Analyzing Shared E-Scooter Data and Identifying E-Scooter First-and-Last-mile Connections

NCDOT Project TA 2025-06
FHWA/NC/TA 2025-06
June 2025

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RESEARCH & DEVELOPMENT

Analyzing Shared E-Scooter Data and Identifying E-Scooter First-and-Last-mile Connections

Final REPORT

Submitted to:

North Carolina Department of Transportation
Research and Development Unit
(Research Project No. RP2025-06)

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June 25, 2025

Technical Report Documentation Page

1. Report No. **FHWA/NC/TA 2025-06**	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Analyzing Shared E-Scooter Data and Identifying E-Scooter First-and-Last-mile Connections		5. Report Date June 25, 2025 6. Performing Organization Code
7. Author(s) Lei Zhu, Ph.D., and Rachael (Yuqiu) Yuan		8. Performing Organization Report No.
9. Performing Organization Name and Address Lei Zhu, Ph.D. https://orcid.org/0000-0003-0170-1178 Rachael (Yuqiu) Yuan Industrial and Systems Engineering Department The University of North Carolina at Charlotte 9201 University City Blvd., Charlotte, NC 28223		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address North Carolina Department of Transportation Research and Development Unit 1549 Mail Service Center Raleigh, North Carolina 276699-1549		13. Type of Report and Period Covered January 1, 2025, to June 30, 2025 14. Sponsoring Agency Code TA 2025-06
15. Supplementary Notes		

16. Abstract

E-scooters have gained widespread popularity worldwide because they alleviate traffic congestion, reduce greenhouse gas emissions, and enhance first-and-last-mile (FLM) connectivity to public transit, addressing various urban mobility challenges and boosting the quality of life in densely populated areas. Shared e-scooter trips complement public transit systems by bridging the gap between transit stops or stations and trip origins or destinations (OD), thus potentially encouraging greater transit use. Since 2019 the trips and status change data have been collected and provided by major commercial e-scooter vendors in the Charlotte metropolitan area. It provides an opportunity to understand the travel patterns of shared e-scooters and to identify e-scooter trips that serve as FLM connections by referencing Charlotte's transit data and other relevant information. This study aims to identify the shared e-scooter FLM connection trips and analyze the travel patterns of FLM trips, spatially and temporally. The temporal and spatial travel patterns of e-scooter FLM connection trips can be used to support the operation and management of e-scooters and transit systems. More information, such as the schedule of the public transit and transit ridership, Point of Interest (POI) and demographic information, can be further analyzed to gain a better understanding of shared e-scooter riders and their trip purposes, providing potential suggestions or improvements for the operation and management of shared e-scooters.

17. Keywords Shared E-scooter; Public transit; First-and-last-mile (FLM) connectivity; Temporal and spatial travel patterns	18. Distribution Statement		
19. Security Classif. (of this report) unclassified	20. Security Classif. (of this page) unclassified	21. No. of Pages 34	22. Price

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

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ACKNOWLEDGEMENTS

This Technical Assistance Request (TAR) project is sponsored by NCDOT and NCSU-ITRE. Michael R. Stafford from the Integrated Mobility Division (IMD) at NCDOT is highly appreciated for providing invaluable technical instructions and guidance for the development of this project. The authors of the report also appreciate e-scooter data provided by the city of Charlotte, NC.

EXECUTIVE SUMMARY

Micromobility services, especially shared electric scooters (e-scooters), have emerged as a transformative mode of urban transportation, providing a flexible, efficient, and eco-friendly alternative for short- and medium-distance trips. E-scooters have gained widespread popularity in cities worldwide because they alleviate traffic congestion, reduce greenhouse gas emissions, and enhance first-and-last-mile (FLM) connectivity to public transit, thereby addressing various urban mobility challenges and boosting the quality of life in densely populated areas. Shared e-scooter trips complement public transit systems by bridging the gap between transit stops or stations and trip origins or destinations (OD), thus potentially encouraging greater transit use.

The city of Charlotte, North Carolina, has introduced shared e-scooters servicing its residents and commuters since 2019. The trips and status change data have been collected and provided by major commercial e-scooter vendors in the Charlotte metropolitan area. It provides an opportunity to understand the travel patterns of shared e-scooters and to identify e-scooter trips that serve as FLM connections by referencing Charlotte's transit data and other relevant information. This study aims to identify the shared e-scooter FLM connection trips and analyze the travel patterns of FLM trips, spatially and temporally.

The study finds that the "first-mile" connection trips take 14.82%, while the "last-mile" connection trips account for 15.81% of the total trips. On weekdays, the peak hours for first-mile connection trips are 8:00 a.m., and the peak hours for last-mile connection trips are 5:00 p.m. Spatially, the "hot" bus stops with FLM connections are at the southwest corner of the Uptown area, and the "hot" light rail stations with FLM connections are near the Southend area. Those temporal and spatial travel patterns shed light on e-scooter FLM connection trips, which can be used to support the operation and management of e-scooters and transit systems.

The identification of FLM connection trips is based solely on the location information of public transit stations and stops, as well as the trip's start and end points. More information needs to be included, such as the schedule of the public transit and transit ridership. Moreover, Point of Interest (POI) and demographic information of the areas can be analyzed to gain a better understanding of shared e-scooter riders and their trip purposes, providing potential suggestions or improvements for the operation and management of shared e-scooters. This analysis can ultimately contribute to the development of a more integrated transportation system.

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Chapter 1. Introduction

1.1 Background

Public transit has been widely adopted due to its sustainability and cost efficiency. High-capacity transit systems, such as subways, buses, and light rail, can significantly mitigate traffic congestion during rush hours. However, the public transit system is usually underutilized, especially in the United States. The accessibility of the public transit system is a key concern, as reaching or departing from certain stations or stops may require walking long distances, which may discourage the adoption of transit. Micromobility options, such as electric bikes (e-bikes) and electric scooters (e-scooters), offer a promising solution to accessibility challenges by providing a convenient way for users to travel from their origins to transit stops or from transit stops to their destinations, also known as the first-and-last-mile (FLM) connection. Many cities in the United States have launched the Micro-mobility program, such as the CitiBike in New York City [1], Capital Bikeshare in Washington, D.C [2], and shared e-scooter services in Austin, TX [3], Nashville, TN [4], Charlotte, NC [5], and Portland, OR [6]. In addition to supporting FLM connections to public transit, micromobility services provide a flexible and sustainable option for short-distance travel, actively reshaping travel behavior in cities.

1.2 Research Objective and Scope

A shared e-scooter service was introduced in the City of Charlotte, NC, in 2019, and it has since become a common sight throughout the city, particularly in the Uptown area [7]. Major shared e-scooter vendors operating in Charlotte have been collecting and providing detailed trip and event status data since 2019. To achieve better operation and management of transportation systems, it is necessary to understand the travel patterns of shared e-scooters and explore e-scooter FLM connection trips by processing and analyzing shared e-scooter travel data provided by the City of Charlotte. Therefore, this study aims to examine the travel patterns of general e-scooters and FLM connection trips from temporal and spatial perspectives, exploring the potential benefits of e-scooter FLM connections to transit systems. The main objectives of the study are listed below:

1. Detecting FLM connection trips from Charlotte's shared e-scooter travel data.
2. Conducting statistical, temporal, and spatial analyses on e-scooter FLM connection trips to understand the travel patterns and potential benefits.

1.3 Report Organization

The following sections of this report are organized as follows. The Literature Review section introduces shared e-scooters, their contribution to travel mode shift, and travel patterns of e-scooter FLM connection trips. The Data and Methodology section provides descriptions of the data used for shared e-scooter trips and public transit in Charlotte. Additionally, it introduces a method for detecting FLM connection trips. The Analysis and Results section presents the statistical comparison, temporal pattern, and spatial pattern of FLM connection trips. Finally, the Conclusion and Future Work section summarizes the findings and future work.

Chapter 2. Literature Review

2.1 Travel Mode Shifts Related to Shared E-scooters

As reported by the National Association of City Transportation Officials (NACTO) in 2023, people took 133 million trips on shared mobility in the U.S., which is 16% more than in 2022. Among the shared mobility options, including dockless bikes, station-based bikes, and dockless e-scooters, the dockless e-scooters accounted for 48.9% of the total 133 million trips [8]. E-scooter trips, which make up a significant portion of shared mobility, have been widely studied in recent years. One of the topics is the mode shift caused by the introduction of shared e-scooters.

Shared e-scooters contribute to travel mode shifts by either substituting for or complementing the existing travel modes, such as public transit, driving, and walking [9]. E-scooter substitution refers to trips that would have otherwise been made by other modes of transportation being replaced by e-scooters. Complementarity, on the other hand, means that the introduction of e-scooters can increase the ridership of other travel modes. Retrospective counterfactual surveys have been widely used to measure the substitution and complementarity. For example, James et al. surveyed 181 e-scooter riders and non-riders in Rosslyn, Virginia, and found out that e-scooter trips replace 39% Uber, Lyft or taxi trips, 33% walking trips, 12% bicycle trips, 7% bus trips, and 7% personal car trips [10]. In 2019, 12,466 people were surveyed in Chicago during a shared e-scooter pilot program from June 15 to October 15. The results illustrated that 34% of the survey respondents indicated that they used e-scooters to connect to transit, 22% indicated that they rode the bus less often, and 13% indicated that they rode the train less often than before the pilot [11]. Besides, shared e-scooter trip-related data have been collected and analyzed to study mode shifts. A study in Nashville, Tennessee, analyzed transit ridership and shared e-scooter trip data from September 2018 to July 2019, along with demographic and weather data. The study found that utilitarian e-scooter trips are associated with a 0.94% decrease in bus ridership on a typical weekday, whereas social e-scooter trips are associated with weekday bus ridership increases of 0.86% [12]. A case study in Indianapolis, Indiana, found that 27% of e-scooter trips could potentially compete with the bus system, and are concentrated in downtown, while 29% of e-scooter trips connect riders to the bus system, which is mainly located outside of downtown, with low bus coverage [13]. However, a study taking the transit data and the shared e-scooters trip data from August 2018 to December 2019 in Louisville, Kentucky, found out that shared e-scooters do not have a significant impact on local bus ridership, though they have the potential to complement express bus routes as they serve the first/last mile of a trip [14].

Aside from the mode shift analysis, other topics, such as user profile analysis [13, 14], safety [15, 16], and energy efficiency [17, 18], have been studied. These studies contribute to the improvement of planning and management of shared e-scooter operations, highlighting their potential as a flexible and sustainable micromobility option. Despite the convenience and benefits that shared e-scooters bring, NACTO pointed out that affordability is a growing challenge. Statistics show that the average cost of a one-way shared e-scooter trip was around $6.00 in 2023, while in North Carolina, the cost of a six-minute e-scooter trip can be as high as $9.00 [8].

2.2 Shared E-scooter for First-and-Last-Mile Service

One reason shared e-scooters can complement public transit is that they provide a convenient first-and-last-mile (FLM) connection to transit systems. Lu et al. pointed out that though public transit represents a significant investment worldwide, the usage remains underutilized, especially in the United States [15]. One key reason is the difficulties in accessing and egressing the public transit stops or stations, namely, the FLM connection problem [15]. As a form of micromobility, shared e-scooters offer a sustainable and flexible solution for FLM connections to transit (e.g., buses and light rails). By developing e-scooter last-mile models using e-scooter trip data in Austin, Texas, Zuniga-Garcia et al. found that the average effect of a 10% increment in transit trips resulted in a 2.5% increment in e-scooter trips in the university area, 1.4% for the downtown area, and an average of 1.7% across the whole city. Also, it is estimated that 25 percent of users use e-scooters for FLM connections [16].

Understanding the factors that influence the willingness to use shared e-scooters and their usage patterns, especially for FLM connections, can help better integrate the shared e-scooter service into the public transit system. A study surveying shared e-scooter users in Seoul, South Korea, suggests that younger individuals with higher incomes and dissatisfaction with the public transit system show a greater willingness to use shared e-scooters [17]. Additionally, people who need to travel through the university district are more likely to use shared e-scooters for FLM connections [17]. In terms of the spatial-temporal patterns of FLM connection trips, Yin et al. analyzed the share e-scooter trip data in Washington D.C. in June 2021 and June 2022 [18]. The results show that FLM trips peak between 4 pm and 7 pm, and the proportion of first-mile trips in the morning is statistically higher than that of last-mile trips. Also, many users ride shared e-scooters to connect with transit for commuting or school trips. Further, most of the FLM trips were found near the areas with the highest density of transit infrastructure [18].

Shared e-scooters may not be popular in some areas. A stated choice experiment (SCE) with students at Portland State University shows that e-scooters are not perceived as a preferred solution to the FLM problem in Portland, Oregon, though certain policies, such as increasing the parking cost in the University, may promote the usage of shared e-scooters [19]. In addition, the stated preference survey conducted in Dublin, Ireland, indicates that only a small proportion of the survey sample, mainly young and male respondents, are interested in using private and shared e-scooters for FLM connections [20].

Chapter 3. Data and Methodology

3.1 Data Description

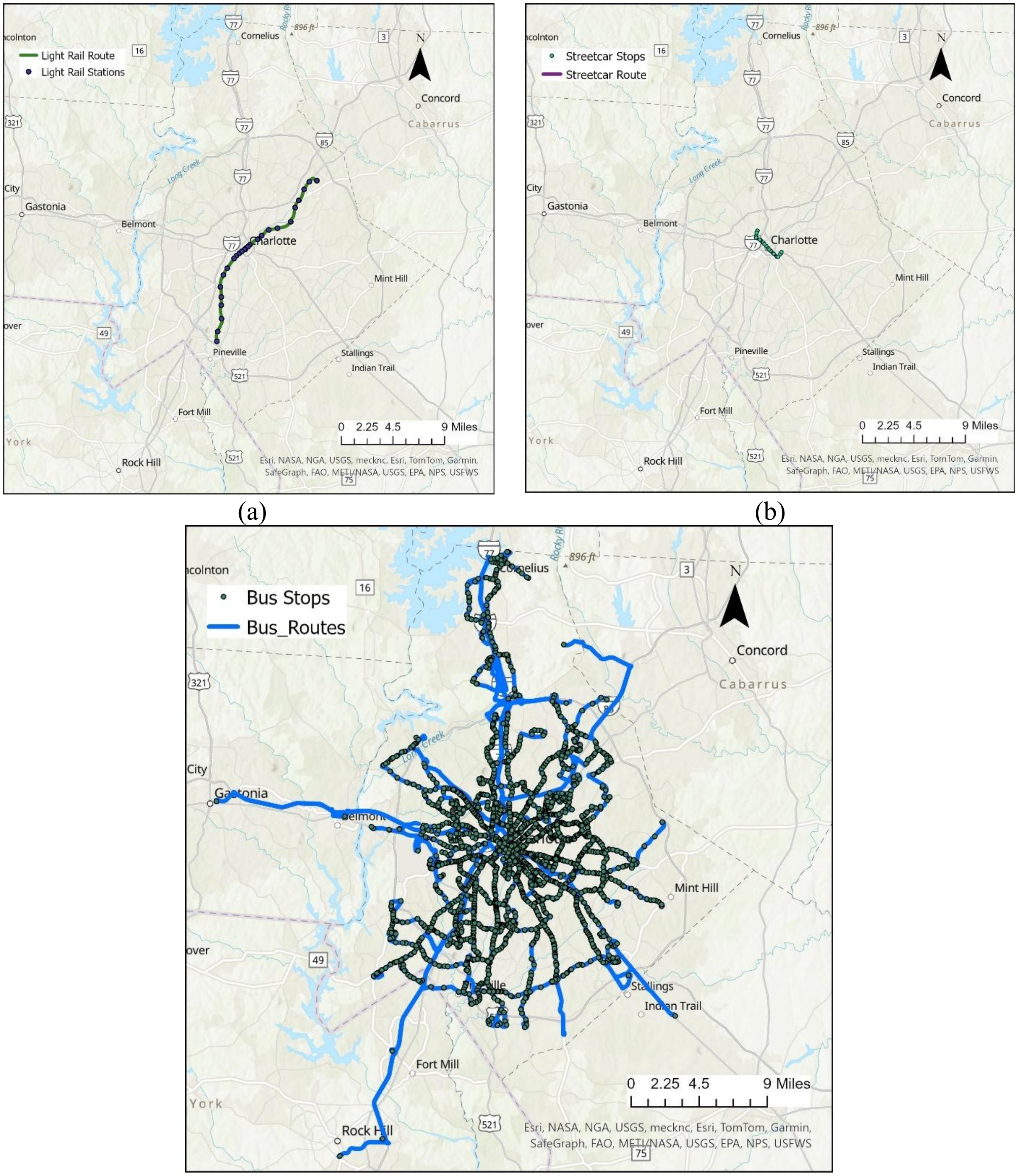
This section introduces the light rail stations and bus stops operated by the Charlotte Area Transit System (CATS), as well as the shared e-scooter trip data provided by the city of Charlotte, NC.

3.1.1. Public Transit Data

Charlotte Area Transit Systems (CATS) provides 68 bus routes, 1 light rail route, and 1 streetcar route across Charlotte, including 2,922 bus stops, 26 light rail stations, and 17 streetcar stops. Routes, stops, or stations information can be obtained from the City of Charlotte Open Data Portal [21]. Figure 1 illustrates transit facilities, including routes, stops, and stations, for light rail (a), streetcar (b), and bus (c). The light rail, called the LYNX Blue Line, is approximately 19 miles long and connects Uptown Charlotte to the University of North Carolina at Charlotte (UNC Charlotte). The service hours are normally from 5:00 am to 12:00 am (midnight). The trains arrive around 15 minutes during peak hours (7 am-9 am, 4 pm-6 pm on weekdays), 20 minutes during off-peak hours, and around 30 minutes after 8:30 pm. The light rail costs $2.2 for a one-way trip [22].

The streetcar, also known as LYNX Gold Line, runs east-west for about 4 miles through Uptown Charlotte. The streetcars operate from 6:00 am to 11:26 pm on weekdays, 8:00 am to 11:26 pm on Saturdays, and 8:00 am to 10:36 pm on Sundays, with a frequency of 30 minutes. The Gold Line is currently fare-free and will cost $2.2 per ride with further notice [23].

The bus system serves Charlotte and its surrounding areas, including local, express, and community routes. The service time is generally from 5:30 am to midnight. The frequency of peak hours for some routes can be as high as every 15 minutes, and the frequency of off-peak hours for some routes is 60 minutes. The one-way fare can be as high as $4.4 for some express routes [24]. It can be observed from Figure 1 that the uptown area has denser stops or stations than other areas.



(a) (b) (c)

Figure 1: Public Transit Routes and Stops in Charlotte: (a) Light Rail; (b) Streetcar; (c) Bus

3.1.2. Shared E-scooter Travel Data

The Shared Mobility Program in Charlotte [25] has been providing shared e-scooter service. Currently, e-scooters provided by specific vendors (i.e., Bird and Lime) are permitted to operate within the Charlotte area from 5 am to 1:30 am daily. E-scooters typically cost $1 to unlock and 15 cents per minute to ride [30], with various discounts available for eligible riders [25]. The shared e-scooter travel data were collected by the vendors and shared for the City of Charlotte following the Mobility Data Specification (MDS) [26], which is a set of APIs (Application Programming Interfaces) that standardize and secure the data sharing process between mobility providers and cities. For transportation planning and management purposes, MDS includes information about vehicles, their locations, and trips taken on those vehicles. However, personal information about the users of shared mobility services was not collected to protect user privacy [27].

Shared e-scooter trip-related data from 2019 to 2024 has been collected and shared. The trip-related information is summarized in Table 1. It shows that e-scooter usage peaked in 2021, following the COVID-19 pandemic, with the highest number of vehicles in operation. On average, the **trip distance is 0.83 miles,** the **travel time is 7.97 minutes**, and the **speed is 6.15 mph** for shared e-scooters in Charlotte.

Table 1: Statistics of Shared E-scooter Trips

Year	**Trip count**	**Operational vehicles**	**Median trip distance(mi)**	**Median travel time(min)**	**Median speed(mph)**
2019	320,351	3755	0.76	7.18	5.98
2020	386,020	3292	0.89	8.37	6.14
2021	**934,131**	**4797**	0.91	9.18	5.9
2022	896,427	3846	0.86	7.93	6.56
2023	680,302	2240	0.74	7.2	6.14
Average	**643,446**	**3585**	**0.83**	**7.97**	**6.15**

To obtain more recent shared e-scooter travel patterns, the monthly numbers of trips from January 2023 to September 2024 are shown in Figure 2. It can be observed that the monthly number of trips ranges from 25,631 (during January 2024) to 81,086 (during September 2023), with **fewer trips during wintertime and more trips during summertime**. The average monthly number of trips is 57,368.

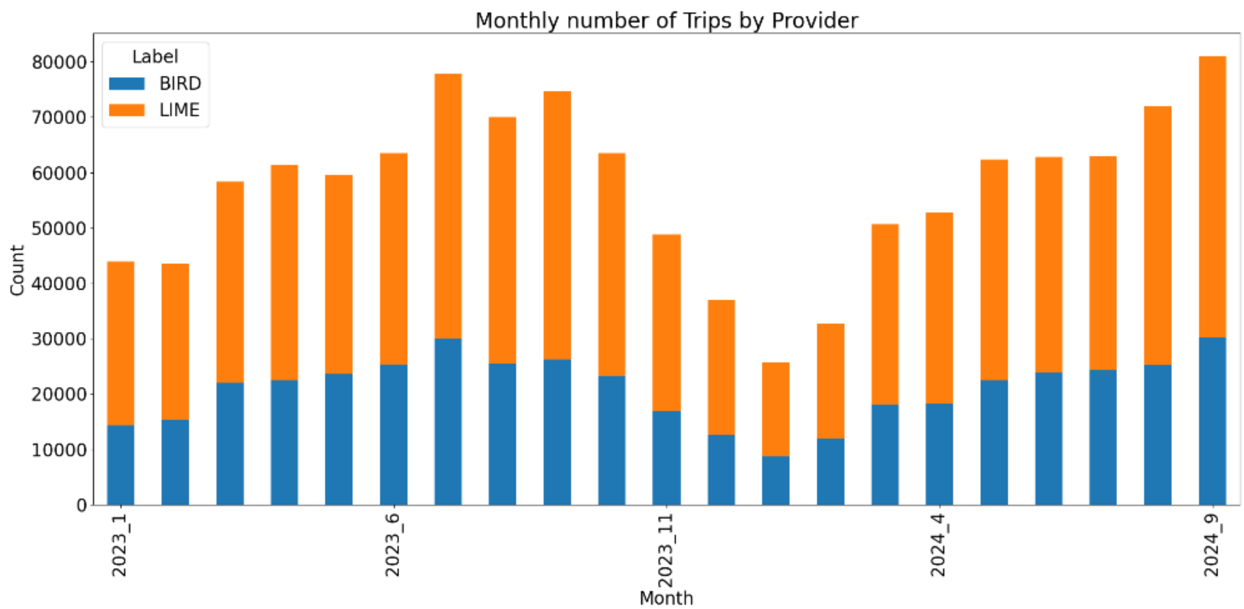
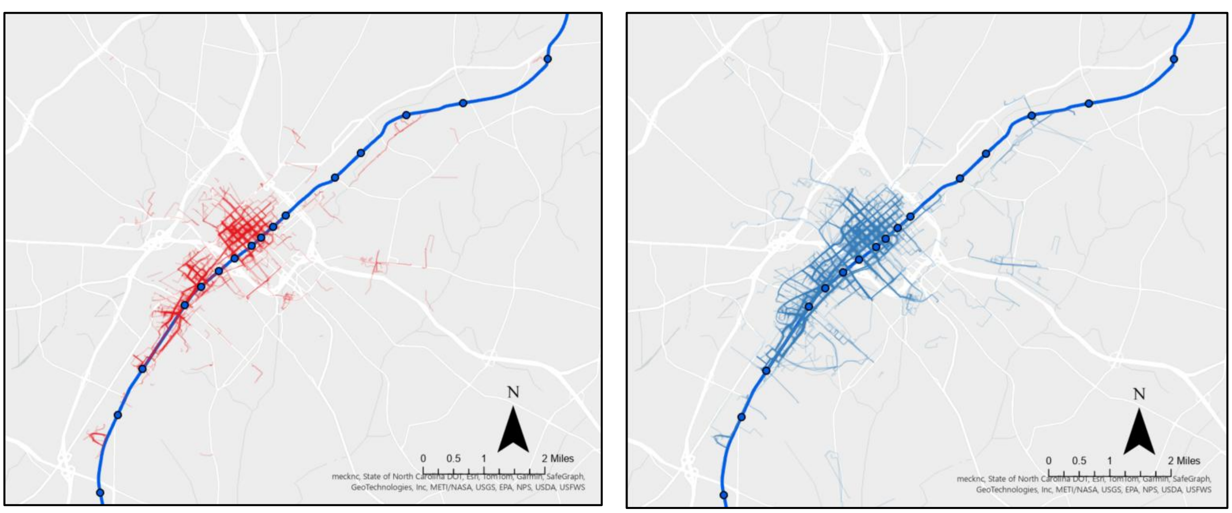
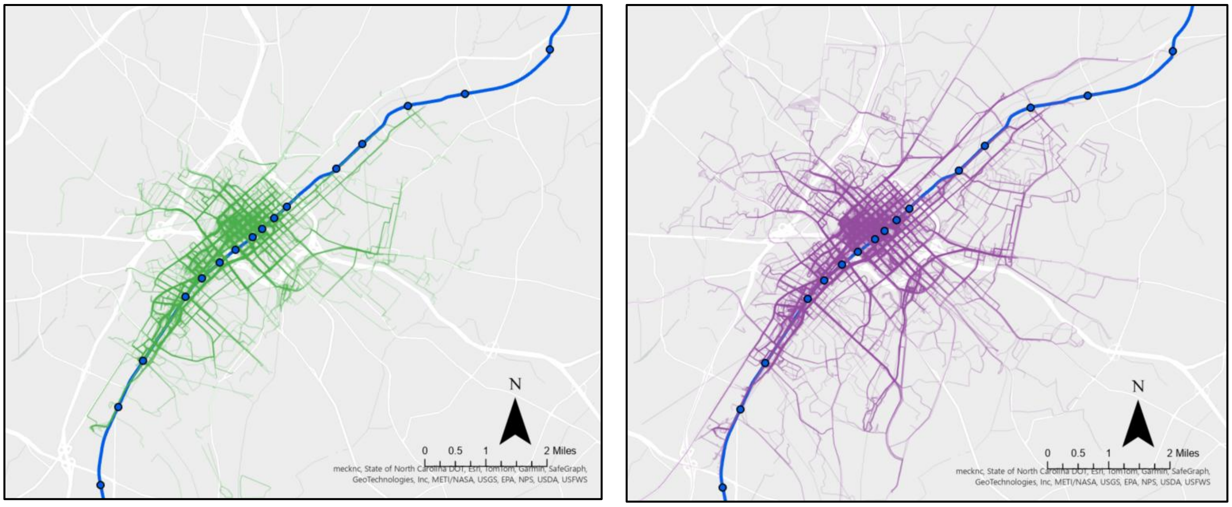


Figure 2: Monthly Number of Shared E-scooter Trips

In addition to travel time, distance, and speed, detailed route information is available for e-scooter trips. Figure 3 illustrates the spatial distribution of shared e-scooter trips based on distance on a typical weekend (September 11, 2021). The distribution patterns indicate an intense concentration in the Uptown area, with movements radiating toward adjacent areas. Primarily, **most short trips were traveled within the Uptown area and along the light rail route**, while **longer trips mostly connected the Uptown area to the surrounding areas**.



(a) (b)



(c) (d)

Figure 3: Spatial Distribution of Shared E-scooter Trips Based on Distance: (a) Distance less than 0.5 miles; (b) Distance from 0.5 to 1 mile; (c) Distance from 1 to 2 miles; (d) Distance greater than 2 miles

3.2 Method for FLM Trip Detection

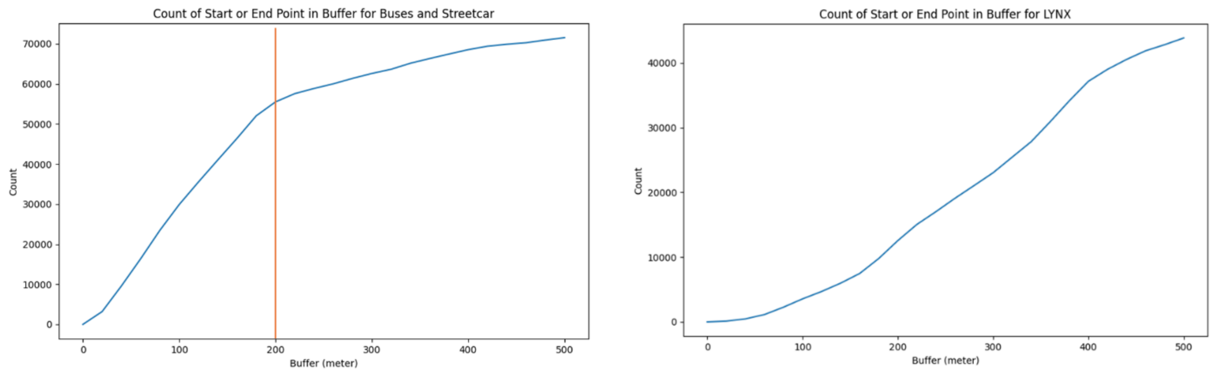
The section introduces potential shared e-scooter first-and-last-mile (FLM) connection trips detection, including data cleaning, stop or station buffer identification, and e-scooter trips classification.

3.2.1. Data Cleaning

To capture the seasonal pattern, a total of 246,539 trips from four months were selected for analysis, including January 2023, April 2023, July 2023, and October 2023. To achieve the desired typical pattern, outliers were removed. Thus, trips with a duration of less than 100 seconds or greater than 2,000 seconds (0.56 hours) and trips with a distance of less than 100 meters or greater than 4,500 meters (2.8 miles) are removed. After removing the outliers, 207,141 trips remain for analysis, accounting for approximately 84% of the total trips.

3.2.2. Buffer Identification

"First-mile" trips connect travelers from their origins to transit stations, while "last-mile" trips connect them from transit stations to their destinations. Thus, the first-and-last-mile (FLM) trips need to have at least one end near the transit stations. A spatial buffer around the transit stations is used to decide if the shared e-scooter trip is potentially for the FLM connection. Given that three types of transit stations are involved in the study — stations or stops for buses, streetcars, and light rail — different buffer values are required. Considering that the stops and size of streetcars are similar to those of buses, while light rail uses longer trains and larger stations, two types of buffers are identified in this study. One buffer is identified for buses and streetcar stops, and the other one is defined for light rail stations by examining the count of start and end points of the shared e-scooter trips. As shown in Figure 4, for buses and streetcars, the increase in count slows once the buffer exceeds 200 meters, indicating that more trips start or end within 200 meters of a bus or streetcar stop. However, this trend cannot be observed in light rail cases. Considering the length of the stations, which can be up to approximately 90 meters (as measured on Google Maps), the buffer value for light rail stations is set at 250 meters. The size of the buffer is consistent with the literature, as Oeschger et al.[20] and Yin et al.[18] pointed out that the buffer varies from study to study and ranges typically from 50 meters to 250 meters.



(a) (b)

Figure 4: Count of Trip Start and End Point within Buffer for (a) Buses and Streetcars and (b) Light Rail

3.2.3. Trip Classification

Based on the buffer and the location where the trips start and end spatially, the e-scooter trips are divided into seven types, as listed below:

1. **First-mile connection (FMC)**: a trip ends within the buffer of any stop or station and starts outside the buffer of any stop or station.
2. **Last-mile connection (LMC)**: a trip starts within the buffer of any stop or station and ends outside the buffer of any stop or station.
3. **Bus-bus connection (BBC)**: a trip starts and ends within the buffers of two different bus stops that belong to two different routes.
4. **Bus-light rail connection (BLC)**: a trip has one end within the buffer of a bus stop and the other end within the buffer of a light rail station.
5. **Bus substitution (BS)**: a trip starts and ends within the buffer of two bus stops that belong to the same route or transferable routes.
6. **Light rail substation (LS)**: a trip starts and ends within the buffer of two light rail stations.
7. **Other (OT):** all the remaining trips.

FMC and LMC trips are defined as e-scooter FLM connection trips, which will be the focus of this study. BBC and BLC trips are considered e-scooter connections for different transit routes or systems that can't be reached without changing modes (e.g., taking e-scooters). While the trips of BS and LS can be replaced entirely by public transit.

Chapter 4. Analysis and Results

By comparing the location where an e-scooter trip starts and ends with the locations of the public transit stations and stops, the shared e-scooter trips classification is shown in

It is worth noting that while the number of trips varies significantly across different months, **the proportion of trip types remains relatively consistent**. Also, the classification only suggests potential trip types, as it is based solely on location data. More accurate classification would require additional information, such as details of the rider's preceding or subsequent trips.

Table 2. It indicates that the potential FLM connection trips (FMC and LMC) take about 30% on average. Besides, other types of connections or transfers are also detected. These two types of connections take 20.08% (BBC) and 5.09% (BLC) on average.

Another type of trip, bus substitution (BS), takes a significant portion (34.08% on average). Few trips are a substitute for light rail trips (LS) (0.38% on average), maybe due to the long distances between light rail stations. Around 10% of trips belong to the "other" type (OT), meaning that the start and end points of the trips are both outside of the buffer zone of public transit stations and stops.

It is worth noting that while the number of trips varies significantly across different months, **the proportion of trip types remains relatively consistent**. Also, the classification only suggests potential trip types, as it is based solely on location data. More accurate classification would require additional information, such as details of the rider's preceding or subsequent trips.

Table 2: Classification of the Shared E-scooter Trips and Related Percentages

Year_Month	FMC	LMC	BBC	BLC	BS	LS	OT	Total Trips
2023_1	13.97%	14.27%	20.80%	5.60%	37.74%	0.41%	7.22%	37747
2023_4	14.56%	15.42%	19.17%	4.76%	35.29%	0.48%	10.33%	50403
2023_7	14.75%	16.29%	19.38%	5.12%	33.24%	0.37%	10.85%	65712
2023_10	16.02%	17.28%	20.96%	4.90%	30.04%	0.28%	10.52%	53279
Average	14.82%	15.81%	20.08%	5.09%	34.08%	0.38%	9.73%	

The following sections will focus on the travel patterns of FLM connection, i.e., FMC and LMC trips, examining travel time, travel distance, and the spatial and temporal distribution of these trips.

4.1 Statistical Analysis

This section aims to determine the typical travel time and distance for FLM connection trips, specifically the FMC and LMC trips, and to investigate whether the travel time and distance of these trips differ statistically from those of other types of trips. To test if one group is statistically different from multiple other groups, the *independence, normality,* and *homogeneity of variance* need to be checked before identifying the appropriate test method. In this study, riding a shared e-scooter is considered an independent event. In terms of normality, the distributions of travel time and travel distance for each trip type are examined, as shown in Figure 5 and Figure 6. Based on the skewness values, which are greater than 1, the **distributions are all strongly right-skewed**.

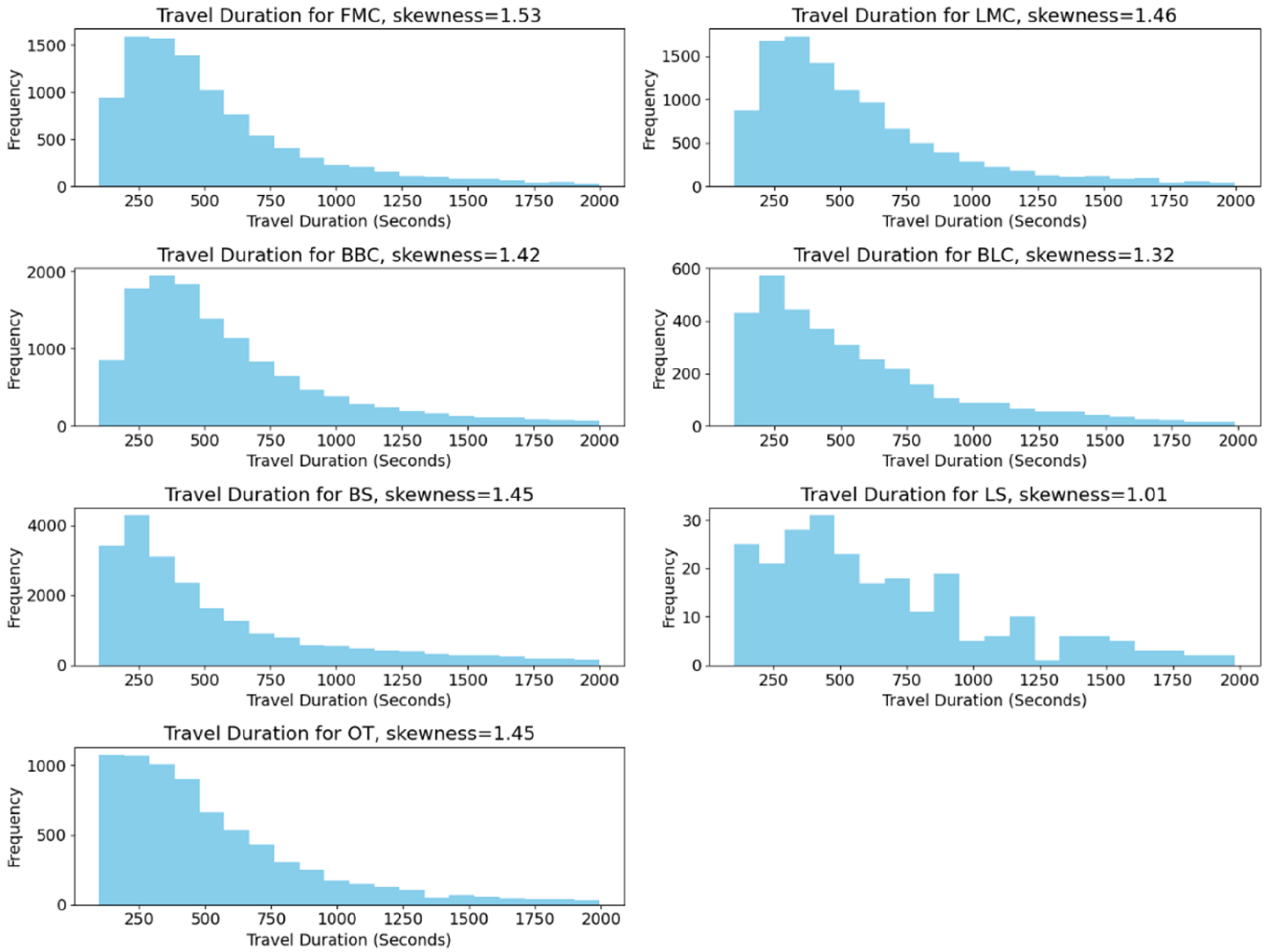


Figure 5: Distribution of Travel Duration

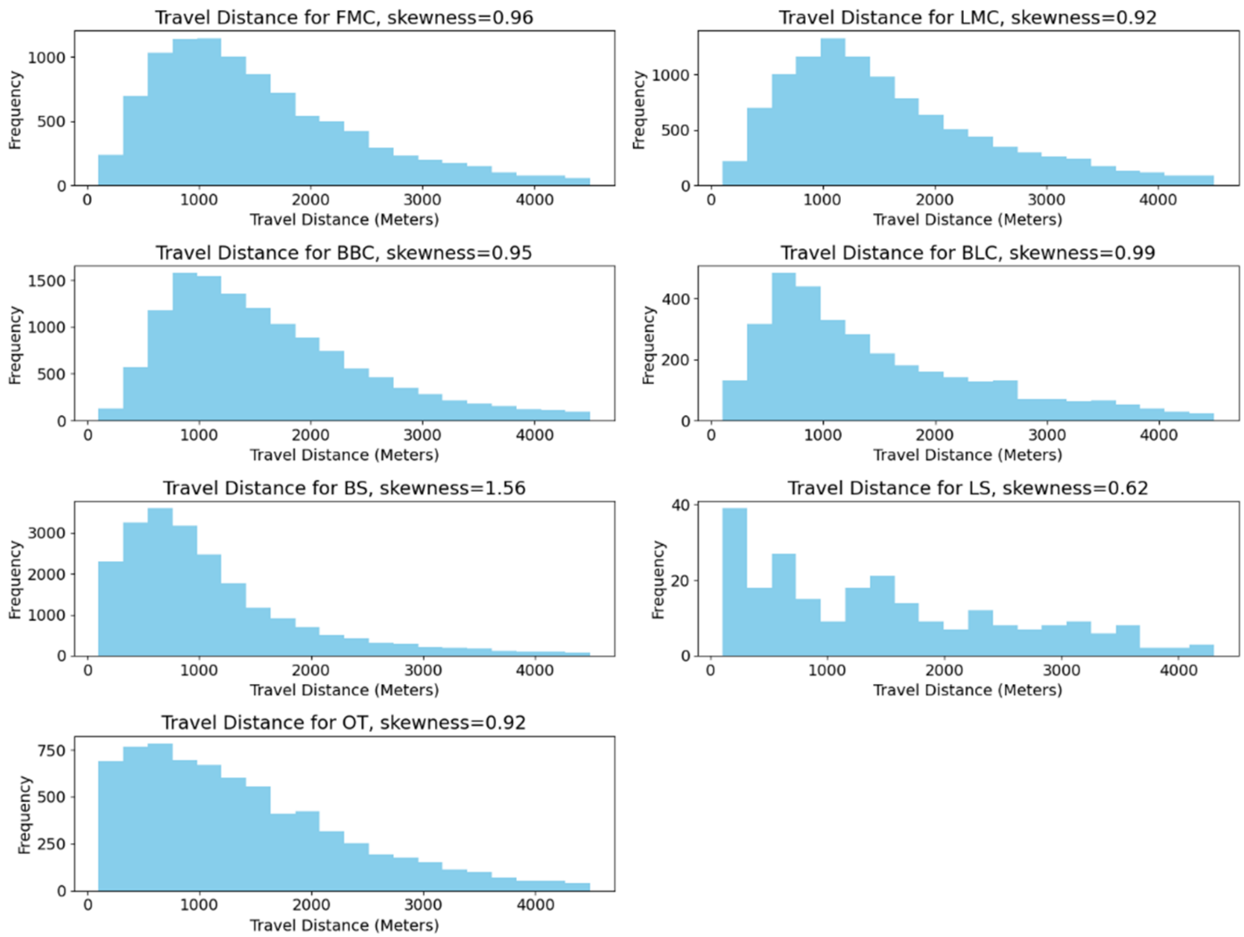


Figure 6: Distribution of Travel Distance

Additionally, Levene's test is used to determine whether the variances of different types of trips are equal for travel duration and distance. The null hypothesis is that variances are equal across groups. The p-values of Levene’s test for travel duration and travel distance are very close to 0, indicating that the **variances among different trip types are significantly different**. Thus, a non-parametric test, *Kruskal–Wallis Test*, is selected to compare the travel time and travel distance among the seven trip types. The null hypothesis is that all groups have equal medians, and the alternative hypothesis is that at least one group has a median that is different from the others. For all trips in the selected 4 months, the p-values are 0 for both travel time and travel distance, indicating that at least one group has significantly different travel durations and travel distances.

To get the pairwise comparison result, *Dunn’s test* is applied. Table 3 and Table 4 present the comparison results for trip travel duration and distance in January 2023, respectively. The tables indicate that **for FLM connection trips, the median travel duration is approximately 7 minutes, and the median travel distance is around 0.8 miles,** which are comparable to the median travel durations of 7.2 minutes and median travel distances of 0.74 miles in 2023. The green color in the tables indicates that the row value is significantly smaller than the column value. In contrast, the yellow color indicates that the row value is significantly bigger than the column value. For example, Table 3 shows that the median travel duration of FMC trips is significantly shorter than that of BBC trips and significantly longer than that of BS trips. The LMC trips are significantly longer than the FMC trips, BLC trips, and BS trips. Similar results can be drawn for travel distance and trips in other months.

Table 3: Dunn's Test Result for Travel Duration

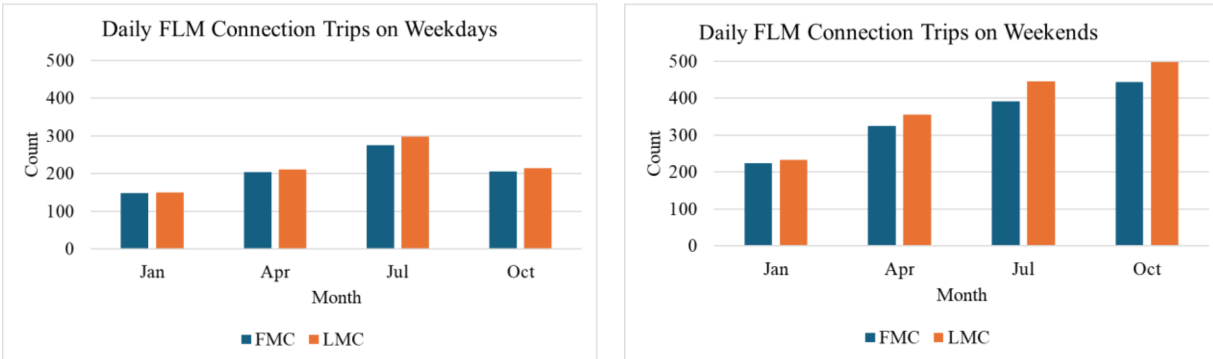
Duration(Min)		6.42	7.05	6.85	6.8	5.65	10	6.37
		FMC	**LMC**	BBC	BLC	BS	LS	OT
6.42	**FMC**							
7.05	**LMC**							
6.85	BBC							
6.8	BLC							
5.65	BS							
10	LS							
6.37	OT							

Table 4: Dunn's Test Result for Travel Distance

Distance(Mile)		0.79	0.85	0.86	0.77	0.56	0.81	0.69
		FMC	**LMC**	BBC	BLC	BS	LS	OT
0.79	**FMC**							
0.85	**LMC**							
0.86	BBC							
0.77	BLC							
0.56	BS							
0.81	LS							
0.69	OT							

4.2 Temporal Analysis

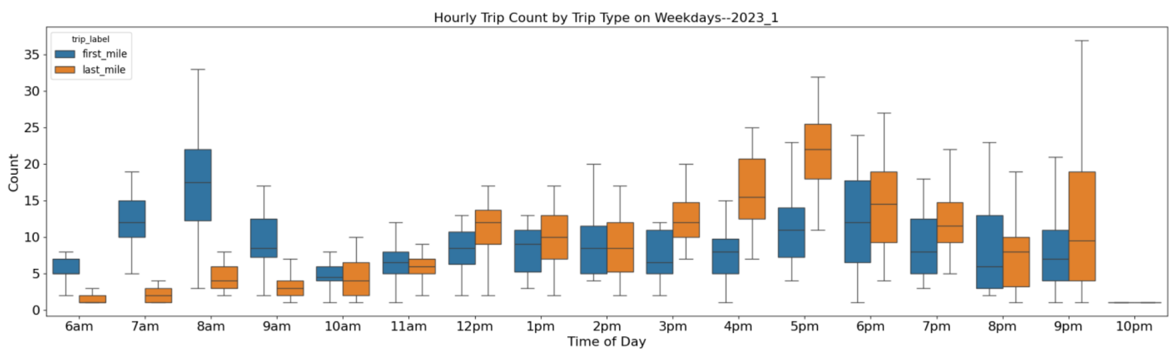
This section examines the temporal distribution of FLM connection trips on weekdays and weekends. Figure 7 shows the average daily FLM connection trips for the selected four months, on weekdays and weekends, in 2023. The data indicates that there are approximately 70.8% more FLM connection trips on weekends than on weekdays, on average, with the average daily number of trips being 213 on weekdays and 364 on weekends, respectively. Additionally, there are approximately 8.6% more LMC trips than FMC trips.



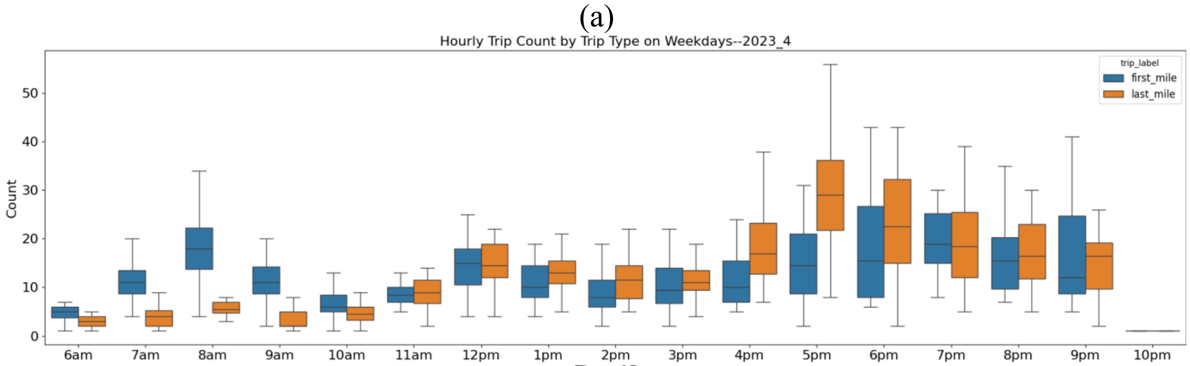
(a) (b)

Figure 7: Daily FMC and LMC Trips on (a) Weekdays and (b) Weekends

Figure 8 and Figure 9 illustrate the hourly count of FLM connection trips on weekdays and weekends for the selected months. Generally, Figure 8 shows that on **weekdays**, there are more FMC trips than LMC trips in the morning, while more LMC trips in the afternoon. Additionally, it can be observed that FMC trips peak at 8:00 a.m. and LMC trips peak at 5:00 p.m. Besides, although the trip count starts to drop after 5 pm, a more pronounced drop can be observed in January and October, indicating that there may be less activity in the early evening, possibly due to the lower temperatures in the Winter and Fall months.



(a)



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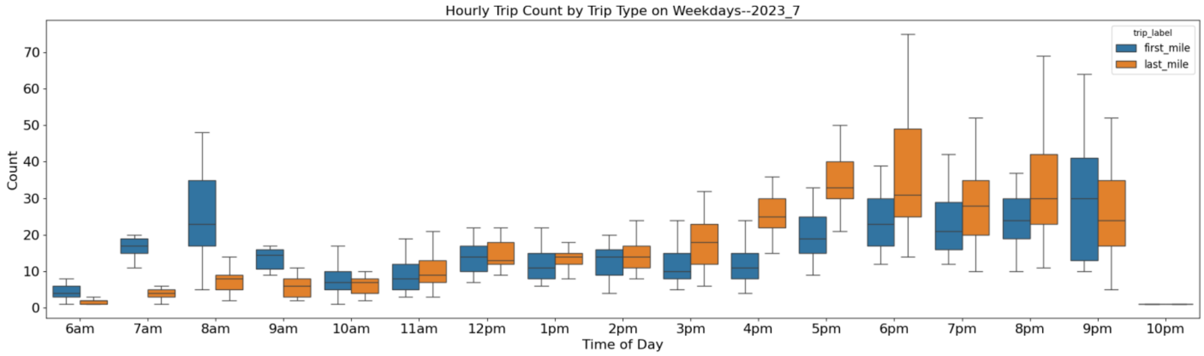

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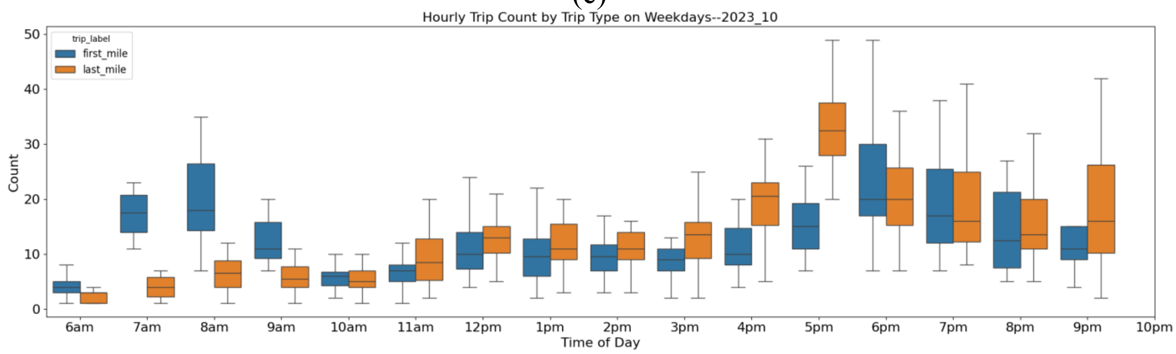
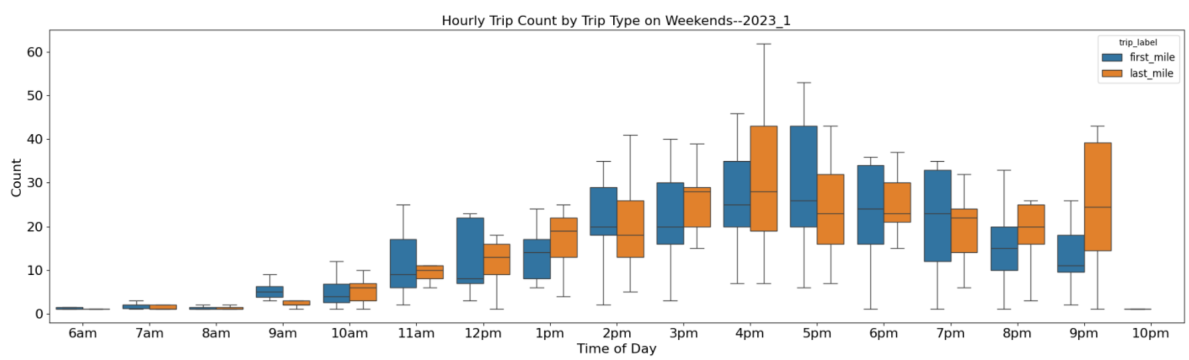


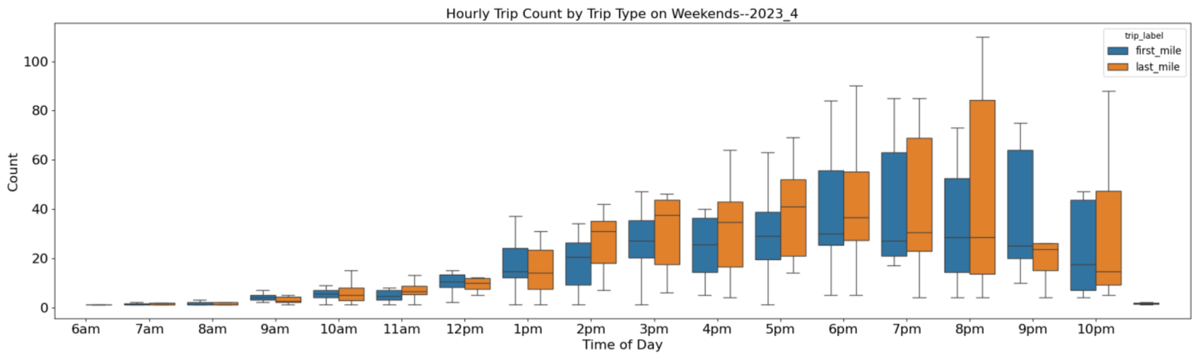
(d)

Figure 8: Hourly Trip Count for FLM Trips on Weekdays: (a) Jan 2023, (b) Apr 2023, (c) Jul 2023, (d) Oct 2023

For **weekends**, Figure 9 illustrates that very few FLM connection trips were observed before 10 am, and there are more trips in the late afternoon or the evening. Besides, FMC and LMC trips share similar patterns on weekends. An obvious peak hour can be observed for January and October, which is around 4-5 pm. Whereas in July and October, the trip count remains high after 5 pm, especially in July, indicating that there may be more activities or events at night in July and October.



(a)



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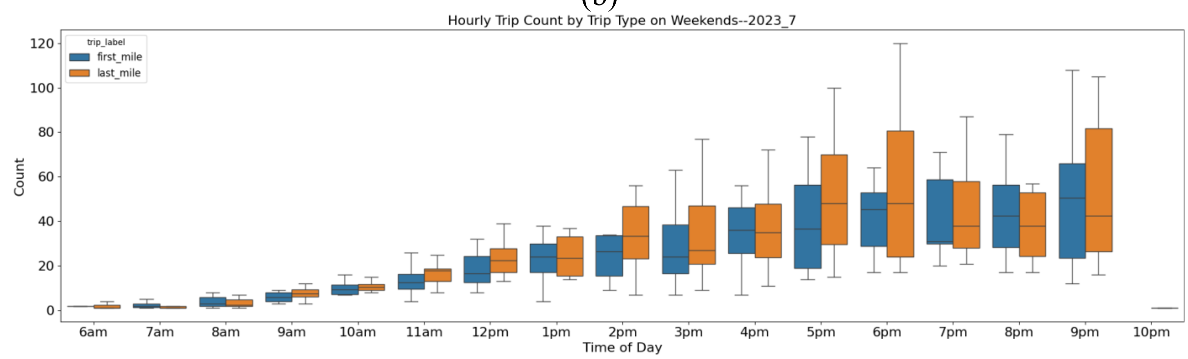

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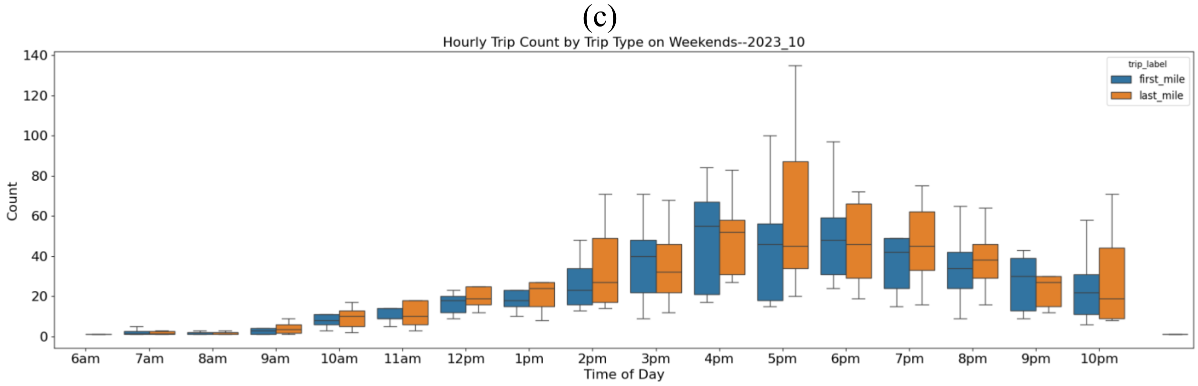


(d)

Figure 9: Hourly Trip Count for FLM Trips on Weekends: (a) Jan 2023, (b) Apr 2023, (c) Jul 2023, (d) Oct 2023

4.3 Spatial Analysis

This section introduces the correlation between the spatial distribution of public transit stops or stations and FLM connection trips. Figure 10 illustrates the public transit stops/stations with FLM connections (i.e., FMC and LMC) and the corresponding travel flows on weekdays and weekends in July 2023, as an example. The red dots represent the location of transit stops or stations, and the size of the dots indicates the number of related trips. The FLM connection travel flows related to different stops or stations are marked in different colors. The numerical value of the color legend represents the rank of each stop or station based on the number of related FLM trips, with a lower value indicating a higher rank and more connection trips to or from the stop or station. Thus, the **dark blue lines stand for the travel flows of top-ranked stops or stations**.

Overall, FMC and LMC for weekdays and weekends share a similar travel pattern. It can be observed that the top-ranked stops and stations are primarily located in the Uptown area and along the light rail lines. The shared e-scooters connect riders from those stops or stations to the surrounding neighborhoods.

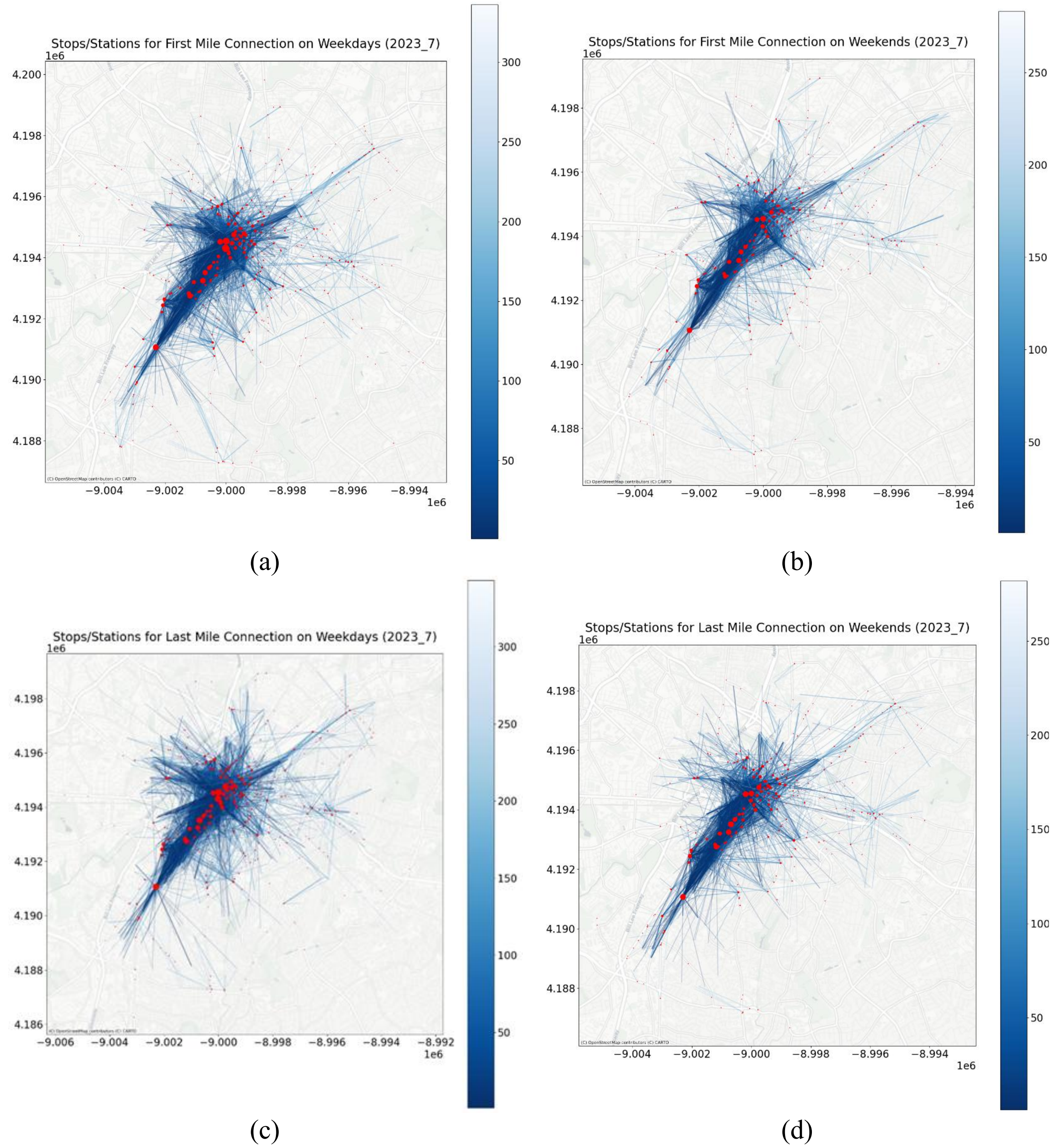
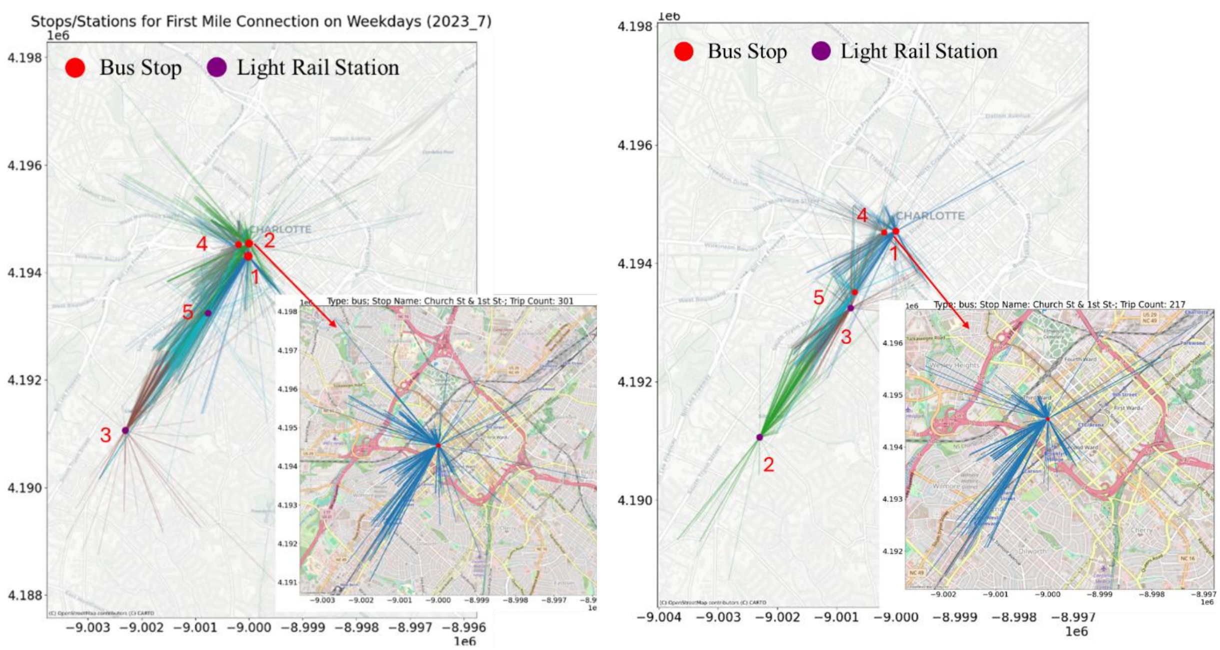


Figure 10: Public Transit Stops/Stations and related Travel Flows for FMC (a) on Weekdays, (b) on Weekends; for LMC (c) on Weekdays, (d) on Weekends

The top 5 stations/stops and the related FLM travel flow are visualized in Figure 11 for weekdays and weekends in July 2023. Detailed information about the stations/stops is presented in Table 5, including the name of each station/stop and its corresponding number of FLM flow. The top 5 ranked stations/stops are largely consistent for both FMC and LMC trips on weekdays and weekends and are **located on the southwest side of the Uptown area**. The common top stations/stops are *Tryon St & Stonewall St (outbound) bus stop, Church St & 1st St bus stop*, and *New Bern light rail station*.

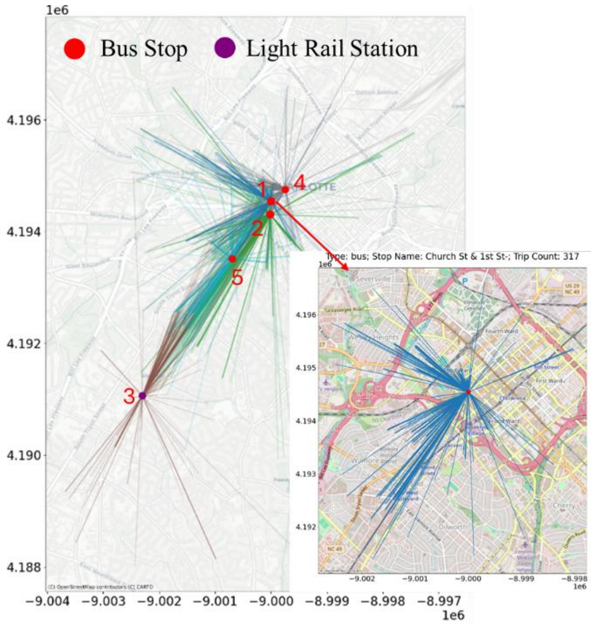
Additionally, Figure 11 illustrates that each station or stop is connected to or from specific areas via the FLM flow. For example, riders connecting to the *Church St & 1st St bus stop* primarily come from the northwest, southeast, and southwest directions, with varying distances to the stop. The *New Bern Station* and *Bland St Station* on the light rail line are near the Southend area of Charlotte, which has many luxury apartments, shopping malls, local shops, and art galleries. The FLM trips related to the two light rail stations are mostly from or to the Southend area.

Additionally, the FLM flows exhibit a similar pattern on weekdays and weekends, although more flows are observed on weekdays. Given that weekends typically see a higher overall number of shared e-scooter trips, the top five stations/stops, counterintuitively, have more FLM trips on weekdays. It can be inferred that on weekdays, **FLM flow may be more related to working or commuting trips**.

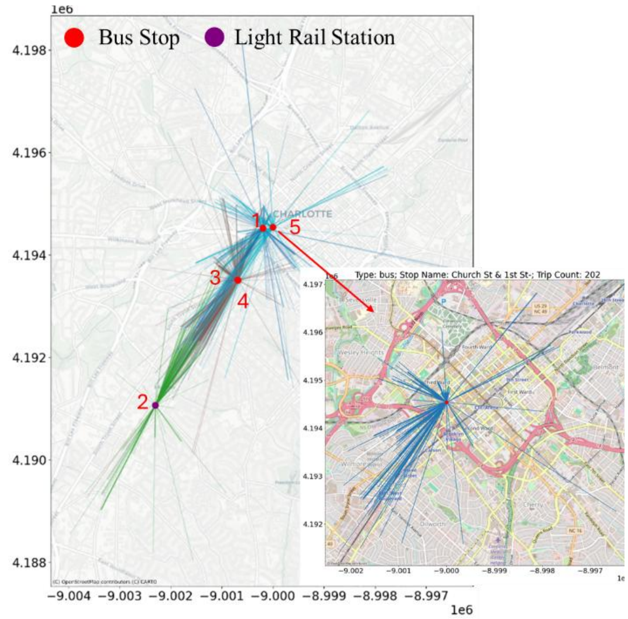


(a) First-Mile Connection on Weekdays

(b) First-Mile Connection on Weekends



(c) Last-Mile Connection on Weekdays



(d) Last-Mile Connection on Weekends

Figure 11: Top-Ranked Stations/Stops and Related FLM Travel Flow

Table 5: Top-5 Station/Stops and Related FLM Flow Trip Count in July 2023

First-Mile Connection Trips on Weekdays (July 2023)			
Rank	Station/Stop	Type	Total Count
1	Tryon St & Stonewall St-outbound	Bus	358
2	Church St & 1st St	Bus	301
3	New Bern	Light Rail	218
4	Stonewall St & Mint St-outbound	Bus	205
5	Bland St	Light Rail	200
First-Mile Connection Trips on Weekends (July 2023)			
Rank	Station/Stop	Type	Total Count
1	Church St & 1st St	Bus	217
2	New Bern	Light Rail	198
3	Bland St	Light Rail	185
4	Stonewall St & Mint St-outbound	Bus	155
5	Tryon St & Bland St-outbound	Bus	153
Last-Mile Connection Trips on Weekdays (July 2023)			
Rank	Station/Stop	Type	Total Count
1	Church St & 1st St	Bus	317
2	Tryon St & Stonewall St-outbound	Bus	298
3	New Bern	Light Rail	255
4	Church St & 3rd St	Bus	250
5	Tryon St & Bland St-outbound	Bus	244

Last-Mile Connection Trips on Weekends (July 2023)			
Rank	Station/Stop	Type	Total Count
1	Stonewall St & Mint St-outbound	Bus	212
2	New Bern	Light Rail	211
3	Tryon St & Bland St-inbound	Bus	207
4	Tryon St & Bland St-outbound	Bus	205
5	Church St & 1st St	Bus	202

Chapter 5. Conclusion and Future Work

To gain insight into shared e-scooter trips serving as first-and-last-mile (FLM) connections to public transit in Charlotte, this study analyzed shared e-scooter trip data in conjunction with public transit stations and stops. First, the e-scooter trip data from four representative months is pre-processed and selected to capture the seasonal trend in travel patterns. Different types of shared e-scooter trips are identified based on the spatial distance between the public transit stations or stops and the start or end points of e-scooter trips. By focusing on the first-mile and last-mile connection trips, the following conclusion can be drawn:

1. Generally, **more shared e-scooter trips were observed in the summertime, on weekends**, and **in the afternoon**.

2. **FLM connection trips account for approximately 30% of the total shared e-scooter trips,** with first-mile connection trips comprising 14.82% and last-mile connection trips making up 15.81%. Those trips may have a significant impact on public transit systems.

3. Statistically speaking, the first-mile connection (FMC) trips are significantly shorter than the bus-bus connection (BBC) trips, but longer than the bus substitution (BS) trips. At the same time, the last-mile connection (LMC) trips are significantly longer than the FMC trips, bus-light rail connection (BLC) trips, and BS trips. Users prefer to use e-scooters for longer "back home" travels.

4. **FMC trips peak at 8:00 a.m.,** and **LMC trips peak at 5:00 p.m.** on weekdays. For weekends, FLM connection trips peak at around 4-5 pm. There are more FLM connection trips during the nighttime of spring and summer compared to other seasons due to the relatively warm weather conditions.

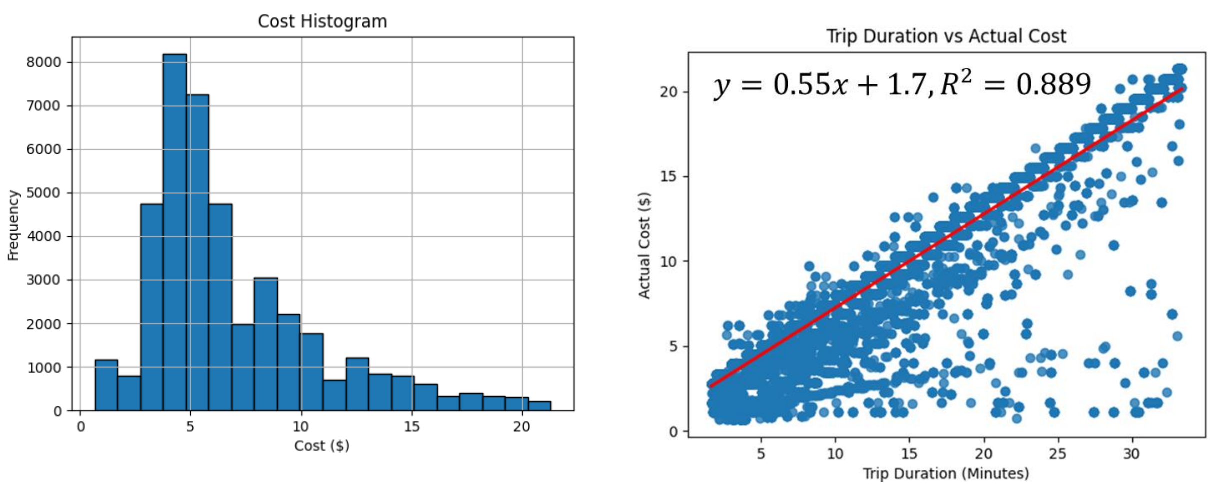
5. **Top-ranked public transit stops or stations** based on FLM connection trips are primarily located **in the Uptown area** and **along the light rail**. Common top stations for both weekdays and weekends are *Tryon St & Stonewall St (outbound) bus stop*, *Church St & 1st St bus stop*, and *New Bern light rail station*. The FLM trips related to the two light rail stations, *New Bern Station* and *Bland St Station*, are mostly from or to the Southend area of Charlotte.

The analysis presents the statistical, spatial, and temporal distributions, as well as in-depth insights into e-scooter trips used for FLM connections. However, one limitation is that the identification of the FLM connection trips is solely based on the location information of public transit stations or stops, as well as the trip's start and end points. To obtain better trip classification results and assess the potential impact of e-scooters, additional information should be considered, including transit ridership and public transit schedules. Moreover, Point of Interest (POI) and demographic information of the areas can be analyzed to gain a better understanding of shared e-scooter riders and their trip purposes, providing potential suggestions or improvements for the operation and management of shared e-scooters and integrated transit systems.

- **Cost and Fare**

The cost, fare, and financial impact are worth studying, as affordability is a key concern when using shared e-scooters. The previous discussion regarding e-scooter cost or pricing mechanisms indicates that the e-scooters typically *cost $1 to unlock* and *15 cents per minute* to ride [28]. The literature indicates that the *average cost of a one-way shared e-scooter trip was around $6.00* in 2023, while in North Carolina, the cost of a *six-minute e-scooter trip can be as high as $9.00* [8]. Figure 12 shows the cost distribution of 50,000 randomly selected shared e-scooter trips in Charlotte, based on the e-scooter data from 2024. Figure 12 (a) illustrates the histogram of the cost, which ranges from $0.66 to $21.3, with most costs being around $5. Figure 12(b) shows the relationship between the trip duration and the cost. The linear regression equation y = 0.55x + 1.7 can effectively describe the data, with an R-squared value of 0.889.

To further understand the shared e-scooter cost mechanisms, more data on actual e-scooters is needed. The potential next steps include collecting more e-scooter cost and travel data, understanding e-scooter fare policy and regulations, consulting with the cities and vendors in NC to obtain trip route information, analyzing the correlation between spatial patterns of trips and the costs, and comparing the affordability of shared e-scooters with other travel modes across different communities in North Carolina.



(a) (b)

Figure 12: Shared E-Scooter Cost in Charlotte(a) Cost Histogram, (b) Trip Duration vs. Cost

Implementation and Technology Transfer Plan

The project outcomes, including e-scooter data processing approaches, FLM trip identification, and temporal and spatial travel patterns analysis methods can be implemented and transferable for any other cities or regions with e-scooter services. NCDOT's Integrated Mobility Division (IMD) and the city of Charlotte, NC, will benefit from this research outcome. Other NCDOT units, such as the Transportation Planning Division and cities with e-scooter service, like Raleigh, will also benefit from this research for their existing or future micromobility service management and operations.

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