicles and pedestrians.
- Use shared lane pavement markings to indicate the presence of micromobility and their right to use the road.
- Establish colored bike lanes, especially in high-conflict areas.
- Provide standard-width bike lanes for safe micromobility travel.
- Install street lights on roadways to enhance visibility, particularly at night.
- Widen sidewalks to minimize conflicts between micromobility users and pedestrians.

For more information, refer to FDOT Report: Exploring Micromobility Services in Florida. [a] – Section 6.3.3- Final Report

GOLF CARTS IN FLORIDA

GC - Residential Neighborhood
Nocatee, Jacksonville

Golf Carts

Golf carts (GCs) are low-speed motorized vehicles designed to transport people, with a maximum speed of 35 mph.

Commonly used to carry golfers and their golf clubs around a golf course, GCs are becoming a popular mode of travel in residential neighborhoods, corporate campuses, beach areas, retirement communities, hospitals, and airports.

GC - Retirement Community
The villages, Northwest of Orlando

Mobility Benefits

- Easy to operate/drive.
- Ease of access and availability.
- Can carry multiple people/items.
- Low operating costs.
- Good for the environment.
- GCs experience minimal queue delay for school drop-off and pick-up activities.
- As the number of golf carts in the system increases, the relative delay and travel time for vehicles tend to decrease.
- Introducing golf carts into the transportation system in suitable areas will result in a reduction in congestion and delays, ultimately improving overall mobility.

Performance Metrics

- Travel time
- Relative delay
- Queue delay (in school zones)

Data Limitations/Constraints

- Limited data for analysis.
- Analysis results are site specific. In this case, the study area was a school zone within Golf cart community and a retiree community.

Recommendations

Safety

- Promote Seat belt use.
- Promote regular maintenance and inspection.
- Promote child safety measures.
- Emphasize safety training and awareness for golf cart users.
- Providing a multimodal path that is not directly adjacent to regular roads.
- Establish speed regulations and age restrictions.
- GC manufacturers should consider installing additional safety features, such as sun visors,

Transportation Agencies

- Promote the adoption of golf carts as a viable transportation option.
- Establish dedicated paths or lanes for golf carts in the school zones.
- Collaborate with schools to develop initiatives that promote golf cart usage.
- Monitor traffic patterns and vehicle compositions in school zones to assess the effectiveness of integrating golf carts.
- Implement a multi-modal transportation approach that includes golf carts.

For more information, refer to FDOT Report: Exploring Micromobility Services in Florida.