Usage, equity, and safety of shared electric scooters: a geospatial analysis of trips taken in Minneapolis, Minnesota

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Abstract

1 Abstract

Shared electic scooters have spread quickly to cities throughout the United States. The scooters, which do not need to be connected to a fixed docking station between uses, can be rented via a cell phone app for short trips in urban areas. Proponents of the scooters argue that they help to solve congestion in urban areas by reducing car trips, while opponents have raised concerns about safety and private use of public right-of-way. While there is research in the areas of docked bike-sharing systems and equitable transit design, there is a lack of research into electric scooters because of their very recent popularity. This research examines a dataset of over 225,000 scooter rides taken in Minneapolis between September and November 2018 from 3 different dimensions: usage, equity, and safety. An analysis of the ride data shows most rides were taken between downtown destinations and between institutional office locations such as college campuses. The number of scooter ride originations are slightly negatively correlated with household income in the surrounding area, indicating a lack of evidence of inequality in scooter usage. No meaningful relationship was found between the amount of enhanced bike infrastructure and the number of scooter rides in an area. These findings will help policymakers to more effectively develop public policy concerning scooters, scooter providers to more efficiently deploy their fleets, and scooter riders to better understand the usage and safety of the scooters.

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2 Introduction

Dockless shared electric scooters first entered the Santa Monica, CA market in September 2017. Over the summer of 2018, scooter companies including Bird Rides Inc. (Bird) and Lime deployed scooters to over 50 American cities and 20 other cities around the world. The electric scooters available to rent from these companies are dockless, meaning they can be parked almost anywhere and are rented using a smartphone. The typical price for scooter rental in 2018 was $1 to unlock and 15¢/per minute. These scooters are most similar to shared bike systems such as the CitiBike system in NYC, Divvy bikes in Chicago, or NiceRide bikes in Minneapolis and St. Paul. However, there are significant differences between docked bikeshare and electronic scooter share, most significantly the vehicle used and the spatial availability of the vehicles.

Given the very recent introduction of shared electric scooters in the summer of 2018, there is a lack of research on the impact that these scooters have on the transportation system of a city. Shared electric scooter companies argue that the scooters can reduce the number of car trips taken by providing an attractive alternative. Opponents of the scooters criticize the use of public right-of-way by private for-profit companies as well as the blight and accessibility concerns of having scooters sitting on public right-of-way. There are also a number of safety concerns involving the scooters, which can reach speeds of up to 15 miles per hour. In this context of limited research and differing opinions on the benefits and costs of the electric scooters a patchwork of regulations have developed. These regulations range from a complete ban on electric scooters to policies regulating the number of scooters in a city and where they can be parked, to a hands-off regulatory approach to the scooters [2].

3 Research Context

3.1 Overview

Shared electric scooters were first launched in the summer of 2017 and the number of scooters in cities around the world quickly grew throughout 2018, which is when the first rentable electric dockless scooters appeared in Minneapolis. However, while the vehicle used is novel, the concept of shared mobility solutions within cities is not.

First Generation: *"Free bikes"*

↓

Second Generation: *"Coin-deposit systems"*

↓

Third Generation: *"IT-based systems"*

↓

Fourth Generation *"Demand-responsive / multimodal"* ⟶ **Shared Electric Scooters**

Figure 1: The progression of bikesharing systems. *Adapted from Shaheen et al. "Public Bikesharing and Modal Shift Behavior: A Comparative Study of Early Bikesharing Systems in North America" [27]*

3.2 This history of bikesharing systems

The emergence of dockless shared electric scooters can be viewed as an evolution of bike-sharing programs. The first public bike-sharing program began in Amsterdam in 1965, when 50 bicycles were left unlocked throughout the city for public use. However, the program failed because of rampant theft and damage to the bikes. Second-generation bike-sharing systems were first launched in Copenhagen in 1995 and incorporated fixed docking stations for the bikes as well as a coin-deposit system to discourage theft. However, anonymity continued to present a problem. In 1998, the first third-generation bike sharing system, Vélo à la Carte, launched in Rennes, France. Third-generation bike-sharing programs incorporated advances in technology that allowed the registration and tracking of customers, as well as payment via credit or debit cards to reduce theft. Third-generation bikesharing systems still relied on central docks for storing bikes. Fourth-generation bike-sharing systems further leverage advances in technology to enable dockless fleets of bicycles that can be located and unlocked with a mobile phone. In the context of this four-generation framework described by Shaheen et. al [27], electric scooters can be viewed as an offshoot of fourth-generation bike-sharing systems, as shown in Figure 1. Electric scooters are similar to fourth-generation bike-sharing systems because of the dockless nature of the system, but differ in the type of vehicle used (bicycle vs. scooter).

3.3 Growth of electric scooters

Over the summer of 2018, scooter companies quickly deployed scooters to dozens of cities around the world [12]. The rapid deployment of these scooters was driven by large amounts of funding from venture capital firms. Between the beginning of

2017 and September 2018, venture capital firms invested over 6.3 billion dollars into bike-rental and scooter-rental startups [13], allowing these companies to scale their operations quickly, in marked contrast to existing publicly-funded bike-sharing companies which grew operations slowly over many years.

3.4 Electric scooters in Minneapolis

The first scooters were deployed in Minneapolis and neighboring St. Paul on the morning of July 10th, 2018 by the company Bird Rides, Inc [8]. The arrival of the scooters was unexpected and both cities rushed to put policies in place around their usage. The Minneapolis City Council approved a resolution on July 24th developing a pilot licensing program for shared scooter operators within the city [17]. The pilot program ran for 144 days. The pilot program set the maximum number of scooters at 200 for the first two months of the program, after which it could be increased to 400 until the program ended on November 30th, 2018. The University of Minnesota held a concurrent pilot program with 200 scooters [5]. The pilot program in Minneapolis also required operators to pay a fee of $20 per scooter and to share usage data with the city. The requirement that scooter operators share usage data with cities gave rise to the public dataset that this research is built on. However, the topic is subject to contentious debate in the industry [31].

3.5 Key topics and research questions

As discussed in Section 4, the novel nature of dockless scooters and their rapid deployment has created a large research gap. This research seeks to contribute to addressing this gap by focusing on three specific topics related to dockless scooters: Usage, Equity, and Safety.

3.5.1 Usage

The usage of dockless scooters, which describes the context and circumstances in which the scooters are used, is important to understand if the scooters are to become a part of the transportation fabric of the City of Minneapolis. This research focuses on analyzing usage to answer three core questions:

RQ-A1 What types of trips are users using scooters for?

RQ-A2 Are scooters being used as a compliment to public transit?

RQ-A3 Are scooters being used for commuting to jobs?

This section seeks to enhance understanding of how the scooters are used, to drive more informed public policy and innovation among scooter companies and other businesses. Usage was an area of interest (along with equity) identified by the City of Minneapolis when designing the pilot program [29].

3.5.2 Equity

Equity, defined as "fair and just opportunities and outcomes for all people" is a key goal of the City of Minneapolis [18]. This goal influences many types of public policy decisions within the City. When developing the dockless scooter pilot program in July 2018, the City identified "equitable access" as an area of interest that the pilot program would be used to evaluate [29]. This research seeks to use scooter trip data to evaluate the degree to which there was equitable access to dockless scooters during the pilot program.

RQ-B1 Is there a relationship between the household income in an area and the number of scooter rides from that area?

3.5.3 Safety

The safety of dockless scooters is an under-researched topic that is relevant to scooter companies, cities, and scooter users. The goal of this research is to further understand the interactions between road design and scooter usage. Better understanding of how road design impacts scooter usage will help improve safety for those using all modes of transport.

RQ-C1 Is there a relationship between the presence of enhanced bike infrastructure and per-capita scooter ride originations?

4 Literature Review

Because of the recent introduction of shared electric dockless scooters in cities around the world, there is a very limited amount of existing research and theory regarding usage patterns of these vehicles. Due to the limited amount of existing theory in this area, this research attempts to utilize existing methodologies and approaches to build an understanding of the impact of scooters in Minneapolis. The following section first describes existing research measuring the accessibility and equity of transportation systems. The second section summarizes existing research concerning usage patterns of shared bikes, which are the most similar to shared electric dockless scooters.

4.1 Measuring the accessibility and equity of transportation systems

Foth et al. [14] examines the relationship between transit accessibility and social need in Toronto, Canada. The study finds that Toronto has a generally equitable transit system, that is, a system which provides benefits to those who are in social need and stand to gain the most from access to transit [14]. More importantly for this research, Foth introduces a methodology for examining the social equity of transportation systems, as well as defining horizontal and vertical equity. The methodology used first generates a social indicator based on relevant variables. For the case of Toronto these are median household income, percentage of labor force unemployed, percentage of newly immigrated residents, and percentage of households spending more than 30% of income on rent. These social indicators are then compared to two metrics: job accessibility and transit travel time. Job accessibility is defined using a gravity-based measure and finding the travel time to certain types of jobs based on Traffic Analysis Zones (TAZs). Transit travel time is the measure of the estimated amount of time that it would take to commute via transit to actual employers in the area. Comparing these two measures to the social indicator allows the researchers to see whether the transit system is providing benefits to the population that needs it. While this study does not examine shared transportation modes (such as docked/ dockless bikes), the methodology used to measure the accessibility of transit and compare it to social need could be applied to dockless scooters. Garrett and Taylor's paper Reconsidering Social Equity in Public Transit [15] provides a theoretical context for analyzing the equity of transportation investment and analyzes recent changes in transit ridership and trends in US policy. Garrett and Taylor reference Norman Krumholz's definition of equity planning as "an effort to provide more choices to those residents who have few, if any, choices." The researchers then describe how the proportion of low-income transit riders has increased over the past few decades as individuals with medium and high incomes have moved towards using cars, encouraged by large public investment in road networks, low gasoline prices, and falling car costs. Following these trends, transit agencies have focused investments on providing alternatives to single-occupancy car usage for suburban commuters, rather than on improving transit offerings for inner-city transit-dependent users. The authors argue that this lack of investment has decreased job accessibility and exacerbated social and economic isolation in low-income areas. It is in this context of American cities that shared electronic scooter operators are beginning operations, often advertising a commitment to inclusive transportation options [16]. To date, no research has examined whether electronic scooters are a realistic choice "for those residents who have few, if any, choices", to quote Norman Krumholz.

4.1.1 Usage patterns of legacy bike-sharing systems

Electric scooters became widely available in US cities in the beginning of 2018 and as of early 2019 there is very little research into the usage patterns of these shared vehicles. However, similar shared systems that utilize docked bikes have been widely available for over 10 years in a variety of cities and have been studied extensively. It is unclear whether the findings from these studies are generalizable to shared electronic scooters, but existing research provides methodologies that can be used to examine the usage of the new vehicles.

Vogel et al. uses data mining techniques to explore trip-level data from the bike-sharing system in Vienna, Austria [30]. The researchers hypothesized that the locations of the stations affected the demand for bikes and the number of users. The researchers tested this hypothesis by using clustering algorithms to identify clusters of locations based on their usage. Cluster analysis found that these clusters were statistically significant, supporting their hypothesis that usage is a function of location. This research proposes a clustering methodology for analyzing bike-share systems, as well as examining general patterns of bikeshare over different timespans. The research also discusses redistribution systems for bikes, to move bikes from places of low demand to places of high demand. The free-floating nature of shared electronic scooters will likely impact the ways in which they are used and increase the diversity of destinations, because there is not a dock that they must be returned to after they are used.

Martin & Shaheen (2014) examines the modal shift dynamics, or changes in the modes of transport people use, as a result of the availability of public bikesharing systems in two cities, Minneapolis, MN and Washington, D.C [28]. This was one of the first studies to specifically examine the impact of bikesharing on the usage of public transit. Martin & Shaheen (2014) found that the presence of bikesharing had differing effects on the usage of rail transportation in the two cities. In Minneapolis, bikesharing systems led to an increase in rail usage (14.7%). However, in Washington, D.C. the opposite was true; bikesharing systems led to a decrease in usage of rail (47.4%).

These findings were based on surveys given to 903 bikeshare users in Minneapolis and 4853 bikeshare users in Washington D.C. Martin & Shaheen (2014) theorized that the differences in rail usage from bikesharing in the two cities can be explained by the layout of each cities' transit system. In cities with lower density and very linear rail networks like Minneapolis, Martin & Shaheen (2014) suggest that bikesharing is functioning as a last-mile facilitator which helps get people to and from rail stations and neighborhoods. However, in more dense cities with intensive rail networks such as Washington D.C. bike-sharing systems may be replacing short rail trips entirely, leading to a decline in the use of rail. The study looked exclusively at dock-based bike sharing systems. This paper will extend this research by examining the patterns of usage in dockless shared electric scooters and how these vehicles could function as a last-mile facilitator because they can uniquely provide door-to-door trips. In this paper, Campbell and Brakewood examine the impact of the introduction of the Citi bike-sharing program on bus ridership in New York City [11]. The researchers utilize a difference-in-differences model similar to the methodology used by Babar & Gordon, using the staged rollout of the bike-sharing docks in New York City as a natural experiment. The researchers hypothesized that bus ridership would decrease in areas where the Citi bike-sharing system is available, because riders would choose to bike instead of riding the bus. The researchers found that the availability of shared bikes decreases bus ridership on nearby routes by 2.42%. However, when they controlled for the amount of bike-friendly infrastructure the impact on bus ridership was lower, at 1.67%, suggesting that some of the decrease in bus ridership can be attributed to improvements made to bike lanes, not the availability of the bike-sharing system itself. The researchers also raise the issue of the indirect effect of bike sharing on non-members behavior. As this study demonstrates, it is important to consider the potential substitute or complementary relationship between shared mobility services and public transit when considering the impact of shared electric scooter use on transportation accessibility.

As shown, there is existing research and theory regarding measuring equity in transportation systems and in the movement of bikes in legacy bike-sharing systems. However, due to the novel nature of shared electronic scooters there has not been any research examining patterns of usage or impact on equitable access for transportation. Given that there in an increased interest among city planners in designing equitable cities and that shared electric scooter operators often require permission from cities to utilize public right-of-way for the storage of available scooters, the impact of scooters on transportation equity is a pressing question. This paper will attempt to address this issue.

5 Methodology and Data

5.1 Data sources

5.1.1 Scooter ride data

The primary data for this research is a dataset with ride-level information on the 225,543 scooter rides that were taken in Minneapolis during the pilot period (July 10th - November 30th). The dataset was assembled by the City of Minneapolis from data provided by the two scooter companies operating within the City during the pilot period: Bird and Lime. The dataset [22] was released publicly on March 3rd 2019. The dataset contains the following information about each ride:

- TripID: a unique identifier for each trip created by the City of Minneapolis
- TripDuration: trip time in seconds
- TripDistance: trip distance in meters
- StartTime: time the trip started, rounded to the nearest half hour
- EndTime: time the trip ended, rounded to the nearest half hour
- StartCenterlineID: the street centerline GBSID the trip started on [20]
- EndCenterlineID: the street centerline GBSID the trip ended on [20]

The City of Minneapolis used an anonymization process to remove personally identifiable information from the dataset before release. This process involved rounding the StartTime and EndTime to the closest half-hour at the quarter hour and pinning the start and end location to the closest street centerline. The full data processing methodology is available from the City of Minneapolis [21].

5.1.2 Binning methodology

A hexagonal grid covering Minneapolis was developed and used for binning the rides. The grid (Figure 2) consists of 854 identically-sized hexagons, each with an area of $.19km^2$ ($.073miles^2$ or 46.97 acres).

A hexagonal grid was used for the aggregation because hexagonal grids are advantageous for analysis of nearest neighbor and movement paths compared to rectangular grids [7]. The data was aggregated into bins rather than using existing TAZ

Hex zones overlaid on a map of Minneapolis

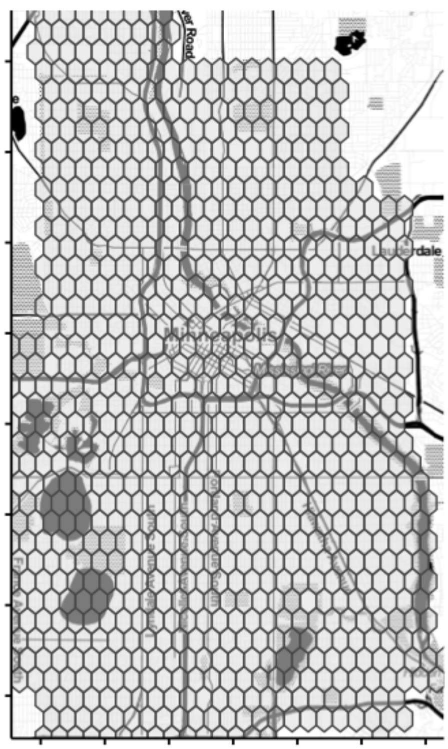

Figure 2: Hexagonal bins used for analysis, overlaid on a map of Minneapolis

data because the hex bins offer increased spatial resolution, meaning that fewer trips start and end in the same bin, as shown in Table 1.

Using TAZ	.193
Using Hex Bins	.156

Table 1: Proportion of trips starting and ending in the same geographic entity

In addition, the hex bins are more intuitive in the context of micromobility vehicles such as scooters when compared to TAZ, which are designed for automobile-centric analysis [10].

5.1.3 Street centerline data

The scooter ride data released by the City included the GBSID of the nearest street centerline for the start and end of the trip rather than geographic coordinates. To allow for geographic analysis, these centerline GBSIDs must be matched with the corresponding geographic features. A dataset describing the geometry of streets within Minneapolis [20] was used for matching. The file was downloaded in Shapefile (.shp) format.

5.1.4 Household income data

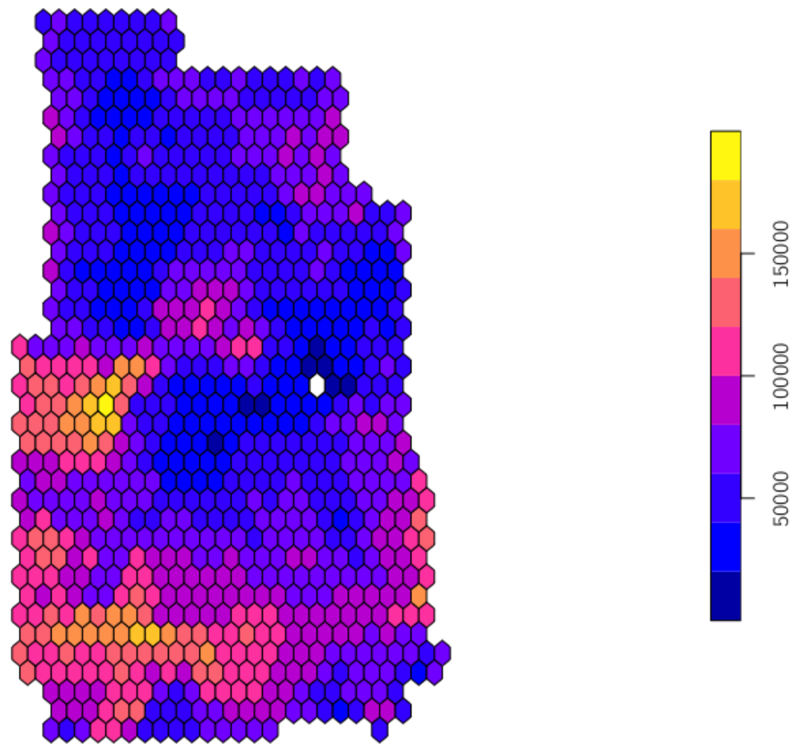

Figure 3: Average income by hex zone

To allow for analysis of the equity of the pilot program (as described in 1.2), average block-level household income data from the 5 year 2013-2017 American Communities Survey [3] was used. This data was spatially aggregated to hex zones by using extensive areal interpolation [24]. The resulting average income by hex zone can be seen in Figure 3

5.1.5 Population data

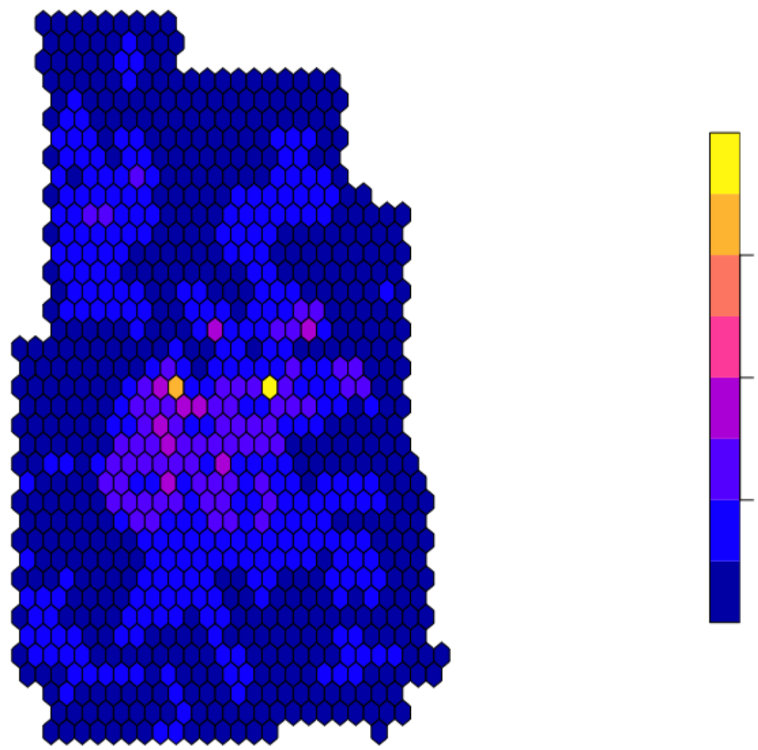

Figure 4: Population by hex zone

To allow for analysis based on the differing populations of each hex zone, block-level population data from the 5 year 2013-2017 American Communities Survey was used [3]. This data was spatially aggregated to hex zones by using extensive areal interpolation [24]. The resulting population by hex zone can be seen in Figure 4.

5.1.6 Student data

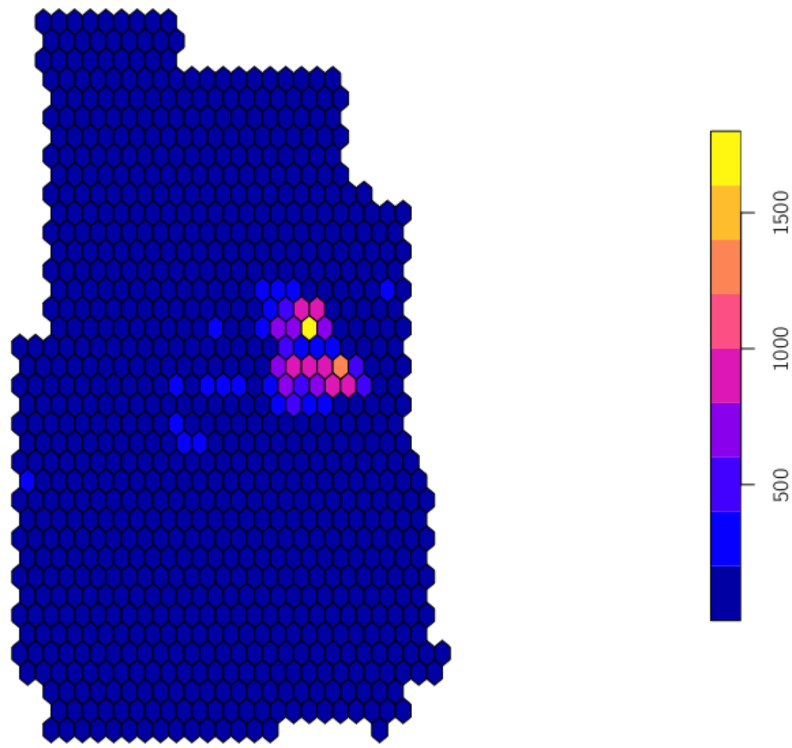

Figure 5: Student population by hex zone

To allow for analysis based on the differing number of college students residing within each hex zone, block-level student population data from the 5 year 2013-2017 American Communities Survey was used [3]. This data was spatially aggregated to hex zones by using extensive areal interpolation [24], using the same methodology as the population data. The resulting student population by hex zone can be seen in Figure 5. It is clear that students are tightly clustered near the campus of the University of Minnesota.

5.1.7 Bike infrastructure data

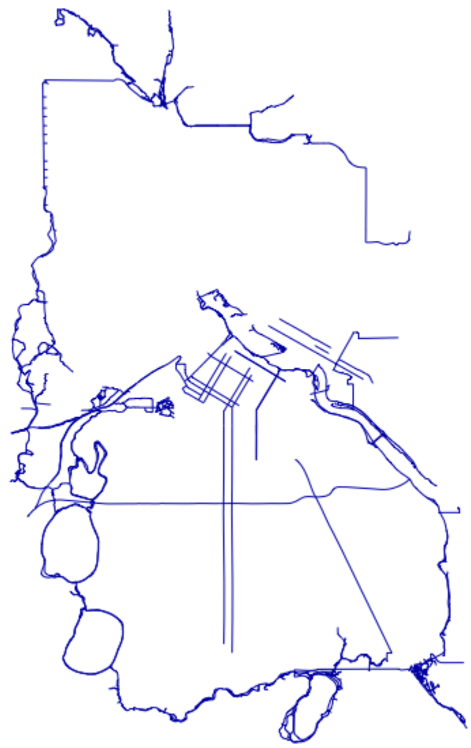

Figure 6: Bike infrastructure in Minneapolis

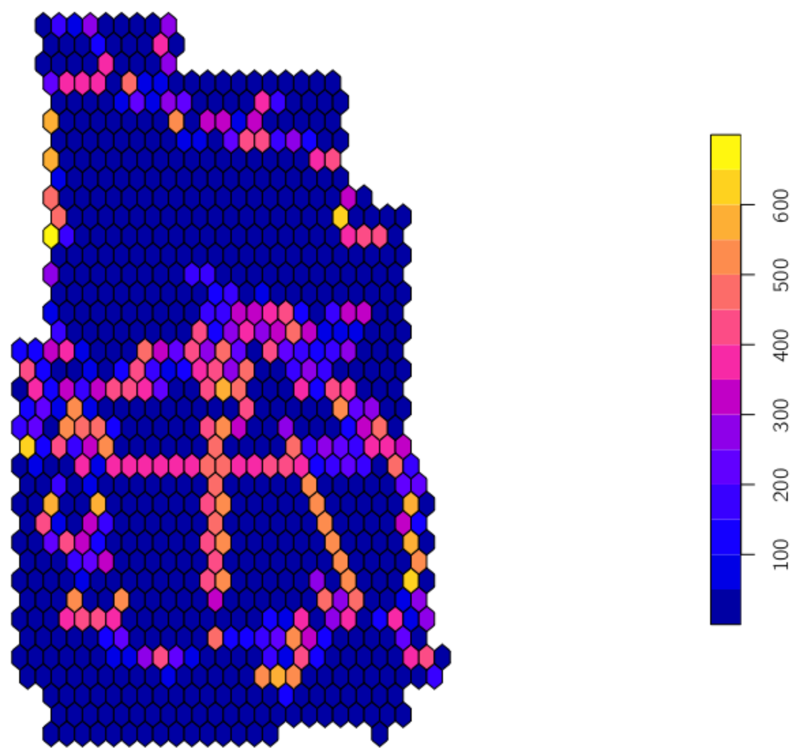

Figure 7: Amount of bike infrastructure by hex zone

Data about the network of enhanced bike infrastructure in Minneapolis [19] was used to model the effects of the infrastructure on scooter usage. Enhanced bike infrastructure is generally defined as bike lanes which are physically separated from car traffic, but the dataset may include some on-road marked bike lanes. It does not include all striped on-road bike lanes but does include bike lanes with plastic pylon separators. Visualizations of the enhanced bike infrastructure and infrastructure by hex zone can be seen in Figure 6 and Figure 7

5.1.8 Minneapolis zoning data

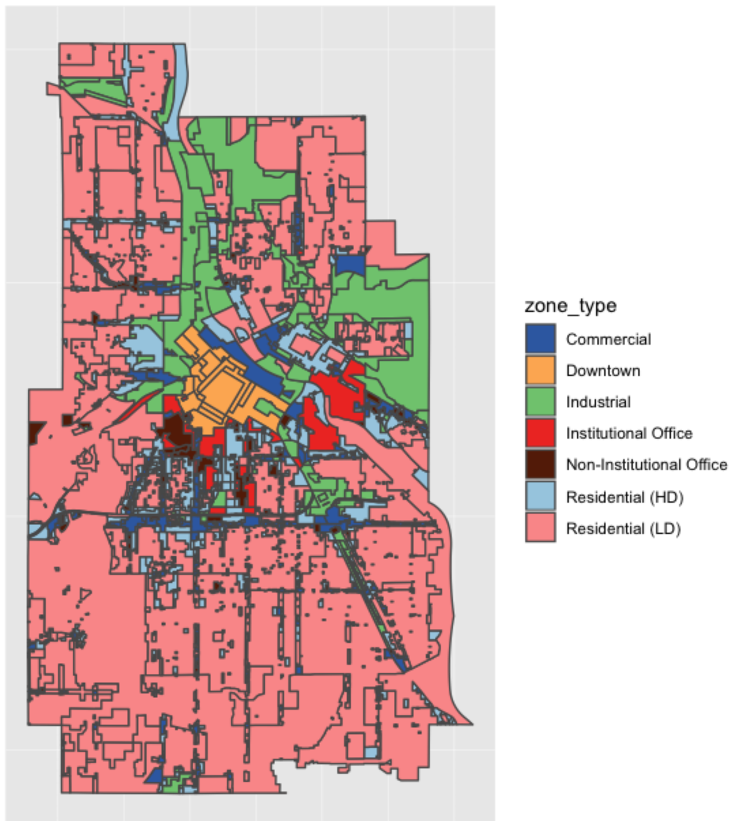

Figure 8: Zoning in Minneapolis

Data about zoning information in Minneapolis [6] was used to determine the character and type of areas where scooter rides began and ended. The City of Minneapolis Zoning Code defines 23 different zoning types [1]. For the purposes of this research, the 23 categories were aggregated to the following 7 categories:

- Commercial
- Downtown
- Industrial
- Residential (Low Density)

- Residential (High Density)
- Institutional Office
- Non-Institutional Office

Visualizations of the zoning in Minneapolis can be seen in Figure 8.

5.1.9 Minneapolis transit location data

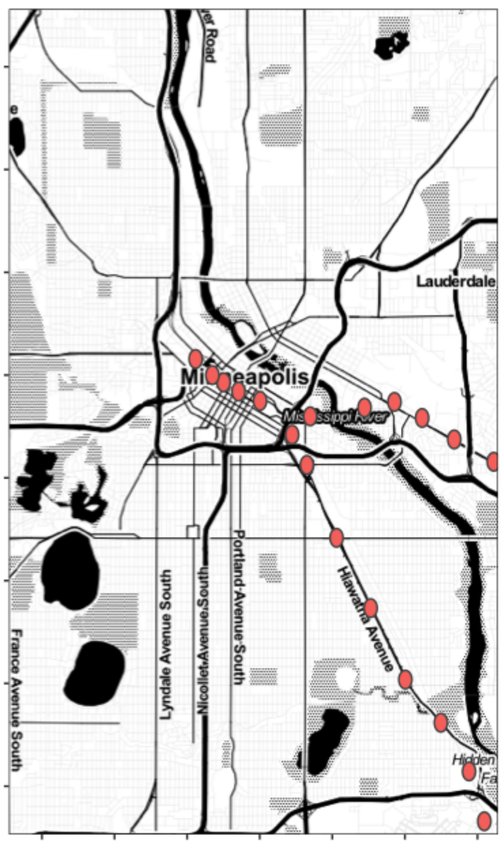

Figure 9: Locations of light-rail stations in Minneapolis, with 200m radius buffer

Data about the locations of light-rail stations in Minneapolis [6] was used to determine whether a given scooter ride began or ended within close proximity to transit. The Twin Cities area has two light-rail lines. 19 stations on these lines fall within the City of Minneapolis (Figure 9).

5.1.10 Technologies used for analysis

All analysis was conducted using the statistical computing language R [25]. The Simple Features (sf) library [23] for R was used extensively for analysis of spatial vector data. The code for all of the analyses described in this paper is available in a GitHub respository: https://github.com/carstonhernke/dockless-scooter-analysis.

6 Analysis and Results

6.1 Usage

6.1.1 RQ-A1: What types of trips are users using scooters for?

The purpose of a trip is a function of both the origin location type and the destination location type. A spatial dataset describing zoning in Minneapolis (Described in Section 5.1.8) was used to assign the origin point and destination point of each scooter ride to one of 7 usage categories (described in Data Sources). This approach was derived from research done by Schonfelder and Samaga (2003) [26] The unique combinations of these 7 categories result in 49 possible trip types. Ride counts were then aggregated based on the trip type, resulting in a vector of length 49 representing the frequency of each trip type (Appendix A). An alluvial diagram was then generated to visualize these relationships 2.

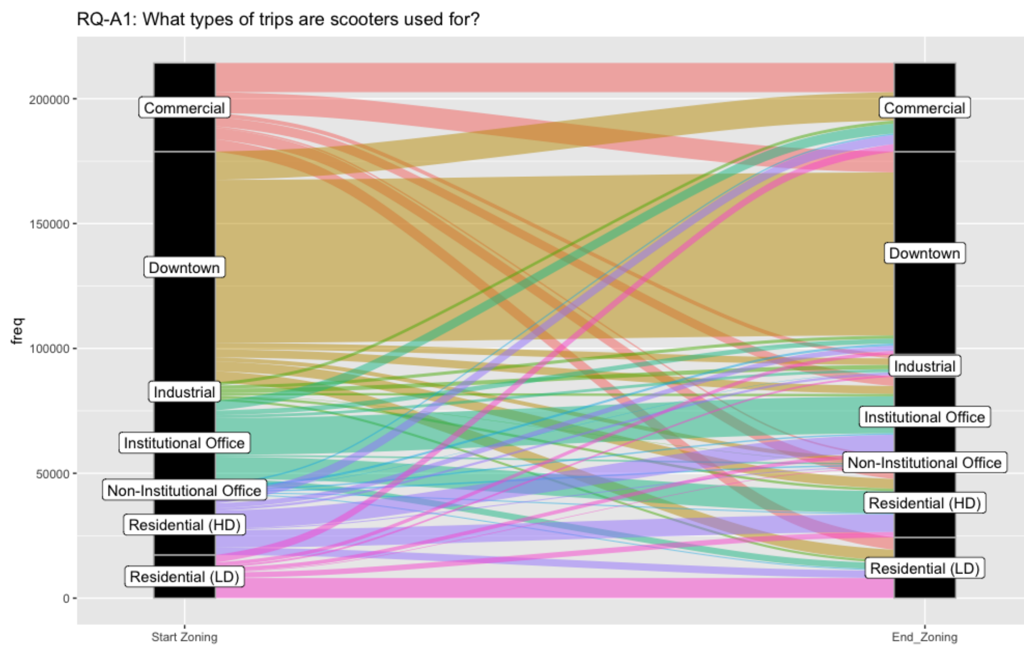

Figure 10: Trip frequency by origin and destination type

Start Zone Type	Frequency	Proportion
Downtown	92451	0.43
Commercial	35472	0.17
Institutional Office	33737	0.16
Residential (HD)	24238	0.11
Residential (LD)	17314	0.08
Industrial	7289	0.03
Non-Institutional Office	3818	0.02

Table 2: Frequency of Start Zone Type

The majority of scooter rides (43%) begin in downtown Minneapolis, followed by 19% in residential areas (low and high density combined), and 17% in commercial areas, and 16% in Institutional Office areas, which includes university campuses. The data shows that 30% of rides both begin and end in Downtown and 7% of rides both begin and end in Institutional Office areas. The dataset used for this analysis is limited and does not contain the starting location for each scooter or availbility data for scooters not in use. Thus, it is not possible to determine whether increased observed usage of scooters in certain areas of the city is due to a higher demand for the service or is purely a function of higher number of scooters deployed in these areas.

6.1.2 RQ-A2: Are scooters being used as a compliment to public transit?

Many groups, including the Institute for Transporation and Development Policy, believe that scooters can provide a compelling solution to the last mile problem frequently faced by public transit systems [4]. To examine the degree to which scooters are being used as a compliment to public transit, a geospatial dataset describing all of the light-rail stations in Minneapolis was used (Described in Section 5.1.9). This data was enriched by creating a 200 meter buffer around each station's coordinates, which represents a reasonable walking distance from scooter to station or vice-versa.

Relationship to Transit
1. No Transit
2. Start Near Transit
3. End Near Transit
4. Start and End Near Transit

Table 3: Categories describing a scooter trip's relationship to transit

The ride data was then compared to the transit location data, and each ride's start and end location was tested to determine whether it was located inside any of the buffer zones. Each trip was then tagged with one of four categories (Table 3). Aggregation was then conducted to identify the proportion of trips that fell into each of the four categories.

Transit Usage Category	Frequency	Proportion
1. No Transit	123301	0.80
2. Start Near Transit	14560	0.09
3. End Near Transit	12957	0.08
4. Start and End Near Transit	3341	0.02

Table 4: Frequency of transit usage category, ordered by decreasing frequency

Table 4 shows the proportion of trips that fall into each of the four transit categories. 19% of rides start, end, or both start and end near transit.

This analysis is limited by the method used to infer the relationship to transit. Because many of the light-rail stations in Minneapolis are close to other points of interest, specifically downtown Minneapolis and the University of Minnesota campus,

Start Zone	End Zone	Derived Commute Type
Residential (LD) OR Residential (HD)	Downtown OR Industrial OR Institutional Office OR Non-Institutional Office	Journey to Work
Downtown OR Industrial OR Institutional Office OR Non-Institutional Office	Residential (LD) OR Residential (HD)	Journey from Work
All Others	All Others	FALSE

Table 5: Logic used to determine whether a trip is a commute

it is difficult to ascertain whether the scooter rider took the scooter to the transit station specifically or to a nearby point of interest. This limitation likely has the effect of overestimating the number of scooter trips that involve transit.

Scooters are often characterized as a solution to the last mile problem [4]. The finding that 19% of scooter rides occur near light rail stations supports the claim that scooters and light rail are often used together. However, it is impossible to claim that the presence of scooters caused light rail rides to occur that would not have otherwise. It is possible that a modal shift from biking or walking to scooters occured among regular transit riders. Further research could use public transit ridership data to attempt to elucidate the relationship between the presence of scooters and public transit ridership. This research could inform strategies, including public-private partnerships, to utilize scooters to increase public transit ridership.

6.1.3 RQ-A3: Are scooters being used to commute?

Commuting is defined by the US Census Bureau as a worker's journey from home to work [9]. To determine whether scooters are commonly used for commuting, two metrics were calculated: The proportion of rides that fit the pattern of a *Journey to Work* and the proportion of rides that fit the pattern of a *Journey from Work*. The logic used to determine whether a given trip fits into one of these categories is given in Table 5. Similar metrics for weekend trips were calculated and used as a baseline. Evidence of commuting behavior using scooters would be manifested by an increased proportion of trips with commuter characteristics on weekdays when compared to weekends.

Scooters are not frequently used for commuting. The proportion of trips that fit a

Day Type	Non Commute Proportion	Commute Proportion
Weekend	0.84	0.16
Weekday	0.82	0.18

Table 6: Proportion of commuting trips, by type of day

commuting pattern is shown in Table 6. The proportion of commuting-pattern trips on weekdays is approximately 2% higher than on weekends, indicating that there is a small number of trips that are truly journeys to work, rather than incidental trips in and out of residential areas.

Examining the proportion of trips that fit the patterns of a commute throughout the day can yield additional insight into how scooters are used to get between home and work. Figure 11 shows the proportion of weekday and weekend trips that fit the pattern of a commute throughout the day. The chart shows that the proportion of weekday trips categorized as *Journey to Work* remains relatively steady throughout the day, while the proportion of trips categorized as *Journey from Work* increases from approximately 11:00 to 19:00. The proportion of trips categorized as *Journey to Work* is similar on both weekdays and weekends, however, the proportion of trips in the *Journey from Work* category is slightly higher on weekdays, especially in the afternoon. This indicates a non-zero number of scooters are used for commuting, more frequently in the afternoon, or *Journey from Work* part of the commute.

A significant limitation of the scooter trip dataset is the lack of a unique identifier for each scooter. Without this identifier, it is impossible to examine how the placement of scooters in the morning affects the usage of scooters for commuting. The number of rides taken from an origin location is a function of both the latent demand for tranportation in the origin location and the availability of scooters in the area. It is possible that there is a high demand for scooters to be used for the *Journey to Work* but scooters were are not commonly deployed in these areas, causing a lack of trips taken. Thus, the findings presented here should be interpreted as descriptive of behavior during the pilot period and not necessarily representative of underlying demand factors.

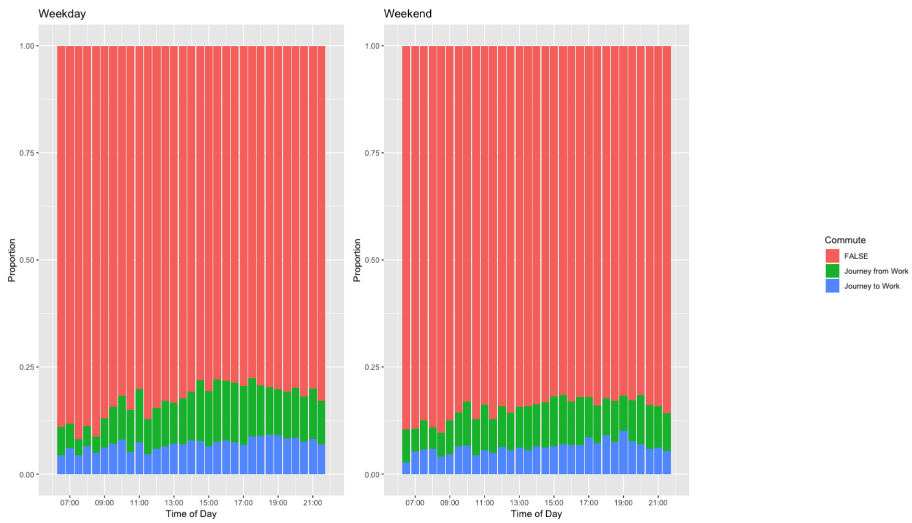

Figure 11: Proportion of weekday and weekend trips that are commutes, by time of day

6.2 Equity

6.2.1 RQ-B1: Is there a relationship between the household income in an area and the number of scooter rides from that area?

To examine whether there is a relationship between the household income of an area and the number of scooter rides from an area, aggregated household income data from the American Communities Survey (described in Section 5.1.4) was used. Counts of scooter ride originations in each hex zone were also calculated. Because the hex zones differ significantly in population (Section 5.1.5), these counts were then transformed to per-capita counts by using aggregated population data by hex zone (described in Section 5.1.5). Figure 12 shows the per-capita ride originations by hex zone.

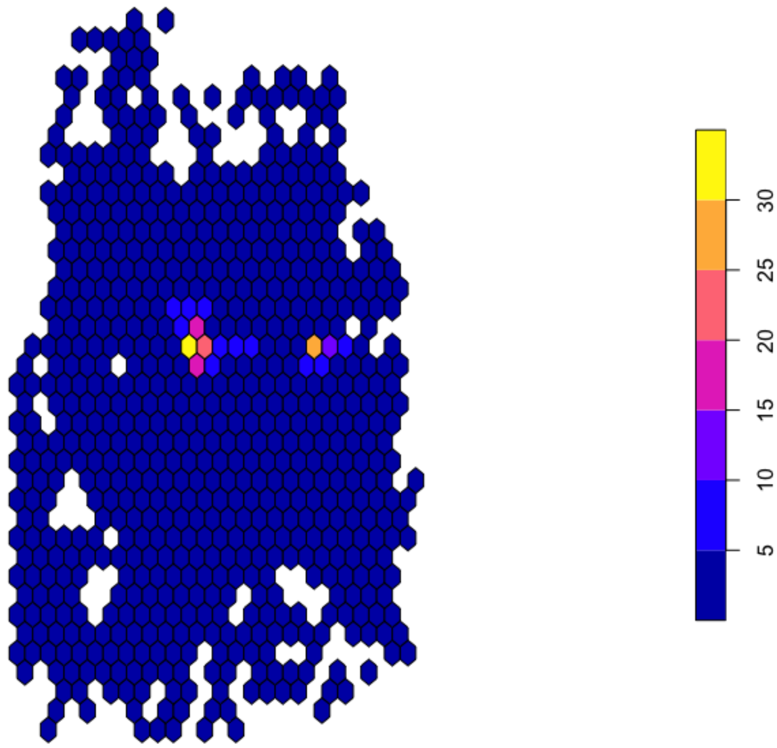

Figure 12: Per-capita ride originations by hex zone

The aggregated household income data was then joined to the per-capita number of scooter ride originations by using the unique ID of the Hex Zone. The relationship between the household income of a hex zone and the per-capita number of scooter ride originations was then analyzed by creating a scatterplot and fitting a linear model to the data.

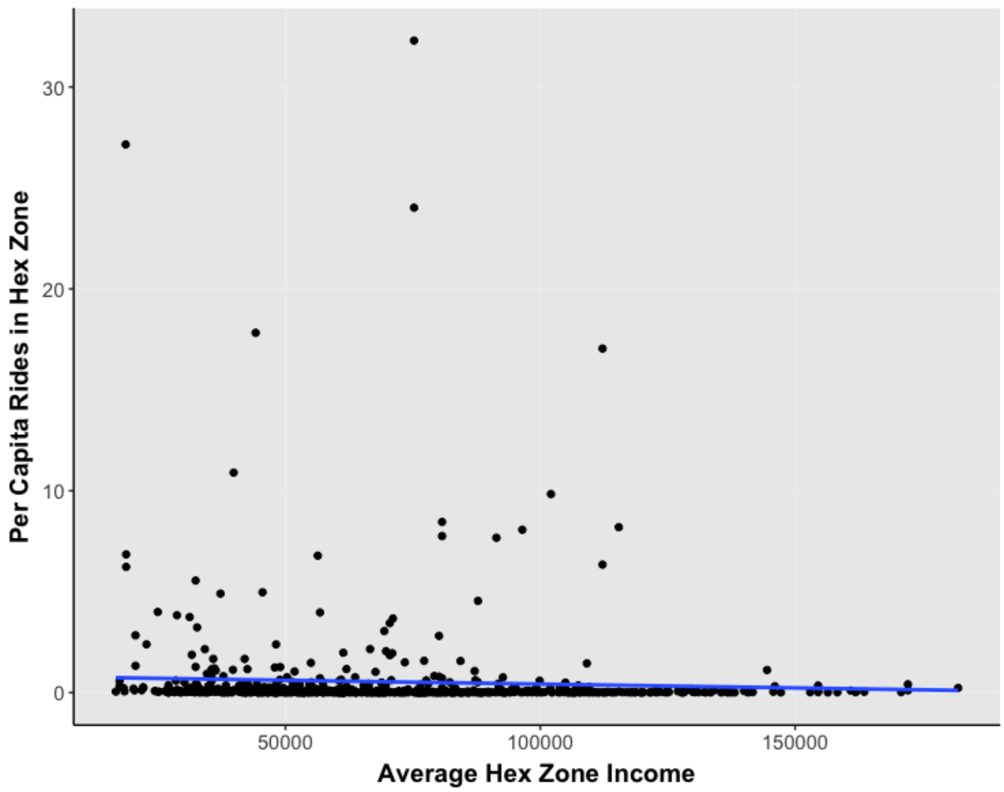

Figure 13: Scatterplot showing household income and per-capita scooter trip originations for each hex zone

Figure 13 shows the relationship between household income within a hex zone and the per-capita scooter trip originations in that zone. There is a slight negative correlation between household income and trip originations, indicating that scooter trips are slightly more likely to begin in lower-income areas of the city. This analysis does not show evidence of widespread inequities in scooter availability. However, limitations in the available data prevent more detailed analysis. The scooter data released by the city contains no demographic information on the rider for each trip. Without this data, the household income of the hex zone where the ride began is used as a proxy for the household income of the rider. This methodology prevents granular analysis, especially in high-density hex zones where there may be a distribution of income levels. The distribution locations of scooters by scooter companies also drives the places where rides begin. There may be a higher level of demand for scooters in a certain area of the city, but unless scooter companies realize this demand and selectively deploy scooters in that area, this demand will not be manifested in the data.

6.3 Safety

6.3.1 RQ-C1: Is there a relationship between the presence of enhanced bike infrastructure and per-capita scooter ride originations?

Minneapolis has over 260 kilometers of enhanced bike infrastructure. Spatial data representing these paths (Described in Section 5.1.7) was acquired from the City of Minneapolis and combined with the hex zones, to produce the kilometers of enhanced bike infrastructure within each zone. The average zone has .099 kilometers of bike infrastructure, with a maximum of .668 and a minimum of 0 kilometers. Because the hex zones differ significantly in population (Section 5.1.5), the per-capita number of scooter ride originations per hex zone was calculated using the population for each zone (Figure 12) The data representing the length of bike infrastructure in each hex zone was joined with the per-capita ride data in each hex zone. The relationship between the kilometers of enhanced bike infrastructure in a zone and the number of trips that began in that zone was then analyzed by creating a scatterplot and fitting a linear model to the data.

There is a very weak relationship between the amount of enhanced bike infrastructure within a hex zone and the average daily number of scooter rides in the zone. A basic linear regression between shows that for every additional kilometer of enhanced bike infrastructure per square kilometer, the average daily number of scooter rides increases by 1.489.

It is plausible that both the number of scooter rides and the amount of bike infrastructure are strongly correlated with a third, confounding variable- population. However, the correlation coefficient between the amount of bike infrastructure and the population of a hex zone is -.0314, suggesting that there is a greater amount of enhanced bike infrastructure in parts of the city with a lower population density.

A weak relationship between the amount of enhanced bike infrastructure and rides suggests that scooter riders' decisions on whether to ride a scooter are not significantly impacted by the presence of enhanced bike infrastructure. Thus, expanding the number of enhanced bike trails in the city with no other policy changes will have a low effect on the number of scooter rides. One hypotheses may explain this observation. The spatial distribution of scooter origin locations is directly related to the places where the scooters are placed after they are charged, so the high number of scooters placed in some hex zones may be able to at least partially explain the high number of ride originations in some of these areas. The specificity of the bike infrastructure data limits the analysis that can be done. The data released publicly does not include some striped bike lanes (bike lanes that are only marked with a painted line on the road), which are one of the most common places where scooters are ridden and the place both scooter companies instruct their customers to ride. The limited quantity of data and the significant left skew of the data (it is more likely for an observation to have fewer rides than many) may also be obscuring a relationship. More specific data about the inventory of different types of low-speed transportation lanes in Minneapolis would allow for an improved analysis.

6.3.2 Discussion

As mentioned, the data suggests that expanding the amount of enhanced bike infrastructure within a hex zone alone will have a low effect on the number of rides started in that zone. These results imply that there are a number of complicated factors that influence a riders' decision to take a scooter versus another mode of transportation. The public policy considerations from this finding are important: cities looking to increase the number of scooter rides and decrease car usage should not expect a policy of just improving bike infrastructure to be successful. The city must understand the impact of a myriad of factors that have not been researched, including the availability of car parking at the destination, the volume of other vehicles currently on the road, the current clothing of the rider, the quality of wayfinding tools, and many others.

6.3.3 Further research

The determinants of scooter mode choice has not been researched significantly. In addition, there is a significant research gap concerning the causes of scooter-related injuries. Scooters are regarded as dangerous by many people, but additional research is needed to see if the perception of the safety of dockless scooters matches the reality. In addition, there is much research into the psychology of risk around bicycling and driving a car, but there is a lack of similar research concerning scooters (cite). Helmets and other safety features are also a large point of contention that is not well-researched yet.

7 Conclusion

This research examined a dataset of over 225,000 scooter rides taken in Minneapolis between September and November 2018 from 3 different dimensions: usage, equity, and safety. An analysis of the ride data shows most rides were taken between downtown destinations and between institutional office locations such as college campuses. The number of scooter ride originations are slightly negatively correlated with household income in the surrounding area, indicating a lack of evidence of inequality in scooter usage. No meaningful relationship was found between the amount of enhanced bike infrastructure and the number of scooter rides in an area. These findings both bring additional insights and raise new questions to policymakers, scooter companies, and scooter users as these stakeholders consider whether and how to incorporate shared electric scooters into the transporation fabric of their communities.

7.1 Discussion

The analysis of the usage of the scooters shows that most rides begin in the downtown area of the city, followed by institutional offices (including university campuses). The plurality of rides that start in these areas end in the same area. This may suggest that individuals view scooters as a simple way to cover distances that would take too long to walk, but don't involve dramatically switching activities. The relative lack of inter-zone travel may be explained by several factors, including a lack of wayfinding and navigation resources for scooter riders, pricing that is not conducive to longer rides, a lack of confidence in the battery life of the scooters, lack of storage capacity on the scooters, and many others.

19% of scooter rides start, end, or start and end within 200m of a Minneapolis transit station. This is significantly higher than the rate that woud be expected for areas of similar size in the city. This suggests that either there is significant demand for scooters to be used as part of a multi-modal transit journey or scooter companies are prioritizing the placement of scooters near transit stations. Further research is needed to determine the true amount of demand for scooters or other forms of last-mile transportation to or from transit. If the former is correct, it is likely that scooters function as a compliment to public transit rather than a substitute. The analysis also revealed that there was limited evidence of people taking the electric scooters to work (Section 6.1.3). Both of these findings are similar and have important public policy implications. If the City of Minneapolis is attempting to increase transit ridership compared to car usage one solution may be to discount or otherwise incentivize scooter rides so that riders can use them to accesss transit stops. Availability of scooters at transit locations is also important. This paper was unable to examine availability of scooters in a given area because their was no unique scooter identifier present in the dataset. However, if transit riders are planning their trip to include a scooter, there must be a scooter available in close proximity to the transit station so that the person does not have to walk a far distance to pick up the scooter. These issues may lead to partnerships between public transit agencies, which are often managed by the government, and private scooter scooter rental companies.

An analysis of the number of scooter ride originations in a hex zone compared to the average household income of the hex zone found a very slight negative correlation, indicating (by this measure alone) equity in the usage of the electric scooters. The analysis is limited by the data available, however. By definition, the location of the scooters in a city drives the availability. Scooter companies and cities currently have control of the location of the scooters at the beginning of each day when they are dropped off after charging. Many cities are experimenting with regulations mandating the placement of a certain proportion of scooters in low-income areas in the morning to ensure equitable access to transporation options. However, scooter companies and cities largely lose control of the locations of the scooters once they are released for the day. After the first ride, the new location of each scooter is a function of the last users' needs. Throughout the day, scooters may cluster to higher-density, higher-wealth areas. This poses problems for regulators and citizens trying to ensure equitable access at all times of the day. However, with real-time data on the location of the scooters, regulators could monitor the distribution of scooters for equity throughout the day. Scooter providers could also redistribute scooters in real-time to comply with regulations, either by incentiving riders to take scooters to a specific part of the city, or by employing individuals to move scooters to underserved areas throughout the day.

As mentioned, the data suggests that expanding the amount of enhanced bike infrastructure within a hex zone alone will have a low effect on the number of rides started in that zone. These results imply that there are a number of complicated factors that influence a riders' decision to take a scooter versus another mode of transportation. The public policy considerations from this finding are important: cities looking to increase the number of scooter rides and decrease car usage should not expect a policy of just improving bike infrastructure to be successful. The city must understand the impact of a myriad of factors that have not been researched, including the availability of car parking at the destination, the volume of other vehicles currently on the road, the current clothing of the rider, the quality of wayfinding tools, and many others.

7.2 Future research

This research relied on observed data about scooter rides. Thus, the findings presented here can only be interpreted as descriptive of behavior during the pilot period and is not necessarily representative of underlying demand factors. To determine where the demand for scooters is highest, an experiment where the placement of the scooters could be modified and the response to these changes could be observed would be required.

Future research could use more granular data to infer the places where rides are starting and ending. This research used zoning maps published by the City of Minneapolis but there are commercially-available point-of-interest (POI) datasets that contain location data and additional metadata for millions of points of interest around the country.

The determinants of scooter mode choice has not been researched significantly. In addition, there is a significant research gap concerning the causes of scooter-related injuries. Scooters are regarded as dangerous by many people, but additional research is needed to see if the perception of the safety of dockless scooters matches the reality. In addition, there is much research into the psychology of risk around bicycling and driving a car, but there is a lack of similar research concerning scooters. Helmets and other safety features are also a large point of contention that is not well-researched yet.

This data utilized interpolated average household income data as a proxy for the socioeconomic status of a rider. Future research could greatly improve accuracy by collecting demographic data for each rider.

The unit economics and profitability of shared electric scooters is a hotly debated question that this research did not seek to examine. Private shared electric scooter operators require access to public right-of-way to operate, which opens the door for significant regulation by cities. Cities must balance the need for regulations on scooter operators to ensure safety and order while still creating an environment where scooter companies may be profitable and offer their service to residents. If a scooter company is unable to be profitable in a market due to regulatory burdens, low demand, or other factors, it will likely leave that market.

Significant future research will be required to fully understand the usage, equity, and safety of shared electric scooters in order to design effective business models, efficient regulations, and safe usage.

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A Appendix: Start and End Combinations

start_zone_type	end_zone_type	freq	pct
Downtown	Downtown	65271	0.30
Institutional Office	Institutional Office	14784	0.07
Commercial	Commercial	11693	0.05
Downtown	Commercial	11351	0.05
Institutional Office	Residential (HD)	8791	0.04
Commercial	Downtown	8336	0.04
Residential (LD)	Residential (LD)	8051	0.04
Residential (HD)	Institutional Office	7278	0.03
Residential (HD)	Residential (HD)	7059	0.03
Commercial	Residential (LD)	4949	0.02
Downtown	Residential (LD)	4517	0.02
Commercial	Residential (HD)	4481	0.02
Institutional Office	Commercial	3935	0.02
Downtown	Residential (HD)	3908	0.02
Commercial	Institutional Office	3738	0.02
Residential (HD)	Commercial	3634	0.02
Downtown	Institutional Office	3153	0.01
Residential (LD)	Commercial	3029	0.01
Residential (HD)	Residential (LD)	2912	0.01
Downtown	Industrial	2612	0.01
Institutional Office	Residential (LD)	2524	0.01
Residential (LD)	Residential (HD)	2165	0.01
Residential (HD)	Downtown	1996	0.01
Institutional Office	Downtown	1919	0.01
Industrial	Industrial	1684	0.01
Downtown	Non-Institutional Office	1639	0.01
Commercial	Industrial	1618	0.01
Residential (LD)	Institutional Office	1556	0.01
Residential (LD)	Downtown	1474	0.01
Industrial	Downtown	1270	0.01
Industrial	Commercial	1251	0.01
Institutional Office	Industrial	1144	0.01
Industrial	Residential (HD)	1021	0.00
Industrial	Institutional Office	964	0.00
Residential (HD)	Industrial	950	0.00
Industrial	Residential (LD)	937	0.00
Non-Institutional Office	Downtown	923	0.00
Residential (LD)	Industrial	755	0.00
Commercial	Non-Institutional Office	657	0.00
Institutional Office	Non-Institutional Office	640	0.00
Non-Institutional Office	Non-Institutional Office	620	0.00
Non-Institutional Office	Commercial	618	0.00
Non-Institutional Office	Institutional Office	593	0.00
Non-Institutional Office	Residential (HD)	456	0.00
Non-Institutional Office	Residential (LD)	435	0.00