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Scooting to a New Era in Active Transportation:Examining the Use and Safety of E-scooters

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THE UNIVERSITY OF UTAH
THE UNIVERSITY OF ARIZONA

Scooting to a New Era in Active Transportation:

Examining the Use and Safety of E-scooters

Final Report

NITC-RR-1281

by

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16. Abstract

The modern transportation paradigm is an ever-shifting target and, most recently, micro-mobility options such as electric shared scooter systems (e-scooters) have been contributing to local municipalities' ability to adapt. Although several agencies have moved towards a "regulate-pilot-evaluate-revise" approach to addressing the transformative technologies of e-scooters, the seemingly overnight proliferation of this new mode in urban areas has brought a great deal of discussion about how this technology is (and should be) used by the consumer. Safety considerations for both e-scooter and conventional transportation mode users is of great concern to planners and decision makers. It is important to understand the characteristics of micro-mobility users to determine the potential impacts of the ubiquitous adoption of this new mode. If users are coming from other modes, or if they are making trips that otherwise would not have been made, this has implications on future demand for active transportation infrastructure.

This study leverages ongoing work at the University of Utah focusing on safety implications of e-scooters and an ongoing collaboration between the University of Arizona and the City of Tucson to monitor a six-month pilot of e-scooters in the Tucson area. This study considers two specific research questions: (1) Are micro-mobility options synergistic, substitutive, or complementary to conventional transportation modes (e.g., biking via personal or shared bicycles, walking, public transit or automobile use) for different trip purposes and activities (e.g., commuting, restaurants, grocery stores, or recreational)? (2) How safely do micro-mobility users interact with other modes in different types of active transportation infrastructure? Wherever possible, we are also interested in understanding whether the use and/or safety implications are disproportionately linked to specific users of the system, or specific trip purposes or activities (and, therefore, land use). From our Salt Lake City data collection, we found that the presence of bike lanes correlates with lower rates of e-scooter riders on pedestrian sidewalks. When light rail is present, sidewalk riding happened at similar rates with and without bike lanes. E-scooter and bicycle users significantly gravitate towards sidewalks on wider roads. Bike lanes (at non-rail intersections) were correlated with an increase in distracted behaviors. In terms of our Tucson survey, older respondents (40-60 years old) were much less likely to have experienced a crash compared with younger riders (<30 years of age). Those who prefer riding on sidewalks were more likely to have experienced a crash of some kind, while those who prefer riding on bike lanes were less likely. As explored in our non-optimal behaviors data collection in Salt Lake City, we observed more riders selecting to ride on the sidewalk when bike lanes were present. However, when riders were near larger roadways, we also observed more sidewalk-riding behavior, even with bike lanes present. This may point to concerns about proximity to vehicles, particularly along faster moving or larger facilities. In any case, the reported use of helmets (21% at least some of the time and 13% while riding) far outweighs our observations in Salt Lake City (2%) or Tucson (2%). A substantial portion of e-scooter riding in Tucson appears to be supporting more recreational travel, including generating more trips for restaurant travel that would not have otherwise happened. E-scooter trips that are substituting for transit travel are more frequent for those with lower incomes or who are older than 30 years of age, but especially for those older than 60 years of age. For transit/e-scooter mode substitutions, income and age matter more than trip purposes or alternative modes available (e.g., more variation explained through demographics). However, trip purpose matters more for e-scooter substitutions with active modes, shared or vehicle modes, or no-trip-taken activities.

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Several additional graduate and undergraduate students helped with the data collection and processing presented within this report from both the Metropolitan Research Center of the University of Utah—including Junsik Kim; Wookjae Yang; Christian Jou; Byron Head; and Romello Warren—and the University of Arizona—Emily Lorenz; Ariel Howell; Dinorah Montano; Safia Francis; Jackson Cassidy; and Alix Huerta.

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DISCLAIMER

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EXECUTIVE SUMMARY

PROJECT PROBLEM AND BACKGROUND

In the past few years, privately operated shared electric scooters (or e-scooters) have taken many cities by storm. Johnson (2019) estimates that 38.5 million e-scooter trips were taken in 2018 in the U.S. As a new form of "micro-mobility," e-scooters have since been praised for addressing last/first-mile concerns; filling a need for short-distance, non-automobile travel; and potentially providing service for transportation disadvantaged neighborhoods. E-scooters have also been reprimanded for issues related to safety and lack of helmet use, occupying precious sidewalk space when parked, and discouraging the use of active or transit modes. In response, many cities have responded either by issuing all-out bans of the new vehicles or by developing and adopting micro-mobility policies, regulations, or permitting requirements to help manage the operation of the new mode in the public right-of-way. This report is a response to the concerns and questions regarding planning for and accommodating e-scooters into the urban landscape. This study considers two specific research questions with implications for both policy and research:

- How safely do micro-mobility users interact with other modes in different types of active transportation infrastructure?
- Are micro-mobility options synergistic, substitutive, or complementary to conventional transportation modes (e.g., biking via personal or shared bicycles, walking, public transit, or automobile use) for different trip purposes and activities (e.g., commuting, restaurants, grocery stores, or recreational)?

Wherever possible, we are also interested in understanding whether the use and/or safety implications are disproportionately linked to specific users of the system, or specific trip purposes or activities (and, therefore, land use).

METHODOLOGY

In this study, we have a two-pronged approach. First, we explore the state-of-knowledge with regards to e-scooter research and policies through a literature review and review of agency regulations (Chapters 2.0 and 3.0).

Second, we explore the (non-) optimal behaviors of e-scooter riders in the real world through systematic observations of behaviors at different intersections and facilities in Salt Lake City UT (Chapter 4.0). We examined how transportation infrastructure—specifically bike lanes, the presence of light rail, and the size of the facility—relates to observations of non-optimal behaviors for different mode users (e-scooters, bicyclists, pedestrians, and drivers). We developed a paired-site analysis to compare similar facilities and observed rates of non-optimal behaviors across different locations, including things such as signal violations, e-scooting/biking on sidewalks or in vehicle lanes, vehicles encroaching on active traveler spaces, and distracted riding/walking. In this part of the study, we have three primary questions:

- Do bike lanes correspond with improvements in optimal behaviors in areas with and without rail transit?

- Does the presence of rail transit correspond with higher rates of non-optimal behavior with and without bike lanes?
- Do larger facilities correspond with higher rates of non-optimal behaviors?

While observations of users and uses can provide useful context about how riders in the field interact dynamically with their environs and infrastructure provided, user surveys can complement these observations with more context about the reasons, preferences, and experiences of e-scooter users. And so, third, we examine a Tucson AZ user survey to explore reported travel and user behaviors as they impact travel demand and safety or crash risk (Chapter 5.0). In this analysis, we first examine the use of e-scooters as a substitutive mode—potentially replacing active travel or vehicle trips, or generating new activities all together—and we explore the reported crash experiences of e-scooter users to inquire whether and which preferences for riding e-scooters impact crash experiences. The survey, conducted in the winter of 2019-2020 (prior to the COVID-19 pandemic), was examined using logistic regression. In this analysis, we estimate mode-substitution models predicting what mode a user would have substituted had e-scooters not been available on their last trip, including "no trip would have been taken," active modes, transit modes, shared modes (including passenger in a vehicle), and vehicle modes. These substitutive transportation modes were estimated as a function of demographics, trip purposes, and alternative mode availabilities. Following, crash experiences were then regressed upon demographics, riding preferences (e.g., on the sidewalk, after dark), and frequency of e-scooter experience. In this analysis, we gain perspective on the relationship between e-scooter use, the uses, and the user. In this analysis, we have two primary questions:

- How are e-scooters substitutes or complements for existing modes? And how does this behavior vary by demographics, trip purposes, and alternative modes available?
- How do crash experiences correspond with (non-)optimal riding preferences, demographics, and e-scooter riding experiences?

FINDINGS

Based on our non-optimal behavior observations, the presence of bike lanes correlates with lower rates of e-scooter riders on pedestrian sidewalks. When light rail is present, sidewalk riding happened at similar rates with and without bike lanes. E-scooter and bicycle users significantly gravitate towards sidewalks on wider roads. Bike lanes (at non-rail intersections) were correlated with an increase in distracted behaviors. In our study, 98% of e-scooter users observed were not wearing helmets, and 8%were riding with two or more passengers per scooter.

In terms of our Tucson survey, older respondents (40-60 years old) were much less likely to have experienced a crash compared with younger riders (<30 years of age). Those who prefer riding on sidewalks were more likely to have experienced a crash of some kind, while those who prefer riding on bike lanes were less likely. As explored in our non-optimal behaviors data collection in Salt Lake City, we observed more riders selecting to ride on the sidewalk when bike lanes were present. However, when riders were near larger roadways, we also observed more sidewalk-riding behavior, even with bike lanes present. This may point to concerns about proximity to vehicles, particularly along faster moving or larger facilities. Overall in Tucson, we see correlations between behaviors determined to be more risk-taking (crossing mid-block, riding in the dark) and crash experiences. Tucson respondents were also less likely to have experienced a crash if they reported riding more than once a week (compared to only once), but that likelihood decreased with more experience riding. In any case, the reported use of helmets (21% at least some of the time and 13% while riding) far outweighs our observations in Salt Lake City (2%) or Tucson (2%) (Appendix A-4).

A substantial portion of e-scooter riding in Tucson appears to be supporting more recreational travel, including generating more trips for restaurant travel that would not have otherwise happened. E-scooter trips that are substituting for transit travel are more frequent for those with lower incomes or who are older than 30 years of age, but especially for those older than 60 years of age. For transit/e-scooter mode substitutions, income and age matter more than trip purposes or alternative modes available (e.g., more variation explained through demographics). For e-scooter substitutions with active modes, shared or vehicle modes, or no-trip-taken activities, trip purpose matters substantially more. Gender does not play a significant role in mode substitutive behaviors based on our Tucson survey analysis.

1.0 INTRODUCTION

1.1 A NEW ERA

In the past few years, privately operated shared electric scooters (or e-scooters) have taken many cities by storm. Johnson (2019) estimates that 38.5 million e-scooter trips were taken in 2018 in the U.S. As a new form of micro-mobility, e-scooters have since been praised for addressing last/first-mile concerns, filling a need for short-distance, non-automobile travel, and potentially providing service for transportation disadvantaged neighborhoods. E-scooters have also been reprimanded for issues related to safety and lack of helmet use, occupying precious sidewalk space when parked, and discouraging the use of active or transit modes. In response, many cities have responded either by issuing all-out bans of the new vehicles or by developing and adopting micro-mobility policies, regulations, or permitting requirements to help manage the operation of the new mode in the public right-of-way. In this study, we explore the use of e-scooters, from both a travel behavior and safety perspective.

1.1.1 Research Objectives and Questions

In the field of transportation research, the study of e-scooters can be valued for the real-time contribution to informing the evolving policies and regulations at city, county, and state levels as well as the ability to directly observe the use and changes in behavior corresponding with the introduction of a new transportation option. This study considers two specific research questions with implications for both policy and research:

- How safely do micro-mobility users interact with other modes in different types of active transportation infrastructure?
- Are micro-mobility options synergistic, substitutive, or complementary to conventional transportation modes (e.g., biking via personal or shared bicycles, walking, public transit, or automobile use) for different trip purposes and activities (e.g., commuting, restaurants, grocery stores, or recreational)?

Wherever possible, we are also interested in understanding whether the use and/or safety implications are disproportionately linked to specific users of the system, or specific trip purposes or activities (and, therefore, land use).

1.1.2 Report Overview

This report includes four main parts. First, Chapter 2.0 provides a literature review, a sweeping glance at recent academic and white paper literature themes. Following, Chapter 3.0 provides a review of agency regulations on shared e-scooter programs. Many of the programs covered in this review were developed prior to e-scooter pilot programs, thus providing a cross section of regulations captured in time. Third, we examine a series of observations in Salt Lake City in Chapter 4.0. In this chapter, we compare differences in (non-)optimal behaviors of e-scooters (e.g., riding on sidewalks) across different intersection configurations. In this chapter, we ask, do bike lanes, road widths, or the presence of light rail make a difference in how e-scooter riders use facilities? Fourth, in Chapter 5.0, we examine a user survey conducted in Tucson for a program evaluation. In this analysis, we explore the modes that users report they substituted for e-scooters and the reported crash experiences. In this analysis, we ask whether Tucson e-scooter trips reduce active travel, generate new trips, or substitute trips in place of vehicle-based travel. We also ask whether the crash experiences of Tucson riders are statistically related to how they prefer to ride (e.g., on sidewalks/bike lanes, after dark). We then explore the lessons and conclusions of this study in Chapter 6.0.

1.1.3 A Comment on this Study and the COVID-19 Pandemic

The COVID-19 pandemic disrupted travel in the U.S. beginning in March 2020, and travel and activity restrictions continued in various ways through 2020 and into 2021. This study began in the Fall of 2019, prior to the pandemic. We recognize that the pandemic has affected travel in numerous ways, including reduced travel (for e-scooter users and other modes) and altered activity patterns (including work, restaurant/shopping behaviors). To clarify, the data studied in this report includes *both* data collected prior to and during the pandemic. The Tucson survey (explored in Chapter 5.0) was conducted prior to the pandemic, as was the review of agency regulations (Chapter 3.0). In both cases, these data provide a comparative resource in pre-pandemic behaviors and regulations.

We conducted the Salt Lake City observations explored in Chapter 4.0 during the pandemic (Fall 2020 and Spring 2021), after e-scooter trips began rebounding. Initial observations of non-optimal behaviors were also conducted in Tucson in January of 2020, prior to the pandemic and travel restrictions in the U.S., to support the Tucson pilot program evaluation. These observations were piloting data collection approaches early on, and while we do not explore these findings in depth in the main body of the report, we do provide these draft reports in the Appendices A-3 Tucson Parking Observation Study and A-4 Tucson User Observation Study.

Authorship Statement
Because this study was conducted over the course of more than a two-year period throughout the pandemic, there were several authors that led different efforts, summarized as chapters, in this report. To acknowledge the role of these individuals and give them appropriate credit, lead authors are recognized at the beginning of each chapter.

2.0 LITERATURE REVIEW

Lead Authors: *Quinton Fitzpatrick; Kristina Currans; Nicole Iroz-Elardo; and Dong-ah Choi*

2.1 OVERVIEW

Since the study of shared micro-mobility programs is an evolving topic, this literature review covers existing research findings and questions from both academic and public resources. While not systematic, this review aims to capture the current state-of-knowledge about e-scooters, their use, safety, operations and management, and other gaps or opportunities not yet covered in the literature.

The review below is organized as follows. First, we explore the users and use of e-scooters to understand who comprises the market for e-scooters, how users and non-users perceive and feel about e-scooters, and how e-scooters are being used. Specifically, this last area of study can be separated into three subsequent research and policy categories: travel or trip characteristics, the potential for e-scooters as vehicle replacements and greenhouse gas (GHG) reducers, and the potential for e-scooters to complement (or substitute for) active and/or public transportation options. Second, we explore the safety implications for e-scooters, which includes evaluating the types of injuries observed and considering the success rates of preventative steps (e.g., regulations and/or public education programs or requirements). Third, we consider the broader findings related to program operations, management, and evaluation of micro-mobility programs and regulations. In this section, we consider the influence on laws, restricted use areas, vehicle requirements and specifications, program operations and management (including parking and ADA compliance), and options to support equitable access to e-scooters. Additionally, we have summarized the limited (but growing) studies on academic and professional program evaluations on the success of regulations. We close this review by considering the gaps in the literature, and opportunities for both research and practice.

2.2 E-SCOOTER USERS AND USE

2.2.1 E-scooter User Demographics and Perceptions

As of October 2019, only one report has published detailed information about e-scooter users. The Portland user survey (2018) captured the uses and travel behaviors of 4,532 e-scooter users—including 3,444 residents and 1,088 out-of-town visitors. The most common characteristics (see Table 1) of Portland e-scooter users were young (85% were between 20 and 49 years old); white (72%); male (61.7%); educated (64.5% held at least a two-year degree); and did not report any type of disability that would restrict their mobility (92%). The nature of the 4.4% of users with reported disabilities can be broken down into four main categories, including: mobility (1.5%), visual (0.26%), hearing (0.32%), and speech (0.32%).

Of the 1,088 respondents who said they were visiting Portland when they used the e-scooters, 22% were visiting for on to two days and 41% were visiting for three to our days, indicating popularity of e-scooters among short-term visitors. These visiting e-scooter users typically identified as white (73%) and male (58%), with 96% reporting no disability (see Table 1).

When comparing e-scooter users who live and work in Portland to demographic averages throughout the city (see Table 2), only 49.6% of Portland residents are between the ages of 20 and 49. By contrast, nearly 85% of scooter users were between 20 and 49 years old. Males are only 49.5% of the population of Portland, but account for 61.7% of surveyed e-scooter users. White residents represent 76.1% of the city population but fall to 72.1% of surveyed e-scooter users, possibly indicating e-scooter users are slightly more diverse. Higher-education degree attainment among Portland residents is 55.2% compared to 64.6% of e-scooter users, suggesting e-scooter users may tend to be more educated. Finally, the median household income of Portland is $61,532; 41.5% of Portland residents have an income above $75,000, higher than the city median, and 35.8% of e-scooter users have incomes above $75,000.

James et al. (2019) identified additional differences in public perceptions of e-scooters between non e-scooter users and users who had ridden e-scooters at least once. Of respondents who had never ridden e-scooters, 76% reported feeling unsafe around them compared to only 24% of users who had ridden at least once. These findings indicate that there may be a significant difference in the perceptions of e-scooters between non-users and users. This trend of perceptions mirrors trends of injuries and comfort levels between riders and non-riders as well (James et al., 2019).

Table 1 Demographics of Resident and Visitor E-scooter Users

Age Range	%	Ethnicity	%	Education level	%	Income Level	%
Resident E-scooter User Responses							
16-20	3.80%	White	72.1%	2-year degree	5.1%	Under $15,000	12.3%
20-29	31.10%	Black or African American	3.2%	College/4-year degree	40.2%	Between $15,000 and $29,999	10.8%
30-39	37.60%	Native American or Alaska Native	2.2%	Master's Degree	14.4%	Between $30,000 and $49,999	19.5%
40-49	17.50%	East/Southeast Asian	6.5%	Doctorate	4.9%	Between $50,000 and $74,999	21.5%
50-59	7.90%	Native Hawaiian, Pacific Islander	2.1%	High School Degree	2.1%	More than $75,000	35.8%
60-69	1.90%	Hispanic, Latino, Spanish Origin	8.3%	Some College	18.7%		
70-79	0.15%			Some High School	2.3%		
80-99	0.04%			Some Post Graduate	5.6%		
				Technical Degree	1.9%		
Visitor E-scooter User Responses							
16-20	4.6%	White	73.2%	2-year degree	4.8%	Under $15,000	12.0%
20-29	39.2%	Black or African American	2.9%	College/4-year degree	40.5%	Between $15,000 and $29,999	9.5%
30-39	32.3%	Native American or Alaska Native	1.7%	Master's Degree	14.7%	Between $30,000 and $49,999	16.9%
40-49	13.1%	East/Southeast Asian	10.0%	Doctorate	5.9%	Between $50,000 and $74,999	19.7%
50-59	8.5%	Native Hawaiian, Pacific Islander	2.7%	High School Degree	7.0%	More than $75,000	41.9%
60-69	2.2%	Hispanic, Latino, Spanish Origin	10.3%	Some College	16.3%		
70-79	0.1%			Some High School	1.6%		
80-99	NA			Some Post Graduate	5.4%		
				Technical Degree	2.7%		

Source: (Portland Bureau of Transportation, 2018); Notes: N=3,444 Portland Residents; N=1,088 Out-of-Town Users ; NA: Not Available

Table 2 E-Scooter User vs. Portland Average Demographics

Attribute (% of Population or Users)	Portland Population	Portland Resident E-scooter Users
White	76.1%	72.1%
Male	49.5%	61.7%
Residents Aged 20-49	49.6%	85.0%
Higher Education Attainment	55.2%	64.6%
Annual Income of $75,000 and Above	41.5%	35.8%

Source: (Portland Bureau of Transportation, 2018; U.S. Census Bureau, 2017)
Notes: N=3,444 Portland Residents

Regardless of the demographics of users, the perceptions of e-scooters tend to be generally positive. In the largest national survey of residents, Populus (2018) surveyed over 7,000 residents (including users and non-users) in 10 cities and found that 70% of respondents had a positive public perception of e-scooters—with a high of 79% in Atlanta, GA, and a low of 52% in San Francisco, CA. At the end of the Portland e-scooter pilot period (2018), 62% of survey respondents (all e-scooter users) viewed e-scooters positively. Perceptions were more positive among respondents under 35, people of color, and those making less than $30,000 per year, at 71%, 74%, and 66%, respectively (see Table 3). The authors suggest that e-scooters might receive more positive perception among younger and lower-income populations because these groups have lower rates of driver's licenses and personal automobile ownership, compared to the general population, and scooters help diversify multimodal transportation options. However, the Portland user survey indicated that while e-scooter users of color tended to view e-scooters more positively than average, respondents also expressed concern over potential discrimination and harassment by law enforcement officials (Portland Bureau of Transportation, 2018).

Table 3 E-scooter Perceptions Among Various Demographic Groups

Demographic	**Positive Perception (%)**
Overall	62%
Respondents identifying as female	72%
Respondents identifying as male	67%
Respondents under 35 years of age	71%
Respondents of Color	74%
Respondents with incomes less than $30,000 per year	66%

Source: (Dill, 2019; Portland Bureau of Transportation, 2018)
Notes: N=4,532

Positive perceptions, however, do not always reflect the use of the e-scooters. While the Portland user survey (Portland Bureau of Transportation, 2018) indicated higher positive perceptions of scooters among females (72%, compared with 67% of male users), Dill (2019) identified that a significant gender gap still exists between female and male users, who account for 34% and 64% of e-scooter trips, respectively.

2.2.2 The Use of E-scooters and its Role as a Transportation Option

There is a general interest in understanding how e-scooters are used in the existing transportation landscape—exploring the types of trips and activities most frequently used and characteristics of those travel experiences—but many studies have explored whether riders use e-scooters as a complement to or a substitute for existing modes. The subtext of these studies examines whether e-scooters can be used to replace certain types of motorized vehicle trips or if they are competitors to some of the more vulnerable modes—such as public transit, bike share, or physically active modes (walking, biking) in general. To first understand the role of e-scooters in the transportation landscape, we address the characteristics of e-scooter trips and travel, as found in the literature and existing studies. We then explore evidence to suggest whether e-scooters act in synergy with vehicle and alternative modes, respectively.

Travel Trip or Use Characteristics

First, we must examine the characteristics of e-scooter use in the U.S. This includes the trip length, trip frequency, and the intention or purpose of the trip (land use or activity). In Portland, the most comprehensive study of an e-scooter pilot program to date saw over 700,000 e-scooter trips during a 120-day period between July and November 2018. Portland estimates that 5,885 scooter trips were taken per day for a total of 801,887 miles traveled by scooter riders during this period. The average e-scooter trip length was between 1.15 and 1.6 miles, with 71% of trips made to reach a specific destination and 28% of trips made for recreational purposes. The top three trip types (excluding recreation) among Portland residents were commuting to or from work (18%), traveling to social or entertainment locations (14%), or traveling to a restaurant (11%). The average trip lasted 19 minutes and cost $3.85. Low-income fares varied, on average, from $1.83 to $2.85 depending on the vendor. Further variations in e-scooter pricing are observed, as Smith and Schwieterman (2018) found that scooters tend to cost riders $1.10 to $1.33 per mile, making them cost effective and competitive compared to cars for short-distance trips between 0.5 and 2 miles (Portland Bureau of Transportation, 2018; Smith & Schwieterman, 2018).

In Indianapolis, IN, an average of 4,380 e-scooter trips was taken per day. Mathew et al. (2019) estimated that the utilization rate of e-scooters in Indianapolis is around 15% during peak hours. A low utilization rate may indicate that there is a serious need to spread e-scooters around to very dense areas, areas with high demand, and areas underserved by other forms of transportation.

A study of e-scooter peak hour timing and use was conducted by Espinoza et al, in Atlanta. E-scooters were heavily used for business-to-business trips, with trips to/from businesses, to/from parking, and trips for recreation filling out the most common e-scooter trips. Afternoon and evening hours between 4 p.m. and 9 p.m. contained the bulk of trips, with few trips occurring earlier in the day by comparison (Espinoza et al., 2019; Mathew et al., 2019).

E-Scooters as a Vehicle Replacement and Greenhouse Gas Reduction Tool

While understanding e-scooter travel characteristics in general is interesting, the larger follow-up research questions investigate how e-scooters fit into the existing transportation landscape. First, agencies are examining the potential use of e-scooters as a policy-lever for reducing overall vehicle miles traveled and, therefore, GHG. In the United States, an estimated 45% of all trips are under three miles long with 78% of those short-range trips made by personal vehicle (Clewlow, 2018). Furthermore, based on National Household Travel Survey data from 2017, an estimated 100,000 million vehicle trips under three miles were taken, totaling roughly 171,000 million vehicle miles traveled. In heavily congested urban areas, Clewlow (2018) found that e-scooter and bicycle trips under three miles are often faster than trips made by car. And from an economic perspective, Smith and Schwieterman (2018) determined that the cost of e-scooters on a per-mile basis makes them optimal for 0.5- to two-mile trips, a distance with the potential to replace a significant portion of short-range vehicle trips.

The short span of many e-scooter trips, as noted in the last section, makes e-scooters a prime candidate for filling a need for short-distance mode options, specifically when they replace automobile travel. In terms of reducing GHG emissions and air pollution, however, the life cycle costs of e-scooters may introduce a more complicated relationship. The authors also provide estimates for carbon equivalents for the materials and manufacturing (excluding use, operations, and maintenance, and considering standard estimates for life span) for the following mode vehicles: personal automobiles (414 g CO_2-eq/mile); shared electric scooters (202 g CO_2-eq/mile); electric bicycles (40 g CO_2-eq/mile); and non-electric bicycles (8 g CO_2-eq/mile) (Hollingsworth et al., 2019).

Aside from the environmental costs and lifespan of e-scooters themselves, the redistribution of e-scooters needed to balance access to technology across urban areas often relies on automobiles, and the impact of charging e-scooters depends on the electricity source(s) of a given area (“green” or conventional). Even if e-scooters replace vehicle trips, considering life cycle costs of e-scooters and corresponding programs, in what circumstances will e-scooters reduce total net GHG emissions? For Hollingsworth, Copeland, and Johnson (2019), current e-scooter programs appear to operate below the necessary effective rates for reducing net GHGs. In a Monte Carlo analysis evaluating life cycle and charging management performance, the authors found that even if e-scooter trips replaced car trips a third of the time (and considering the likely partial substitution of low-energy modes like biking and walking), these programs would still result in a net increase in GHG emissions (Hollingsworth et al., 2019). In order to be carbon-equivalent neutral (or to reduce emissions), the authors indicate three potential paths (and ideally all three): either increase the life span of e-scooters to more than two years each; increase the number of e-scooter trips that replace automobile trips from one-third to one-half; and/or improve the management of e-scooters (including restricting charging for only scooters that need it, optimize redistribution efforts, and encourage redistribution efforts that take advantage of carbon-free energy sources). (Note: Increasing the life span of e-scooters to more than two-years each corresponded with 30% reduction in GHG emissions (from 202 to 141 g CO_2-equivalent per passenger mile).)

Hollingsworth, Copeland, and Johnson (2019) quantified an overall 202g CO_2-equivalent impact per passenger-mile (50% materials and manufacturing; 43% daily charging impact). The authors estimate that redistribution and scooter collection processes could reduce life cycle costs of e-scooters and corresponding programs between 72-87% (discussed further in the section on Redistribution Efforts on page 23). Chester (2019), quoted in Hollingsworth et al. (2019), estimated that the manufacturing and materials, distribution, and charging for e-scooters to be around 320 g CO_2/mile. Hollingsworth et al. refined and extended this analysis through simulation to identify sensitivities corresponding with variations on policy, management, and operations.

An additional life cycle analysis conducted by Moreau et al. arrived at a similar conclusion to Hollingsworth, Copeland, and Johnson. This study found that increasing the lifespan of e-scooters significantly decreases the total GHG emissions per device. By increasing the life cycle of e-scooters to 913 days, or nine and a half months, the kilogram CO2 equivalent per kilometer due to material consumption breaks even with other transportation modes, on average. Increasing the lifespan of e-scooters along with improving redistribution and charging practices can result in significant GHG reductions per vehicle (Moreau et al., 2020).

E-Scooters as a Complement or Substitute for Alternative Modes

While e-scooters provide an attractive potential alternative to automobile travel, many cities and researchers express concern over whether e-scooters might also replace trips made by alternative modes, such as public transit or publicly managed bike share, which could further endanger the viability or use of these already vulnerable modes. Additionally, trip replacements of active transportation in general (biking and walking) could further inhibit active and healthy behaviors in some populations.

For longer transit trips, e-scooters may intuitively help to solve the first mile-last mile problem that often hinders access to public transit systems (Circella et al., 2019; Johnson, 2019). During Portland's pilot program (2018), users indicated if e-scooters had not been available, they would have considered taking the trip using automobiles (19% personal vehicle, 15% ride hailing service); walking (37%) or biking (5%); or using public transit (10%). Eight percent of respondents would not have made the trip at all if a scooter was not available, suggesting that e-scooters may be filling a need for transportation options for short trips. The report did not provide information regarding modal substitution and trip purpose to inform whether e-scooters are more or less substitutable for specific types of travel.

A similar survey of e-scooter users was conducted by James et al. in Rosslyn, VA. Of 181 surveyed riders, 39% of e-scooter trips replaced Uber, Lyft, taxi, and ride sharing trips, 33% for walking trips, 12% for bike trips, 7% for car trips, and 7% for bus and public transit trips. Overall, 52% of surveyed users said they were using ride share services less frequently due to e-scooters (James et al., 2019).

The work on multimodal travel demand models by Smith and Schwieterman (2018) suggest that e-scooters are likely filling a space resulting from limited public transit options in some neighborhoods. The authors indicate that in "parking-constrained environments” e-scooters may help increase the number of non-automobile trips from an estimated 47-75%. If planned and programmed with other alternative modes in mind, e-scooters are likely to be more competitive for trips in which they can arrive no more than two minutes slower than automobile trips. Furthermore, Smith and Schwieterman suggest that, when assuming a six-minute average vehicle parking time, alternative modes of transportation are considered “competitive” if they arrive no more than eight minutes longer than the shortest possible drive time.

While e-scooters are a promising alternative to replacing significant numbers of automobile trips, preliminary observations indicate that e-scooters may be replacing more walking, bicycling, and transit trips than is ideal. Portland (2018) observed that nearly 60% of e-scooter users would have walked, biked, or taken public transit if no e-scooters had been available, compared with approximately 30% who would have taken a vehicle. If scooters are indeed replacing alternative transportation modes at a higher rate than automobile trips, assessing potential drains on vulnerable public and active transportation options are valid concerns. The extent to which e-scooters are pulling users away from alternative forms of transportation is currently unknown and difficult to discern. Further travel surveys and pilot program evaluations—including this ongoing study—may help reveal the rates at which e-scooters are used as substitutes or complements.

2.3 SAFETY, INJURIES, AND PREVENTATIVE STEPS

2.3.1 Safety and Types of Injuries

A more complete review of e-scooter injuries was published in 2021 by Iroz-Elardo and Currans. In this section, we explore themes identified in the literature. Significant increases in the number of e-scooter programs since 2018 have led to concerns for public health and safety. The number of scooter-related injuries has increased substantially as new cities and programs have become established across the U.S. and the world. For example, Badeau et al. (2019) observed only eight scooter-related injuries in a five-month period in 2017 in Salt Lake City compared to 50 during the same period in 2018. Most significantly, Namiri et al. (2020) found that e-scooter-related hospital admissions throughout the United States rose from 4,582 in 2014 to 14,651 in 2018, an increase of 222%. Moreover, many moderate to severe traffic-related injuries have been measured in cities which have implemented e-scooter programs, with a majority of injuries resulting from falling off of the e-scooter. The leading cause of major injuries for e-scooter incidents has been identified as severe head trauma (Lazo, 2019; Mancuso, 2019; Multnomah County Health Department, 2018; National Transport Commission, 2019; Portland Bureau of Transportation, 2018; Siman-Tov et al., 2017) with fractures to extremities also prominent.

Understanding e-scooter safety can be informed by knowledge – including data systems – for bicycle and pedestrian safety. Even though non-motorized modes are at higher risk for injury and death, estimating crash and injury rates for modes other than vehicles has long been a challenge due to variation in definitions, a fractured data collection system, and underreporting (Injury Surveillance Working Group 8 (ISW8), 2017). Transportation-based tracking systems rely on police and ambulance reports, which are often skipped when the only injured party is a cyclist or bicyclist. As a result, the U.S. Centers for Disease Control and Prevention (CDC) reports significantly higher fatality rates for active modes than transportation sources: 6,678 pedestrian deaths in 2015 (CDC, 2017) whereas the U.S. Department of Transportation only reported 5,376 deaths for the same year (National Center for Statistics and Analysis, 2016). The public health system relies on vital statistics for fatalities and health insurance claims codes – the international classification or ICD codes – for injuries. However, collisions or single-party accidents that result in minor injury – for example, bad scrapes and bruises – often skip formal medical attention and thus are also missed in the CDC's system. Further, injury rates of active modes are, by definition, dependent on miles traveled by active modes – a notoriously difficult measure to consistently collect (Goodwin et al., 2013).

Tracking injuries during pilots of e-scooter programs is a unique opportunity to benchmark injury rates *before* private e-scooters become prevalent in a quasi-experimental design where cities can also require vendors to report trips and miles, thus conveniently tracking exposure. However, the sudden increase in e-scooter trips and resulting injuries also means that the standard tracking system with ICD codes in the medical system has not yet been updated for e-scooters. Thus, injury tracking requires creative data mining to track injuries through public health and medical systems. Recently, a few independent studies in the U.S. have been investigating e-scooter-related emergency department visits, discussed below and shown in the summary in Table 4. The two main strategies being used are (1) public health departments leveraging the National Syndromic Surveillance Program (NSSP) (Centers for Disease Control and Prevention, 2019) developed for emergency disease systems to track e-scooter injuries from admissions/discharge data for emergency departments in real time *across* an entire region; and (2) using internal electronic medical records (EMR) data from one or two emergency departments associated with a medical school, which also tend to be the Level 1 Trauma centers for the region. It is important to recognize that while the NSSP approach will capture a slightly wider range of injury types by including cases that utilized a low-level emergency room and, in some states, urgent care facilities associated with hospitals, both approaches do not capture cases of only minor injuries that do not rise to the level of needing medical assistance in an emergency setting.

At least two public health departments have used the NSSP to track e-scooter injuries: (Austin Public Health, 2019; Multnomah County Health Department, 2018). During the Portland pilot—when more than 700,000 e-scooter trips were made—the Multnomah County Health Department (2018) identified 176 emergency department visits (approximately 5% of the 3,220 transportation-related ER visits) or visits to urgent care facilities associated with a hospital system directly related to e-scooter injuries, with as many as 20 visits per week. The health department used NSSP to search emergency room admissions and discharge notes and, to a lesser extent, urgent care clinic visits for the word "scooter" in the record; results for patients older than 16 years that were not obvious mobility scooter injuries were then included. Of the 176 reported injuries, 13% had required an ambulance trip, 7% resulted in a concussion diagnosis; there were no recorded e-scooter-related fatalities during this period compared to 14 traffic-crash-related deaths. Minor-to-moderate superficial injuries to the extremities were the most common cases presented. Additionally, ER staff estimated that twice as many ER visits occurred due to bicycle-related injuries were recorded during the same period (Multnomah County Health Department, 2018). This report estimated approximately 2.2 e-scooter injuries resulting in an emergency or urgent care visit per 10,000 miles traveled (Multnomah County Health Department, 2018).

The CDC supported Austin Public Health to conduct a similar study between September and November 2018. The 87-day study period evaluated the injuries sustained by 190 e-scooter users—14% of all patients were hospitalized with a variety of major injuries, as reported in Table 4. The Austin study is unique in that it also included follow-up interviews, providing insight into some risk factors. Less than 1% of those injured wore a helmet while 29% reported using alcohol in the previous 12 hours of the crash. Perhaps more concerning, 33% of those injured reported it was their very first ride; 37% thought excessive speed contributed to the crash (Austin Public Health, 2019). This report estimates that approximately 20 individuals were injured per 100,000 e-scooter trips during the three-month study period.

NSSP data is only available to public health agencies. At least three additional studies have been published by reviewing the electronic medical records of emergency rooms associated with medical schools: Salt Lake City, UT; Los Angeles, CA; and a pooling of data from San Diego, CA and Austin, TX. In general, data from these types of emergency departments—many of which serve as a region's trauma center—likely skews towards serious injuries. Still, certain themes emerge. Those seeking care for an e-scooter injury are not wearing helmets, often intoxicated, and likely to sustain head injuries and fractures.

When looking across all five studies, additional themes emerge. The vast majority (upwards of 80%) of injuries are individuals falling off the e-scooter; it appears that collisions with vehicles represent another 10% and that the remaining crashes are with stationary objects. Very few injuries (generally less than 5%) resulted from collisions between e-scooters and/or between an e-scooter and pedestrian. These types of crashes are being treated differently in each study. If mentioned, they are often excluded from the "cases." Generally, there are less than five per study. See Sikka et al. (2019) for a case study of a pedestrian injured by an e-scooter. Thirteen percent (Multnomah County Health Department, 2018) to 24% (Badeau et al., 2019) arrive at the emergency room via ambulance; this is important because it indicates that data from first responder paramedics will be insufficient. Additionally, at least 40% of those seeking emergency room care are being categorized as moderately serious injuries (Austin Public Health, 2019; Kobayashi et al., 2019). Finally, every study is reporting the distribution of injury type (or body site) differently, making it nearly impossible to pool the data.

Other U.S.-based studies provide more targeted reporting of e-scooter injuries. For example, Trivedi et al. (2019) reports on 52 head and face injuries in the first seven months of e-scooters being available in Dallas; in this emergency room, the 52 patients represented 58% of all e-scooter cases. A similar study is available documenting 13 neurosurgical cases from the first 15 months of e-scooters in D.C. (Schlaff et al., 2019).

The San Francisco Department of Public Health (2019) has also reported on their nine trauma-activated protocol cases in 2018. Sikka et al. (2019) reports on a single case to demonstrate how pedestrians hit by e-scooters are at risk.

Several non-U.S. studies provide insight into comparisons with other modes and helmet use, even if comparisons require caution given differences in medical systems. Siman-Tov et al. (2017, p.) is an early reporting on 63 e-scooter injuries in all Israeli emergency departments. The primary purpose of this study was actually e-bikes and thus the authors abstracted e-bikes and pedestrian injuries at the same time, providing an interesting contrast between the modes. Mitchell et al. (2019) reports on 54 e-scooter injuries during a two-month scooter share pilot in Brisbane, Australia. This particular study reports a uniquely high helmet usage rate (46%) that can be attributed to a legal mandate for helmets; it also clearly shows a statistically significant reduced risk of head injury when wearing a helmet.

Table 4 E-Scooter-Related Studies of Emergency Room Utilization by Cause and Type of Injury in U.S.

Measure Tracked	(MCHD 2018)[1]	(Austin Public Health, 2019)	(Sikka et al., 2019; T. K. Trivedi et al., 2019)	(Badeau et al., 2019)	(Kobayashi et al., 2019)
Study Area	Portland, OR	Austin, TX	Los Angeles, CA	Salt Lake City, UT	San Diego, CA and Austin TX
Reported Exposure	700,000 trips[2]	936,110 trips 891,121 miles 182,333 hours	---	---	---
Total E-scooter-Related Emergency Patients	176 patients (5% of total visits)	190 patients	249 patients	50 patients	103 patients
Total ER Visits	3,220 total visits tracked (5%)	Unknown	Unknown	~25,000 (including non-ED) visits	Unknown
Types of Study and Tracking	Surveillance – NSSP	Surveillance – NSSP, County EMS data, interviews	2 ED/Medical Centers via EMR data	1 Regional Trauma and 1 ED via EMR data	2 San Diego and 1 Austin Medical Center via EMR data
Time Period of Study	4 months 7/25/2018 – 11/20/2018	3 months 9/5/2018 – 11/30/2018	09/01/2017 – 07/31/2018	5 months 06/15/2018-11/15/2018	9/01/2017 – 10/31/2018
Comparison to Control Period	Yes, 1 month prior	No	Maybe	Yes (2017)	No
Cause of Injury	Percent (%) of Total E-scooter Related Injuries Observed				
Falling, single rider	83	---	80.2	---	---
Collision with object or vehicle	14 (vehicle)	10-16 (vehicle) / 10 (curb) / 7 (object)	8 (vehicle) / 11 object	---	---
Risk Features	Percent (%) of Total E-scooter Related Injuries Observed				
No Helmet	80.7 – 94.7[13]	99. 5	88.1-95.6[13]	100	98
Alcohol	9	29	4.8	16	48[14]
On Sidewalk	1	33	26.4[15]	44	
1st Ride		33			
Excessive Speed on Scooter		37			
Injury Type	Percent (%) of Total E-scooter Related Injuries Observed				
Head Injury	7[4]	48	40.2	20[5]	18[16] / 27[17] / 17[18]
Major			2.0	8	

Minor			38.2	12	
Fracture	---	35	31.7	36[10]	42[19] / 27[20]
Injuries to the extremities	---	70 (upper)/ 55 (lower)	27.7[c]	34[11] 40[12]	42
Requiring Ambulance Trip	13	---	---	24	
Trauma Activation				6	
"Severe" Injury		42 (NTSB)			43 (ISS – moderate+)
Required Hospital Admission		14	6	16	33[21] / 8[22]

Notes:
---: Not reported.; [1] Reported twice as many bicycle-related incidents during the time period.; [2] 2.5 injuries per 10,000 trips; 2.2 injuries per 10,000 miles; [3] The records examined did not indicate the 'fault' of the collision.; [4] Concussion Diagnosis.; [5] major defined as skull fracture and/or intracranial hemorrhage; minor defined as closed head injury and/or concussion.; [6] 36.5% to head, face, and neck; 4.8% traumatic brain injury, 3.2% spine and back.; [7] Upper extremity.; [8] Lower extremity.; [9] Sprains, contusions, injuries without fracture or head injury; [10] Major musculoskeletal injury (fractures and dislocations)[11] Minor musculoskeletal injury (sprains/strains); [12]Superficial soft tissue injury (abrasions, hematomas, and lacerations); [13] Lower figure excludes cases missing helmet data; higher figure records rate for documented helmet status; [14] 79 of 103 patients screened; [15] Data gathered during separate in-field observation period.; [16] intracranial hemorrhage; [17] facial fractures; [18] concussion; [19] extremities; [20] face/head; [21] surgery; [22] ICU.

2.3.2 Demographics of Those Injured

Although information is limited in studies of e-scooter-related injuries, it is possible to identify some potential demographic trends. In Portland's pilot (2018), 83% of the patients observed in the 176 ER visits were between 18 and 44 years old (5% were below 18 years; 12% above 45 years old). Comparatively, the respondents of their user survey indicated that 72.5% of users were between 16 and 39 years old (17.5% fell between 40 to 49 years old)—prorating those proportions might suggest around 79% of users would be between 18 and 44 years old (Portland Bureau of Transportation, 2018). Similarly, Trivedi et al. (2019) observed approximately 61% of injuries in users aged 18 to 40 and 10.8% in users under 18 years old. Of those patients, 58.2% were male and had an average age of 33.7 years (N=249 ER visits). This study did not provide cross-tab results for gender and age.

A review of scooter-related injuries in Austin by the CDC identified that the median age of the 190 patients was 29, with a majority of patients being male (55%), and white (65%) or Hispanic/Latino (22%). In the observations between September and November of 2018, 52% of recorded incidents occurred in the street, 18% of incidents involved motor vehicles, and 29% involved first-time riders (Austin Public Health, 2019).

Men visited the ER for e-scooter-related incidents more frequently than women, but in similar proportions to the overall user statistics in Portland. Males accounted for approximately 60% of ER visits and approximately 62% of user-survey respondents (Multnomah County Health Department, 2018; Portland Bureau of Transportation, 2018). Similarly, Trivedi et al. (2019) observed that 58.2% of ER patients during their study in Southern California identified as male.

2.3.3 Non-Optimal Scooter Usage

Besides behaviors resulting in injuries, e-scooters exhibit various non-optimal behaviors that cause potential conflicts with other travel modes, and thus contribute to creating an unsafe environment. Lyons et al. (2019) observed national behaviors of active transportation modes at a protected intersection in Salt Lake City and categorized seven different non-optimal behaviors of scooter users: riding on sidewalk; riding on street; clockwise riding; wrong direction on bike lanes; crossing in crosswalk; crossing in street; disobeying signal; and stopping in wrong place (see Table 5).

In this study, compared to the most similar users—bicyclists—e-scooters displayed higher rates of non-optimal behavior in every category with the exception of riding in the roadway. E-scooters also demonstrated similar but slightly higher rates of making exposed left turns and stopping out of place. E-scooter users were much more likely to disobey the signal compared to their bicycling counterparts, with 16.8% of users crossing against cars' movement. The non-optimal behavior that e-scooter users were most likely to exhibit was riding on sidewalks. A total of 43.2% of all observed e-scooter users were riding on sidewalks instead of the protected bicycle lanes or in the roadway, where they are expected to operate. Similarly, e-scooter riders also crossed the intersection within the crosswalk instead of crossing in the bicycle lane at a rate of 22.1%, compared to bicycle users' 5.1%.

Table 5 Non-Optimal Behavior Rates of E-Scooter and Bicycle Users

Behavior group	Non-optimal behavior	Proportion of others (mostly scooting)	Proportion of those bicycling
Approaching	Riding on sidewalk	43.2	12.2
	Riding on street	5.3	7.8
Turning/crossing	Clockwise riding/wrong direction on bike lanes	12.6	7.8
	Crossing in crosswalk	22.1	5.2
	Crossing in street	3.2	2.6
	Disobeying signal	16.8	12.2
Stopping	Stopping in wrong place	4.2	2.6
Note: Non-optimal behavior rates were calculated by dividing the counts of behaviors by the estimated usage counts. Although the *others* category included users riding a skateboard and Segway, 97% of it was scooter users.			

2.3.4 Helmet Use and Public Education

One of the major concerns raised by public agencies and the media over e-scooters is the number of crashes and injuries resulting from operations. In general, both scooter users and scooter companies do not appear to place a significant emphasis on safety—

at least not enough to increase helmet compliance and decrease non-optimal use of e-scooters. Observed rates of helmet use are very low for e-scooter users, which have caused additional concerns about increased risk of traumatic brain injury in the event of a crash. The CDC (Morano et al., 2019) observed helmet use rates of just 2% among users in Austin. Of 130 confirmed scooter-related injuries, 45% were head injuries (Morano et al., 2019). Trivedi et al. (2019) found only 4.4% of the 249 patients (over one year) visiting the ER for e-scooter-related incidents were recorded wearing helmets. Badeau et al. (2019) found that out of 50 emergency room visits, none of the patients were recorded as wearing a helmet at the time of the collision. In Calgary, Alberta, Canada, 10% of 671 e-scooter-related emergency room visits involved a head injury and no patients were recorded wearing helmets (Basky, 2020). A review of e-scooter-related injuries in emergency rooms throughout the United States found that only 4.4% of all users admitted to emergency rooms were wearing helmets (Namiri et al., 2020). Staff observations of 128 scooter users during an eight-day period reported only a 10% helmet use rate among users in Portland. Additionally, 29% of all user complaints submitted to the agency during the Portland scooter pilot were related to a lack of helmet use (Portland Bureau of Transportation, 2018). While helmet use is generally not required in the U.S. and, in some cases, will be difficult to require given existing laws for cyclists and even motorcyclists, there is evidence from Brisbane, Australia, that a helmet can statistically result in significant reduced risk of a head injury.

Table 6 Helmet Use for Various Study Locations

Location	Helmet Use	Number of Observations	Source
Austin, TX	<1.0%	190 Injured Riders	(Austin Public Health, 2019)
Southern California	11.9 %	84 ER visits (reporting helmet information)	(T. K. Trivedi et al., 2019)
Salt Lake City, UT	0.0%	50 ER visits	(Badeau et al., 2019)
Brisbane, Australia	60.9%	785 e-scooter users	(Haworth & Schramm, 2019a)
Portland, OR	20.6%	29 ER or Urgent Care visits (reporting helmet information)	(Multnomah County Health Department, 2018)

In addition to low helmet use, the novelty of e-scooters and lack of education about e-scooter-related traffic laws may pose additional safety concerns for all road users. In municipal programs, the burden to provide use and safety education to e-scooter riders is placed on scooter companies. Unfamiliarity with proper scooter operation is a concern for public safety, as only 25% of surveyed e-scooter users reported having sufficient training with a variety of mobility devices (National Transport Commission, 2019) (note: sampling strategy and response statistics were not reported). Improper education of e-scooter traffic laws was also reported to be a problem during the Portland pilot, with 66% of users stating they were not aware that scooters were prohibited on sidewalks and in Portland parks (Portland Bureau of Transportation, 2018).

2.4 PROGRAM OPERATIONS, MANAGEMENT, AND EVALUATION

While research into the users, use, and safety of e-scooters is ongoing, government agencies at the city, county, and state levels across the U.S. have done a substantial amount of work to regulate, monitor, and evaluate e-scooters through regulations, mandates, statutes, ordinances, permitting requirements, and operational agreements, etc., (Anderson-Hall et al., 2019; Griffee et al., 2019; Herrman, 2019; National Transport Commission, 2019; Sandt & Harmon, 2018; Smith & Schwieterman, 2018). Since e-scooters operate in the somewhat informal gig economy—similar to some bike share companies and ride sharing options such as Uber, Lyft, and others—regulations continue to play catch up with the evolving technology(ies) (Griffee et al., 2019; Herrman, 2019; National Transport Commission, 2019; Sandt & Harmon, 2018; Smith & Schwieterman, 2018).

2.4.1 Laws, Restricted Use Areas, Vehicle Requirements, and Data Sharing

A majority of municipalities treat e-scooters similarly to bicycles, requiring e-scooters to operate in bike lanes, appropriate shared-use paths, and generally prohibiting them from riding on sidewalks and pedestrian paths (Griffee et al., 2019). However, some studies have indicated some non-compliance with expected roadway behavior; an intersection survey in Salt Lake City revealed that 43% of e-scooters were observed riding on the sidewalk illegally (Lyons et al., 2019). Training and experience over time riding these devices may lead to lower rates of sidewalk use and, ultimately, decrease the number of scooter-pedestrian conflicts; however, no studies to the authors' knowledge currently evaluate the success of public information and education programs corresponding with e-scooter use compliance.

Should jurisdictions choose to completely prohibit the use or parking of e-scooters in certain areas, geofencing technology can be employed. Griffee et al. (2019) identified three uses of geofencing and spatial technology: restricting e-scooter operation within or outside of certain areas, prohibiting users from ending rides in certain areas, and restricting travel speeds. Out of a review of 39 jurisdictions, 12 required geofencing technologies to allow agencies or private developments to restrict use. The most common restricted areas were identified as dense parks and plazas, trails, cemeteries, stadiums, and convention centers. Additionally, coastal city marinas and university campuses tended to prohibit scooter parking or use altogether (Griffee et al., 2019).

Agencies have also regulated e-scooter device requirements and specifications, including device weight, speed limits, and various safety and mechanical devices, such as brakes, lights, audio devices, and use labels (Griffee et al., 2019). In the state of Queensland, Australia, e-scooters have a weight limit of 60 kilograms, robust and high-quality braking systems, and a set speed limit of 25 kilometers per hour, around 15 miles per hour (National Transport Commission, 2019). In the United States, specifications vary by jurisdiction. Regulations in Portland require maximum speeds of 15 MPH (Portland Bureau of Transportation, 2018), while Chicago, IL, mandated maximum speeds of 20 MPH (Anderson-Hall et al., 2019). Chicago appears to have changed its speed limit to 15 MPH between the Anderson-Hall et al. study in August 2018 and the Griffee et al. study in August 2019—an indication of how fast regulations are changing. Griffee et al. identified 21 (out of 39) municipalities mandating a maximum speed of 15 MPH (17 cities) through 20 MPH (two cities) speed limits. Additionally, three cities further limited speeds in specific, high-traffic areas (Griffee et al., 2019). Herrman (2019) found that scooters generally operate between 15 and 30 MPH, depending on the type of motor used. However, no studies to the authors' knowledge have documented observations that the actual operating speeds of e-scooters fall within the required speed limits.

For purposes of improving and managing e-scooter programs, municipalities may have requirements for data sharing by e-scooter companies. Griffee et al. identified 23 municipalities out of 29 which required some level of data sharing to evaluate program operations. The primary use of scooter data was to determine the minimum utilization rate (MUR), a performance indicator measuring the ratio of fleet size to user demand (Griffee et al., 2019). Ridership data may also be used to make additional program improvements by evaluating ridership and parking patterns, evaluating the progress of equity goals, or informing future policy decisions regarding the use of e-scooters. While customer data is required to be protected by scooter companies using data industry best practices, sharing user data may pose a potential security risk for the theft of personal and financial information (Portland Bureau of Transportation, 2018).

2.4.2 E-scooter Program Operations and Management

E-scooter programs generally contain three categories of provisions for operations and management. Vendors are responsible for complying with deployment and redistribution requirements, meeting city parking and ADA requirements, and sharing vehicle trip data (Griffee et al., 2019).

Redistribution Efforts and Implications for Greenhouse Gas Emissions
Redistribution and fleet size requirements ensure that e-scooter availability is spatially balanced across a municipality, preventing an oversaturation of scooters in certain districts which also helps prevent scooters from becoming a public nuisance, particularly on the pedestrian right-of-ways. Anderson-Hall et al. (2019) identified cities that have expressly mandated maximum deployment numbers for e-scooter fleets: Charlotte, NC, allowed 300 units per company; Portland allowed 683 per company; and San Francisco allowed 1,250 e-scooters (and up to 2,500 with fleet bonuses). Most jurisdictions (N=27 out of 39) have conditions in their local regulations for redistribution of e-scooters (Griffee et al., 2019), requiring, in some cases, that devices be removed and redistributed in response to user demand, public complaints, or other program requirements. The review found that companies were given one to 12 hours to respond to complaints (such as improperly parked scooters), with 25 of those 27 jurisdictions providing a two-hour window to respond to improperly parked and defective devices. Chicago included an additional program requirement stating that more than 50% of a scooter fleet may be deployed in the central business district at the start of a day; similarly, Oxford, OH, limited vendors to deploying no more than 50% of their fleet to the uptown district each day (Griffee et al., 2019).

Few studies have evaluated or publicly published whether companies are complying with redistribution requirements. The City of Portland (2018) issued two warnings to scooter companies for failing to meet the minimum 100-unit deployment number for East Portland, an equity zone. There is no indication of the consequences associated with a warning; however, poor compliance could lead to cease-and-desist orders, resulting in the termination of scooter programs (Anderson-Hall et al., 2019; Griffee et al., 2019; Portland Bureau of Transportation, 2018).

While there is high potential for e-scooters to be used as a substitute for automobile travel, the process of managing and operating the redistribution of e-scooters can negate potential benefits from personal use. In the Monte Carlo simulation analysis exploring life cycle costs of e-scooters, Hollingsworth, Copeland, and Johnson (2019) suggest two operational strategies for reducing GHG emissions (from the baseline 202 grams of CO_2-equivalent per passenger mile): use fuel-efficient vehicles for e-scooter collection (reduction of 12.3% to 177 g CO_2-eq/passenger mile); and use logistics to reduce the driver distance per scooter for collection and/or redistribution (reduction of 27.2% to 147 g CO_2-eq/passenger mile). With more efficient collection processes, the necessary proportion of e-scooters needed to “replace” automobile trips (as discussed in the section on E-scooter Users and Use) to meet carbon-neutral standards would drop to between 35-50% substitution. The analysis concluded that vehicle mileage generated from scooter redistribution efforts accounts for over 40% of the environmental impacts of any substitutive effects of e-scooters replacing vehicle trips. Poor redistribution and life cycle practices were identified as major contributors to environmental impacts as well. Additionally, the authors observed that one out of every six scooters in Raleigh, NC, was at or above 95% battery life at the end of operating hours. However, these devices were still collected, resulting in unnecessary charging and vehicle miles traveled. Changing redistribution and charging practices can reduce emissions from 5-50%, depending on management practices.

When considering the contribution of e-scooters towards reducing GHG emissions, the short life span of each device is one of the main contributing factors to increased emissions. Hollingsworth et al. (2019) indicated that if the life span of e-scooters were increased at least two years, there would be a significant decrease in GHG emissions associated with manufacturing and production. When combined with optimal distribution practices, the likelihood that e-scooters generate more GHG emissions than the transportation options they are replacing drops from 65% down to 4%. Better management practices and increased device life cycles would make e-scooters a significantly greener transportation option than at present (Hollingsworth et al., 2019; Moreau et al., 2020).

Parking and ADA Compliance

Consistent adherence to parking regulations is one of the most common criticisms of e-scooter programs, with news media, feedback surveys, and reports on e-scooter use citing improper parking as a nuisance. In fact, 14% of all unique complaints submitted during the Portland scooter pilot concerned improperly parked devices (Portland Bureau of Transportation, 2018). Most municipalities with scooter programs have outlined parking regulations as a condition of a company's operating agreement (Anderson-Hall et al., 2019; Griffee et al., 2019; Herrman, 2019; Populus, 2018). Dockless e-scooters are most often required to be parked in the "furnishing zone" or painted "bins" located on sidewalks, but out of the immediate public right-of-way to avoid blocking pedestrian traffic (Anderson-Hall et al., 2019). Fang et al. (2018) stated that well-parked e-scooters should meet three criteria—scooters should be parked upright, placed on the "pedestrian periphery" or already obstructed areas, and not blocking pedestrian traffic. Griffee et al. (2019) found that required sidewalk space clearance for scooter parking varied from a minimum of three feet to a minimum of 10 feet, depending on the size and location of the road. This review also identified eight municipalities which utilized "bins" to manage scooter parking. Finally, the review also identified five municipalities which expressly stated minimum parking clearances for access to ADA facilities (Griffee et al., 2019).

Despite public and media concerns over improperly parked e-scooters, Fang et al. (2018) found that out of 530 e-scooters observed in San Jose, CA, 90% did not obviously pose an obstruction to pedestrian travel. Of those 530 devices, 11 were found to be explicitly blocking pedestrian access. Additionally, Brown et al. (2019) performed a case study of parked bicycles, e-scooters, and motor vehicles in five major American cities. Only 1% of all (865) bicycles and e-scooters combined were improperly parked in a way that impeded pedestrian access. By comparison, 24.7% of all (2,631) parked motor vehicles impeded pedestrian traffic. The authors hypothesized that the recent introduction and unfamiliarity with e-scooters has generated significant attention which may give e-scooters the appearance of blocking pedestrian access more frequently than evidence suggests.

With so few studies evaluating the parking and ADA compliance of e-scooters, this may be a fruitful area of research, particularly evaluating the success of different policies and practices (e.g., public information programs, vendor-led education programs, parking “bins” or designated areas, and methods to enforce vendors’ and/or users’ compliance).

2.4.3 Equitable Access

E-scooters show promise in helping bridge gaps in short-distance trips, such as accessing public transit by helping to solve the first- and last-mile problem (Populus, 2018; Smith & Schwieterman, 2018). Smith and Schwieterman indicate that dockless e-scooters in Chicago appear to increase job access within a 30-minute radius by 16%. E-scooters also enjoy a substantially higher positive perception among low-income groups (see section E-scooter User Demographics and Perceptions), making e-scooters a potential fruitful new transportation option for historically transport-disadvantaged communities.

Griffee et al. (2019) identified 17 agencies with active policies supporting equity within e-scooter programs and regulations. Of those, 13 agencies included fleet incentives for vendors that include equity zones or areas of opportunity within their service area. These “equity zones” were included to encourage vendors to offer a minimum level of service to transportation-disadvantaged areas. Program requirements for equity zones vary by municipality and total fleet size. For example, Portland required 100 devices at a minimum be deployed to East Portland, and Denver, CO, required at least 100 devices out of 350 to be deployed in opportunity zones (Griffee et al., 2019; Portland Bureau of Transportation, 2018). In the case of the Portland pilot (2018), only one company consistently met the 100-unit minimum deployment requirement for East Portland and the overall compliance with equity goals was stated as unsatisfactory. It is unknown to what extent opportunity zones affect e-scooter ridership in underserved areas, nor is it clear the extent to which companies are meeting equity zone requirements through redistribution efforts.

Table 7 Examples of Equity-Zone Requirements

Agency	Equity Zone Requirements
Denver, CO	100 of 350 devices deployed in “opportunity zones”
Portland, OR	100 devices deployed in areas defined by the 2035 comprehensive plan
San Jose, CA	Minimum of 20% of fleet deployed in a “community of concern”
St. Paul, MN	Minimum of 30% of fleet deployed to “areas of concentrated poverty”

Source: Chapter 4.0

2.4.4 Public Education, Safety, Outreach, and Customer Service

E-scooter operating agreements stipulate that companies must provide consistent public outreach, safety education, and customer service to scooter users. The Portland pilot (2018) mandated public education for proper operations, parking, and safe use of e-scooters, but the initial evaluations suggest that safety and operations education efforts were not overly successful—for example: 66% of scooter users stated that they were not aware of traffic laws prohibiting scooters from sidewalks and Portland parks. Additionally, Halfon (2019) cited a *Consumer Reports* survey which found that one in four e-scooter users were unsure of which traffic laws they should follow.

Although most municipal regulations and operation agreements require helmet use for operating e-scooters, it appears the rule is rarely enforced. Helmet use among scooter users ranges from 0-10%, even when mandated by state law (Halfon, 2019; Lazo, 2019; Portland Bureau of Transportation, 2018). Both improper device use as well as low rates of helmet use may be attributed to low enforcement rates by public agencies, inadequate education practices by e-scooter companies, and general user non-compliance. (In Portland (2018), approximately 67% of user survey respondents indicated that they knew that helmets are required, and 50% learned about e-scooter laws through vendor applications.)

While a majority of municipalities with active e-scooter programs required a short response time for dealing with “emergency” situations (improperly parked or defective devices), most municipalities also required scooter companies to maintain a responsive customer service program (Griffee et al., 2019). Griffee et al. identified that 19 out of 27 municipalities required companies to maintain a 24-hour customer service program; five municipalities required companies to maintain a local brick-and-mortar office; and 15 municipalities required a direct point-of-contact with a company representative or office for local issues. Companies involved in the Portland pilot consistently responded to city requests within one hour (Portland Bureau of Transportation, 2018), but the level of customer service and response times to complaints offered in other cities is currently unknown or unpublished.

2.5 E-SCOOTER GAPS AND OPPORTUNITIES

Although a thoroughly documented pilot program and a collection of articles and reports have been written about e-scooters, a significant number of gaps still exist. In current practice, the excitement around e-scooters may drive a number of innovations in research and practice (in addition to private company developments). It is rare in research that entirely new modes of travel may be introduced to so many different cities and populations in an observable fashion. Observing these trends and changes and capturing behavior through observations, surveys, and passive data collections may provide real insight into behavioral decisions and patterns. This is particularly true after the newness of shared, dockless e-scooter programs wear off and the routine of behavioral patterns settles back down.

Similarly, there is an opportunity in studying and evaluating users and use of new transportation modes, particularly in understanding how users may substitute or complement the new mode for existing options. This poses both potential benefits and problems. In general, replacing personal vehicle trips of short distance and duration means that e-scooters may help take personal vehicles off the road to some extent—possibly reducing traffic but also lowering potential vehicle miles traveled and GHG emissions. Throughout this literature review, however, we have learned that this substitutive impact must be substantially higher in order to offset the impacts of redistribution, charging, and life span processes and operations. This in itself continues to be an important area of research and understanding.

Similarly, some evidence suggests that e-scooter trips may be used as substitutes for public transit trips and/or active travel. This poses two concerns. On a net regional level, even a small reduction in public transit use may impact revenues and some ridership estimates. However, the areas where e-scooters are most commonly used (generally the most accessible or dense areas) are also areas where public transit tends to be strongest. Additionally, in some areas with weak public transit access, e-scooters may fill the need of access/egress to public transit sites. The concern corresponding with reductions in active travel extends to larger concerns related to the public health implications and costs of further reducing active travel, thereby increasing corresponding implications related to disease and societal costs. On the other hand, for some individuals, e-scooters may also encourage multimodality, increasing the likelihood that e-scooter users will also be more likely to increase their use of other alternative mode choices, including walking, biking, transit, and bike share. The research on the use of e-scooters as substitutes or complements is still reliant on simulated experiments and surveys not grounded in specific travel observations (instead asking users to recall experiences, sometimes from months before).

It goes without saying that the safety of all transportation modes is an important area of research. However, many researchers have noted that by studying e-scooter crashes, injuries, and incidents, the lack of transparent and well-documented bicycle and pedestrian crash and injury information—and the dearth of understanding of the total use of active transportation options—makes it exceedingly difficult to compare across modes. Ideally, research in e-scooter crashes should consider opportunities to also explore and expand research to incorporate other active transportation modes wherever possible. Furthermore, few studies have explored compliance rates and optimal behaviors of all alternative mode users. While focusing on crash and injury data can identify the types of interactions and circumstances that contribute to the most severe outcomes, identifying rates of actual behavior can also help agencies and practitioners evaluate facilities in terms of the safety and comfort of facility characteristics (like configuration, special facilities, striping, etc.).

And finally, while many agencies hold operating agreements with vendors to implement their programs in their cities, few have developed and published program evaluations to hold these companies accountable to the public for which they now serve. The ability to evaluate and revise programs and policies is a hallmark of effective municipal operations, but the speed at which new technology is introduced is often faster than the speed at which most agencies are equipped to operate. There is ample room for academic and public partnerships aimed at evaluating policy and practice iteratively. Ideally, experiences related to e-scooter evaluations and research will encourage agencies and academics to partner to evaluate other conventional practices and concerns that have also plagued public agencies.

3.0 REVIEW OF AGENCY REGULATIONS ON SHARED E-SCOOTER PROGRAMS

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Note: This portion of the study was conducted and documented prior to the COVID-19 pandemic and corresponding lockdowns. We include it in this report to document a systematic review of public agency regulations regarding e-scooters, pre-pandemic. A draft of this chapter was presented at the Transportation Research Board Annual Meeting (2020) and an invited event related to the Transportation Research Forum (2020, presented virtually in response to the pandemic).

3.1 OVERVIEW

Whereas urban transportation methods have heavily relied on transit and car-centric means, technological advances and trends have recently shifted towards micro-mobility and shared methods, resulting in a rapidly changing transportation landscape. While there has been a sharp increase in one of these technologies, shared electric scooters (or e-scooters), cities have had to work quickly to develop, adopt, and revise new regulatory policies to address and manage these new entities. The result has been city-led efforts grappling with policies managing everything from placement, parking, geofencing, vehicle specification requirements, fee structures, data management and sharing, safety features, to liability—all of which have implications on equitable access, economic development, public health, safety, and welfare. This study aims to illuminate the concerns and considerations of agencies across the U.S. through their regulatory policies managing public access to shared e-scooter programs.

E-scooters have been praised for being fun, convenient, and a sustainable alternative to car-oriented means (such as one-person trips, car share and ride-hailing services) and a supplement to a multimodal lifestyle. However, both public and academic leaders also have concerns based on questions related to public safety, dockless disorganization, and the reduction of pedestrians, bicyclists and transit riders who utilization them in lieu of their normal transportation method. It is around these topics that agencies find themselves questioning: What do we know about the impacts of e-scooters or other micro-mobilities? And how do cities regulate such a new and popular method of transportation method? Studies that support new policies are limited but growing.

The objectives of this study are twofold. First, we aim to explore the limited (but growing) literature concerning studies and evaluations of shared e-scooter programs along themes of safety, use and users, and operations and management. Second, we provide a detailed analysis of regulations adopted from 40 agencies within the U.S. This analysis documents themes and considerations across all types of policies—from permitting requirements to public ordinances. A similar review was completed last year by Anderson-Hall et al. (2019); however, e-scooter programs have grown tenfold over the past year, with substantially more agencies engaging in the regulation of this new transportation technology. In this paper, we aim to expand and update the number of cities reviewed from Anderson-Hall's review. But first, we provide a review of the background from academic research, white papers, and news reports.

3.2 BACKGROUND

Overall, there is limited (but accelerating) literature considering the implications of e-scooters on cities and individuals. While some studies have suggested e-scooters and other similar micro-mobility options may provide a viable low-cost transportation option, others point to the mounting concerns related to the safe operation and use of the technology. This short background review touches on the studies evaluating or predicting the safety, use and users, and operation and maintenance of e-scooters. In general, findings across studies have not yet identified a consistent narrative of the users or use of the tool, leading many to predict ridership using existing similar modes, such as dockless and station-based bike share (either electric or manual).

3.2.1 Injuries and Safety

Proper policymaking for new modes must balance the goal of maximizing transportation options while also ensuring public safety (Anderson-Hall et al., 2019). And although a 2018 poll suggests general public favor (70% to 30%) for micro-mobility options in major U.S. cities (Populus, 2018), concerns about the safety of e-scooters are not entirely unfounded. Safety concerns have reached such a point that the CDC has initiated an effort to try to better understand injuries from this new mode with an epidemiological lens (Lazo, 2019). In a study focusing on both electric bicycles (aka e-bikes) and e-scooters, Siman-Tov et al. (2017) estimated that e-bike- and e-scooter-related injuries increased by 600% over a two-year period. In a smaller pilot study, the initial findings suggest that micro-mobility users demonstrate unsafe behavior at similar rates to cyclists (Lyons et al., 2018)—finding indications that increases in active transportation usage at downtown protected intersections can primarily be attributed to micro-mobility e-scooters. In most jurisdictions with pilot programs or e-scooter legislation, riding on the sidewalk is often prohibited but enforcement of illegal riding is inconsistent (Anderson-Hall et al., 2019; Halfon, 2019; Lazo, 2019; Mancuso, 2019; National Transport Commission, 2019; Populus, 2018; Portland Bureau of Transportation, 2018; Sandt & Harmon, 2018). Although most municipalities required e-scooter users to wear helmets, observed helmet use is very low across all jurisdictions, creating safety concerns relating to head injuries (Halfon, 2019; Lazo, 2019; Portland Bureau of Transportation, 2018; Sandt & Harmon, 2018). During the micro-mobility pilot period implemented in Portland, for example, recorded helmet use was found to be around 10% (Portland Bureau of Transportation, 2018), and as low as 2% among riders in Austin (Lazo, 2019). As e-scooters are new to urban areas, few studies have quantified crash rates, including the type and severity of crashes and potential causes. A brief study during the Portland pilot identified 176 emergency room visits as a result of scooter operations out of a total of 700,000 recorded scooter trips. During this period, no fatal injuries were recorded as a result of e-scooter operations. The most common injuries consisted of head and superficial extremity injuries. One-third of recorded injuries were to the head and neck, and 7% of emergency room visits resulted in a concussion diagnosis (MCHD, 2018).

3.2.2 Use and Users

In a broad exploration of data collected across the United States, Populus (2018) found that women have used station-based bike share services at nearly half the rate of men (12% versus 21%), accounting for approximately 25% of all station-based bike sharing trips and suggesting a gender gap in station-based bike sharing use. While their data are limited, Populus (2018) estimates that a smaller percentage of women have since tried e-scooters compared with men. However, more recently, evidence from the Portland pilot (not yet peer reviewed) suggests that women may enjoy e-scooters for recreation, but use them less for commuting (Dill, 2019). In terms of demographics, Circella et al. (2019) indicates the likely micro-mobility users are “active travelers” who tend to live in smaller households with fewer children, have fewer vehicles available, and live in urban neighborhoods with better access to non-motorized modes. While some argue that micro-mobility technologies may compete with public transit usage, in 2017 an estimated 74% of the growing 35 million e-scooter trips occurred in transit-rich urban areas (Garcia-Colberg, 2019). In contrast, Smith and Schwieterman (2018) estimated the use of e-scooters in Chicago provide a low-cost transportation option that operates as a strong complement to transit. In Portland, e-scooter trips from residents (34%) and visitors (48%) tended to replace driving and ride-hailing trips (Portland Bureau of Transportation, 2018).

3.2.3 Operations and Management

At present, e-scooter operations and management (O&M) practices have been primarily built into the permit application terms of pilot programs. Elements of O&M include things like: the spatial distribution of scooters (restrictions in service areas, distribution across space); any redistribution requirements; vehicle parking requirements; or vehicle servicing and reporting requirements. However, the success of these regulations—that constrain or incentivize spatial deployment of vehicles; redistribution of vehicles; and maintain compliance in regards to parked vehicles—are unclear. In Portland, 72.8% of scooters were compliant in the parking requirements, 2.8% of e-scooters parked impeded access to ADA facilities, 5.3% of parked e-scooters completely blocked pedestrian traffic, and 8.1% partially blocked pedestrian traffic (Portland Bureau of Transportation, 2018). In San Jose, 72% of scooters were parked on sidewalks and 23% were parked on adjacent properties—90% of parked scooters did not impede pedestrian traffic (Fang et al., 2018). Parking issues in Portland, however, made up 14% of all complaints issued and, by anecdotal observation, pilot staff observed fewer parking-related complaints as the pilot program progressed (Portland Bureau of Transportation, 2018).

3.3 METHODS AND DATA

In this section, we describe the two-step process we used to: (a) identify and collect; and then (b) code and analyze e-scooter regulations which come in many forms including, but not limited to, adopted memorandums, policies, regulations, permitting requirements, ordinances, and codes. As we identified new agencies, we added new documents—and corresponding new themes and characteristics—to our sample. Initial documents were then re-reviewed to ensure a consistent coding of documents. We continued to iterate through this process until we could no longer identify any new major themes or characteristics.

3.3.1 Identifying and Collecting Agency Regulations

First, to identify and collect regulations from cities or counties, we completed an iterative series of online searches. These searches included investigating existing, comprehensive websites—Smart Cities Drive or SCD (Smart Transportation and Urban Transit, 2019) and the Shared Use Mobility Learning Center or SUMLC (Shared Use Mobility Learning Center, 2019)—and individual agency websites that were known to have e-scooters in (or near) service. Most jurisdictions we observed have programs that were operational, a handful had yet to begin (e.g., Chicago and Winston-Salem), and several had finished and/or extended their pilot program. One such case, St. Paul, re-implemented their e-scooter program for the 2019 year. St. Paul's second year of operation saw an allowance of 2,000 shared-mobility devices, raised from 300 during the pilot program in 2018.

Through the mapping dashboard on SCD's website, we identified key qualities of e-scooter regulations in cities across the U.S. These include spatial locations and dispersion; e-scooter bans; currently permitted vender(s); and spatial distribution of vender(s). This map enabled us to identify additional agencies to explore manually. While SCD provides some hyperlinks to relevant documents for agencies' e-scooter program, not all of the links were relevant for this study. For example, some lead to the city's educational page on local e-scooter rules, a news article reporting on their presence, or adopted policies and/or regulations related to their program's enactment.

The SUMLC yielded several agency documents related to its e-scooter programs. To identify relevant documents, keyword searches were performed on terms such as: "dockless," "shared mobility," "pilot program," "e-scooter," "active transportation," and "micro-mobility." SUMLC provides a summary of the act of legislation by the local jurisdiction along with hyperlinks to the related permitting documents.

Outside of the SCD and SUMLC resources, the process of aggregating e-scooter policies and regulations proved to be difficult. E-scooter policies of many of the cities that are known to have e-scooters were often unable to be found publicly online. While care was taken to capture a diverse set of cities from all regions across the continental U.S., the process of identifying cities to be included in this study was constrained by the availability of documents online. We were not able to find any publicly available regulations for at least two dozen agencies that are known to have e-scooters currently operating in their jurisdictions. It is possible that these agencies do not have any regulations in place. The final sample of regulations analyzed in this sample includes forty agencies representing the sample of current policy trends for shared micro-mobility, specifically e-scooters (see Table 8 and Table 9).

Table 8 Jurisdictions Included in this Policy Review, 1 of 2

Jurisdiction	Transit Systems	Population in 2018[3]
Albuquerque, NM	BRT, CR, LB	560,218
Arlington County, VA[1]	SW, BRT, LB	237,521
Atlanta, GA	CR, SC, SW, LB	498,044
Austin, TX	CR, LB	964,254
Baltimore, MD	SW, CR, LR, LB	602,495
Boise, ID	LB	228,790
Charlotte, NC	LR, SC, LB	872,498
Chicago, IL[1]	SW, CR, LB	2,705,994
Cincinnati, OH	LB, SC	302,605
Columbus, OH	BRT, LB	892,533
Dallas, TX	LR, CR, SC, LB	1,345,047
Detroit, MI	LR, LB	672,662
Denver, CO	CR, LR, LB	716,492
Durham, NC	LB	274,291
Fort Lauderdale, FL	CR, LB	182,595
Greensboro, NC	LB	294,722
Indianapolis, IN	LB	867,125
Lubbock, TX	LB	255,885
Long Beach, CA	LR, LB	467,354
Memphis, TN	LB	650,618
Miami, FL	SW[2], LB	470,914
Minneapolis, MN[1]	LR, BRT, CR, LB	425,403
Montgomery County, MD[1]	SW, CR, LR, LB	1,052,567
Oakland, CA	SW, LB	429,082
Oxford, OH	LB	22,885

Notes: SW: Subway; LR: Light-rail; BRT: Bus Rapid Transit; CR: Commuter Rail; SC: Streetcar; and LB: Local Bus.;

[1] Regulations originally implemented for a pilot or demonstration program.;

[2] Miami has above-group mass transit system that operates similar to a subway.;

[3] U.S. Census Bureau (2018) Estimates (Table: PEPANNRES – Annual Estimates of the Resident Population: April 1, 2010 to July 1,2018).;

[4] Policy References: (City of Albuquerque, 2018, 2019); (City of Atlanta, 2019; Department of City Planning, 2019); (Austin Department of Transportation, 2018); (Baltimore City Department of Transportation, 2018; City of Baltimore, 2019); (City of Boise, 2018); (Charlotte Department of Transportation, 2018); (City of Chicago, 2019); (City of Cincinnati, 2018; City of Cincinnati, Ohio, 2018); (Department of Public Services, 2018); (City of Dallas, 2018); (City of Detroit, 2018); (Denver Public Works, 2019a, 2019b); (City of Durham, 2018b, 2018a); (City of Fort Lauderdale, 2018); (City of Greensboro, 2018); (City of Indianapolis, 2018); (City of Lubbock, 2018); (City of Long Beach, 2018); (City of Memphis, 2018); (City of Miami, 2018); (City of Minneapolis, 2018, 2019); (Montgomery County, 2019); (City of Oakland, 2018); (City of Oxford, 2018).

Table 9 Jurisdictions Included in this Policy Review, 2 of 2

Jurisdiction	Transit Systems	Population in 2018[3]
Portland, OR[1]	LR, CR, SC, LB	583,776
Providence, RI	LB	179,335
Raleigh, NC	LB	469,298
Sacramento, CA	LR, LB	508,529
Salt Lake City, UT	LR, CR, SC, LB	200,591
San Diego, CA	LR, BRT, CR, SC, LB	1,425,976
San Francisco, CA	SW, LR, CR, SC, LB	892,533
San Jose, CA	LR, BRT, CR, LB	1,030,119
Scottsdale, AZ	LB	255,310
St. Louis, MI	LR, LB	302,838
St. Paul, MN	LR, BRT, LB	307,69
Virginia Beach, VA	LB	450,189
Washington, D.C.	SW, CR, SC, LB	702,455
Winston-Salem, NC	LB	246,328

Notes: SW: Subway; LR: Light-rail; BRT: Bus Rapid Transit; CR: Commuter Rail; SC: Streetcar; and LB: Local Bus.;
[1] Regulations originally implemented for a pilot or demonstration program.;
[2] Miami has above-group mass transit system that operates similar to a subway.;
[3] U.S. Census Bureau (2018) Estimates (Table: PEPANNRES – Annual Estimates of the Resident Population: April 1, 2010 to July 1,2018).;
[4] Policy References: (Portland Bureau of Transportation, 2018); (Department of Public Works, 2018); (City of Raleigh, 2018); (City of Sacramento, 2018); (Salt Lake City Corporation, 2018); (City of San Diego, 2018b, 2018a); (San Francisco Municipal transportation Agency, 2018); (City of San Jose, 2018; Department of Transportation, 2018); (City of Scottsdale, 2018); (City of St. Louis, 2019); (City of St. Paul, 2019; Williams, 2004); (City of Virginia Beach, 2011); (Department of Transportation, 2019; District of Columbia, 2018); (City of Winston-Salem, 2019).

3.3.2 Analyzing Agency Documents

Once the agency documents were compiled, we dissected the documents to identify patterns of similarities and differences. Throughout this iterative process of reviewing and coding the documents, we identified nine initial overarching themes: fee schedule; presence; reasons for removal; data sharing; equity; parking regulations; safety factors; education requirements; and goals.

We then reviewed the full set of documents more thoroughly, coding the documents based on qualities and differences within each of the themes. The details of different elements of regulations under these themes were compiled in Excel, and re-coded to distill major patterns discussed in the following section. During this process, we also looked for elements of any one agency's documents that might vary. For example, when reviewing varying requirements associated with "Regulations Related to Safety," we identified several categories of safety (e.g., brake requirements, illumination requirements, front and/or rear lights, speed limits, rider education, age requirements, and safety reporting). The full coding scheme was then reviewed (and repeated) for consistency.

During this second, more thorough review, if new agencies and/or documents were identified, the new documents were coded based on the revised criteria and reviewed for any new themes or elements that might appear. This iterative review process continued until the authors were confident they captured the major themes and variations in the corresponding criteria for all agencies studied. The major themes identified during this process and explored in the following section include: fees and charges; ridership and data requirements; vehicle specifications and safety concerns; parking and restricted access; and equity.

3.4 RESULTS

3.4.1 Fees and Charges

Not surprisingly, one of the most common features in e-scooter regulations are the fees and charges associated with application and permitting of venders, device and/or per day or per trip fee. One common theme across most regulations is the presence of use and/or permitting fees offsetting burdens on the system. Permitting and/or licensing fees are paid by the vender annually per scooter to operate within the jurisdiction. Alternatively, cities may charge a per trip or per day fee to the rider. These fees are akin to automobile vehicle licensing fees, but in micro-mobility policies that take many different forms.

In the case of permitting and application fees, most agencies charge an annual and/or daily device fee. The range of the fee that allows the operation of e-scooters within a jurisdiction annually, for example, was as little as $250 for Durham and up to $50,000 for a “licensing fee” according to Miami’s ordinance. Although geographically located close to Miami, Fort Lauderdale’s population is just 25%, yet the city requires only a $150 annual operating fee. Portland was a unique outlier, charging a per-trip fee of $0.25 per trip taken on a shared-mobility device. Two agencies currently impose more than one use fee to the vender and/or rider. The wide variation in fee rates and units may correspond to state or county regulations defining or restricting the use and application of fees and/or charges.

Table 10 Fees and Charges by Jurisdiction, 1 of 2

Jurisdiction	Fee Type	Who is charged?	Amount (USD)	Unit
Atlanta, GA	Application	Vendor	$100	Per application
	Fee	Vender	$12,000	Per vender license
Chicago, IL	Permit Fee	Vender	$250	Per application
Cincinnati, OH	Application	Vender	$5,000	Per application
	Fee	Vender	$1	Per scooter
Columbus, OH	Application	Vender	$2,100	1-100 scooters;
	Fee		$4,200	101-200;
	Per Day Fee		$6,300	201-300;
	Annual Fee		$8,400	301-400;
			$9,600	401-500;
			$21 per device	>500
Dallas, TX		Vender	$808	Per application
Denver, CO		Vender	$150	Per application
		Vender	$15,000	Per vender license
Durham, NC	Application	Vender	$1,000	Per application
	Fee	Vender	$250	Per vender license
	Application	Vender	$100	Per scooter
Fort Lauderdale, FL	Fee	Vender	$150	Per vender license
	Permit Fee	Vender	$10	Per vender license
Greensboro, NC	Application	Vender	$500	Per vender license
	Fee	Vender	$50	Per scooter
Indianapolis, IN	Permit Fee	Vender	$15,000	Per vender license
	Annual Fee	Vender	$1	Per scooter
Long Beach, CA	Permit Fee	Vender	$2,336	Per vender license
	Annual Fee	Vender	$177.62	Per vender license
Lubbock, TX	Permit Fee	Vender	$750	Per vender license
Miami, FL	Annual Fee	Vender	$15,000	Per vender license
	Permit Fee	Vender	$1	Per scooter
Nashville, TN	Per Day Fee	Vender	$500	Per application
	ROW Fee			
	License Fee			
	Permit Fee			
	License Fee			
	Per Day Fee			
	Application			
	Fee			

Notes:
For any jurisdiction listed in Table 8 *or* Table 9 *but not listed in this table, this indicates no relevant requirements were identified in the documents reviewed.*

Table 11 Fees and Charges by Jurisdiction, 2 of 2

Jurisdiction	Fee Type	Who is charged?	Amount (USD)	Unit
Portland, OR	User fee	Rider	$0.25	Per trip taken
	Application	Vender	$250	Per application
	Fee	Vender	$5,000	Per vender license
Providence, RI	Permit Fee	Vender	$1	Per scooter
San Francisco, CA	Per Day Fee	Vender	$5,000	Per application
	Application	Vender	$25,000	Per vender license
St. Louis, MO	Fee	Vender	$500	Per application
	Permit Fee	Vender	$10	Per scooter
St. Paul, MN	Application	Vender	$100	Per scooter
	Fee	Vender	$0.25	Per scooter per trip
	Annual Fee			for all trips that
	Annual Fee			begin or end on
	Park Impact			parkland
Winston-Salem, NC	Fee	Vender	$1,000	Per vender license
		Vender	$100	Per scooter
	Application			
	Fee			
	Annual Fee			

Notes:
For any jurisdiction listed in Table 8 *or* Table 9 *but not listed in this table, this indicates no relevant requirements were identified in the documents reviewed.*

3.4.2 Ridership and Data Requirements

Many agencies view the utilization of e-scooters as an important metric to evaluate how effective an e-scooter system may be and if the venders are meeting any requirements or goals put forth in the governing documents. For the cities reviewed in this study, the effective usage of the scooters has been measured in distance ridden, time ridden, frequency of trips or “active” riders, or number of times a device is used.

Agencies generally aim to track whether e-scooters (a) are not oversaturating neighborhoods, and (b) that the devices are consistently available for their residents within service area. Many require venders to meet a minimum utilization rate, or MUR. The MUR calculates the average number of trips per device within a fleet conducted in a day, a week, and/or a month (i.e., a fleet size of 500 devices yielding 1,300 rides in one day has a MUR of 2.6 rides per device). Based on the establishment of a threshold MUR within regulations, a vender’s fleet size can be evaluated for possible expansion, reduction, or maintenance. For five of the observed agencies, the required MUR fell between 2.0 and 3.0 average trips per device. Per Charlotte’s ordinance, an operator’s fleet must maintain a MUR average of at least 2.0 per month, or the fleet is subject to removal in increments of 50 at a time. In contrast, if the devices within the fleet maintain an average greater than a 3.0, the operator may request an increase in fleet size of 50 mobility devices per month. It should be noted that some cities cap the number of excess scooters that are permitted as variances.

In order to calculate MURs or evaluate the spacing and availability of the vehicles, 23 of the observed agencies required some form of minimum data sharing. There are prominent and consistent data requirements shared amongst the cities, such as the number of trips taken in a particular period (day, week, and/or month); the duration (both time and distance) of a trip; and, as mentioned previously, the average number of rides in a time period. The majority of the observed cities also require the origin and destination of each trip (spatial location in the format of longitude and latitude) to be shared. The most common data formats required include: Mobility Data Specification (MDS), JavaScript Object Notation (JSON), and/or General Bike Feed Specification (GBFS). The last, GBFS, was the most preferred. Also embedded within those permitting documents were clauses requiring the operator to have real-time application program interface (API) to review use data, pointing to the desire for real-time evaluation and monitoring of operations and redistributions. In Washington, D.C., an "on-board GPS technology" was required, allowing real-time data via an API that "does not obtain spatial information by relying on a customer's smart phone" (Department of Transportation, 2019, p. 4). Thirteen of the 40 jurisdictions reviewed have required the location where trips originate and where they end, and four of those 13 required the operator to provide a spatial depiction of those taken trips. Less frequently, the agencies in Arlington, Minneapolis, Nashville and Portland include a clause requiring spatial maps displaying the trips and routes e-scooter riders have taken.

In addition to user-behavior data, most cities may have some stipulation that requires vendors to provide spatial information about the e-scooters when parked. The data requirements typically include data describing scooter locations (both parked and in motion) and ridership information. As an example, Washington, D.C., requires the dockless sharing vehicles to transmit GPS data "at a minimum of every 90 seconds while in use to ensure accurate location data is conveyed" and "at a minimum of every 60 minutes while parked to ensure accurate location data is conveyed" (Department of Transportation, 2019, p. 4).

Processing raw e-scooter data can be problematic for cities or counties with limited budget for processing "big data." In response, some agencies included requirements allowing the data to be shared to third-party data aggregation firms contracted by the local government. Data processing and analysis capabilities vary across agencies, but some agencies have opted to outsource the analysis and data privacy concerns to prominent third-party data companies such as Populus, Shared Streets, and Remix. In an initial review of similar services, these contracts appear to range from no fees to upwards to $30,000 annually, depending on the size of the jurisdiction and service areas, as well as the complexity of requested analysis. Capabilities of these companies include the spatial depiction of accidents reported to the vender; providing the jurisdictions with heat maps of heavily traveled routes; and spatial depiction of e-scooters in use or parked. Beyond the capabilities that third-party data firms can provide, the staff time that would be dedicated to understanding and computing the provided data could be onerous. Logically, agencies may be able to circumvent the cost of the third-party data firms if they have access to internal data processing skills and labor, or they might justify this cost within their fee schedules.

3.4.3 Vehicle Specifications and Safety Concerns

Most agencies place restrictions on the vehicle specifications, likely in response to safety concerns. The most common specifications included the shared mobility devices being equipped with front lights, back lights, brakes, unique identifying numbers, and (to a lesser degree) a device that has the capability of emitting a noise as an alert. Some ordinances specified to what distance the lights must be visible. Such ordinances include that of St. Louis, which required a light to be seen from “300 feet in front and from all sides” and “500 feet to the rear.” Similarly, but further reaching, was Winston-Salem’s requirement of lights being visible from “500 feet on all sides.”

An apparent and consistent specification was the restriction on the maximum speed capability of the vehicles. Of the 21 jurisdictions that outlined a maximum speed, 17 restricted the maximum speed at 15 MPH. Just two jurisdictions required a lower speed (Arlington and Washington, D.C.), and two cities placed their limit at 20 MPH (Columbus and Indianapolis).

Following the association of speed and safety, three cities restricted speeds in specific areas: Baltimore limits the scooters to 8 MPH along the Inner Harbor Promenade; San Jose limits the devices to 12 MPH in the downtown core; and St. Paul has a 10 MPH limit in designated parkland areas of the city. Although required, there has been some concern and doubt whether these vehicles can be adequately constrained to their location-specific speed restrictions.

Table 12 Jurisdictions with Vehicle Specification

Jurisdiction	Front Light [1]	Rear Light [1]	Brake	Speed Limit (MPH)	Reduced Speed Zones (MPH)
Arlington, VA	Yes	Yes	Yes	10	-
Atlanta, GA	-	-	-	15	-
Austin, TX	Yes (300’)	Yes (300’)	Yes	15	-
Baltimore, MD	Yes	Yes	Yes	15	Yes, 8
Boise, ID	-	-	-	15	-
Charlotte, NC	Yes	Yes	Yes	15	-
Chicago, IL	Yes	Yes	Yes	15	-
Cincinnati, OH	-	-	-	15	-
Columbus, OH	Yes	Yes	Yes	15	-
Detroit, MI	Yes	Yes	Yes	15	-
Fort Lauderdale, FL	-	-	-	15	-
Indianapolis, IN	Yes	Yes	-	20	-
Long Beach, CA	-	-	Yes	15	-
Lubbock, TX	500’	500’	Yes	-	-
Miami, FL	-	-	-	15	-
Montgomery County, MD	-	-	-	15	-
Nashville, TN	Yes	Yes	-	15	-
Portland, OR	-	-	-	15	-
Sacramento, CA	-	-	-	15	-
San Francisco, CA	Yes	Yes	Yes	-	-
San Jose, CA	-	-	-	15	12
St. Louis, MO	Yes	Yes	Yes	15	-
St. Paul, MN	Yes	Yes	-	-	10
Winston-Salem, NC	Yes	Yes	Yes	-	-
Washington, D.C.	-	-	-	10	-

Notes:

-: Indicates no mention of vehicle specification requirements

[1] *If the requirement specified the distance from which the light must be seen, the distance is included in parentheses.*

For any jurisdiction listed in Table 8 *or* Table 9 *but not listed in this table, this indicates no relevant requirements were identified in the documents reviewed.*

Twelve agencies required a minimum rider age between 16 and 18: (N=7 for 16 years; N=5 for 18 years). Albeit, Chicago requires granted permission for anyone between 16 and 18 to ride, and Columbus requires anyone between 16 and 18 to wear a helmet when riding a device. Oxford’s ordinance states “persons holding a valid driver’s license” may operate an e-scooter.

We were surprised to discover that there are few requirements related to injury or crash reporting. Arlington and Portland included language relating to injury reporting within their data share agreements. It is speculated that many injuries go unreported, perhaps due to incidents involving solely the e-scooter user, and that privacy laws inhibit that reporting from being shared.

3.4.4 Rebalancing/Removal

As e-scooters are dockless, many agencies have expressed concern about how e-scooters are rebalanced across service areas. Dockless means that the user may end their trip in any location that is deemed acceptable per the ordinance, city code, and/or the permitting regulations or areas deemed restricted by private owners and/or campuses. Multiple agencies that we studied have specific time frames to which improperly parked and/or improperly functioning e-scooters must be rebalanced and/or removed following a reported complaint. The response times to which a reported scooter must be addressed range from as little as two hours to as long as 12 hours. This varies by jurisdiction but primarily by the time of day and which day of the week. To ensure that removal and rebalancing on reported e-scooters is conducted, 19 of the jurisdictions have required a 24-hour customer care line, five have required operators to maintain a local office, and 15 have required a dedicated staff point-of-contact from the company.

Table 13 Operation and Response Time Requirements by Jurisdiction, 1 of 2

Jurisdiction	Required Response Time (weekdays)	Required Response Time (holidays and weekends)	Hours of Operation
Arlington, VA	2 hrs.	2 hrs.	-
Austin, TX	2 hrs. (6:00AM – 6:00PM), 10 hrs. otherwise	10 hrs.	-
Baltimore, MD	-	-	4:00AM – 11:00PM
Charlotte, NC	2 hrs.	2 hrs.	-
Chicago, IL	2 hrs.	2 hrs.	5:00AM – 10:00PM
Cincinnati, OH	2 hrs.	2 hrs.	-
Dallas, TX	2 hrs.	12 hrs.	-
Durham, NC	2 hrs.	12 hrs.	-
Fort Lauderdale, FL	2 hrs.	12 hrs.*	-
Indianapolis, IN	2 hrs. (6:00AM – 9:00PM), 6 hrs. (9:01PM – 5:59AM)		-
Long Beach, CA	2 hrs.	2 hrs.	-
Lubbock, TX	2 hrs.	2 hrs.	-
Miami, FL	2 hrs.	2 hrs.	-
Montgomery County, MD	2 hrs. (6:00AM – 11:00PM), Response prior to 8:00AM (11:00PM – 6:00AM)		5:00AM – 10:00PM
Nashville, TN	2 hrs. (6:00AM – 10:00PM), 10 hrs. (10:00PM – 6:00AM)		-
Oakland, CA	3 hrs. (9:00AM – 6:00PM), 12 hrs otherwise	12 hrs.	-
Oxford, OH	2 hrs. (6:00AM – 6:00PM), 10 hrs otherwise	10 hrs.	6:00AM – 9:00PM (removal by 10:00PM)

Notes:
-: Denotes information that was not identified in the documents reviewed.
**: Fort Lauderdale requires a 12-hour response time during holidays only; All other days are 2 hours*
For any jurisdiction listed in Table 8 *or* Table 9 *but not listed in this table, this indicates no relevant requirements were identified in the documents reviewed.*

Table 14 Operation and Response Time Requirements by Jurisdiction, 2 of 2

Jurisdiction	**Required Response Time (weekdays)**	**Required Response Time (holidays and weekends)**	**Hours of Operation**
Portland, OR	Varies: 20 min.: Emergency (obstruction of dedicated transit lanes, tracks, travel and bicycle lanes); 30 min.: Emergency (obstruction of pedestrian thruways, other obstruction requiring immediate removal); 60 min.: Non-emergency (placed on private property, rebalancing off-hours, other obstructions and nuisances)		-
Providence, RI	2 hrs.	2 hrs.	"Unavailable for rental and removed from the street between sunset and sunrise"
Raleigh, NC	2 hrs.	2 hrs.	7:00AM – 10:00PM
Sacramento, CA	2 hrs.	2 hrs.	-
San Diego, CA	2 hrs.	10 hrs.	-
San Francisco, CA	1 hr.	1 hr.	-
San Jose, CA	2 hrs.	2 hrs.	-
St. Paul, MN	2 hrs.	2 hrs.	-
Washington, D.C.	2 hrs.	2 hrs.	24 hours / 7 days a week / 365 days a year
Winston-Salem, NC	2 hrs.	2 hrs.	6:00AM – 9:00PM

Notes:

-: Denotes information that was not identified in the documents reviewed.

**: Fort Lauderdale requires a 12-hour response time during holidays only; All other days are 2 hours*

For any jurisdiction listed in Table 8 *or* Table 9 *but not listed in this table, this indicates no relevant requirements were identified in the documents reviewed.*

Out of the 27 observed agencies, 25 require the operators to address the rebalancing and/or removal issue when related to a reported complaint of an improperly parked and/or non-functioning e-scooter within two hours of the complaint. It is noteworthy that Portland included additional specification by establishing a hierarchy of emergency and nuisance obstructions. An e-scooter must be removed within 20 minutes if the device is affecting transit/travel/bicycle lanes; non-emergency obstructions require the device to be rebalanced within one hour.

Pertaining to special events, some agencies have a clause that grants them the right to require the operator to remove devices if deemed unsafe for the public. Fort Lauderdale requires its operators to remove their fleet(s) 24 hours before a tropical event. Three cities prone to winter weather, Cincinnati, Providence and Arlington, reserve the right to require operators to remove devices in extreme weather events.

Many agencies appear concerned about e-scooters during specific times of the day, most notably late evening and before dawn, where individuals riding e-scooters may face a higher risk of incidents on public transportation facilities. From this, 20% of agencies have language within their regulations that require the shared-mobility devices to be completely removed from city streets.

3.4.5 Parking and Spatial Restrictions

Restrictions on parking primarily address the complications associated with obstruction of dockless scooters. Various prohibitions are identified, with restricted proximity in terms of distance to fire hydrants, intersection pedestrian push buttons, transit platforms and stops, bicycle racks, bicycle share points, curbs and cutouts. Cities and counties have also been dealing with improper parking of scooters by imposing mandates including: vender education programs to train users; requiring users to photograph parked vehicles to end rides; outlining bins or designated e-scooter parking places in popular parking areas; and geofencing of parks and/or districts where e-scooter use is deemed to be problematic.

Contrary to the common discussion in the media, few agencies offer clear restrictions in terms of providing designated/painted bins or parking spaces for the scooters. Perhaps this is the case, as when the programs start, agencies and the operators may have a general idea and/or area where e-scooter users will be parking, but await operations and the retrieval of data to identify target areas for bins. However, embedding a clause that requires or mandates that the operators will be responsible for designating, or at least educating, the users on parking in the bins in the future maybe a valuable strategy.

Geofencing, the capability to spatially constrict e-scooters into or outside of designated areas, prohibits users from parking in a particular location, lowers the speed at which an e-scooter can ride and is another consistent topic within the regulations. Geofencing was referenced in at least 12 of the cities, with language primarily stating that the operator must have the capability to geofence, or the city retains the right to decide if areas could be designated as no-park areas. Such is the case in Oxford, where the regulations state that the “City manager, or his designee, reserves the right to determine certain street blocks where free-floating bicycle share or e-scooter parking is prohibited or to create geo-fenced stations within certain areas where bicycles and e-scooters shall be parked.”

Table 15 Parking and Spatial Restrictions by Jurisdiction

Agency	Capability in Geofencing?	Photo Required	Sidewalk Space Clearance	Bins	Distance related to ADA
Arlington, VA	Yes	-	-	-	-
Atlanta, GA	Yes	-	-	-	-
Austin, TX	Yes	-	3’	Yes	-
Baltimore, MD	Yes	-	-	-	-
Charlotte, NC	Yes	-	6’	-	-
Chicago, IL	Yes	Yes	6’	-	-
Cincinnati, OH	Yes	-	-	-	-
Dallas, TX	Yes	-	4’	-	-
Denver, CO	Yes	-	5’ (8’ on arterial roads)	-	-
Detroit, MI	Yes	-	6’	-	6’
Fort Lauderdale, FL	-	-	4’	-	-
Greensboro, NC	-	-	6’	-	-
Indianapolis, IN	Yes	Yes	-	Yes, “Drop zones”	-
Long Beach, CA	Yes	-	4’	Yes, “Home zones”	4’
Miami, FL	Yes	-	3’	-	-
Montgomery County, MD	-	-	-	Yes	-
Oxford, OH	Yes	-	-	Yes	-
Portland, OR	-	-	6’	-	5’
Providence, RI	-	-	4’	-	-
Raleigh, NC	Yes	-	5’	-	-
Sacramento, CA	-	-	-	Yes	-
Salt Lake City, UT	-	-	10’ on Main Street; 8’ elsewhere in Zone 1; 5’ in Zones 2 and 3	Yes	15’
San Diego, CA	Yes	Yes	-	-	
San Jose, CA	-	-	-	Yes	“Complies with Americans with Disability Act clearance standards”
St. Paul, MN	Yes	-	5’	-	“Adjacent to, within, or blocking”
Washington, D.C.	Yes	-	5’	-	-

Notes:
-: Denotes information that was not identified in the documents reviewed.
For any jurisdiction listed in Table 8 *or* Table 9 *but not listed in this table, this indicates no relevant requirements were identified in the documents reviewed.*

In cities that did require geofencing, commonalities were noticed. Dense, urban parks and plazas, trails, cemeteries, stadiums and convention centers were the typical areas that were prohibited for parking, or scooter activity all together. Baltimore, St. Louis, and Washington, D.C., geofenced their stadiums; Charlotte and Arlington geofenced cemeteries; Miami and San Diego geofenced marinas; and Atlanta and Dallas have restricted access on inner-city trails. Some universities also had restricted access or limited speed. Boise State University has enacted a “slow-zone” and North Carolina State University in Raleigh has prohibited scooting all together.

3.4.6 Equity

While not the most prominent theme, 14 of the studied cities include policies that aim to promote equity ranging from equity-zone terms, cash-free options, smartphone-free accessibility, and discount opportunities. Although the terms vary, equity-zone policies indicate neighborhoods or districts where (a) venders are required to offer some minimum level of service or (b) venders may receive some additional benefit from servicing. Across the 12 jurisdictions with equity-zone terms, some require a count of vehicles or a percentage of the vender’s fleet required within designated zones. Durham set its boundaries by census tracts: “at least 20% of devices within census tracts 9, 10.01, 10.02, 11, 13.01, 13.03, & 14.” Portland used areas that were identified in its 2035 Comprehension Plan: “Deploy a minimum of 100 Shared Scooters or 20% of the Permittee's fleet (whichever is less) each day in the historically underserved Eastern Neighborhoods as defined by the City of Portland's 2035 Comprehensive Plan.” Minneapolis identified areas based on an update within the city’s Transportation Action Plan: “800 in downtown & surrounding neighborhoods, and at least 600 scooters must be distributed in areas of concentrated poverty in north, northeast and south Minneapolis, and align with the work of the Minneapolis Transportation Action Plan update.”

Accessing e-scooters is typically processed through the operator’s smartphone application. Recognizing that all residents may not possess a phone capable of said apps, 11 of the agencies have embedded smartphone-free accessibility into their regulations to ensure all individuals may have access to e-scooters.

Discounted opportunities and cash-free options were required by some jurisdictions (at least eight of the observed pool of agencies). However, two agencies required operators to provide unlimited, 30-minutes-or-less trips to individuals who met a certain financial requirement. For example, Oakland and Oxford, respectively, require operators to offer:

“a discounted membership plan for those with low-incomes, equivalent for one year of unlimited 30 minute rides for those who participate in the State Nutritional Assistance Program (SNAP) or California Alternative rates for Energy (CARE)”

and:

“low-income customer plan that waives any applicable bicycle/e-scooter deposit or unlock fee and offers an affordable payment option and unlimited trips for under 30 minutes to any customer with an income level at or below 200% of the federal property guidelines, subject to annual renewal.”

Table 16 Equity Policies by Jurisdiction

Agency	Smartphone-free Option	Cash Option	Discount Option	Equity Zones	Percentage and/or Numbers
Atlanta, GA	Yes	Yes	Yes	Yes	-
Baltimore, MD	Yes	Yes	Yes	Yes	No more than 35% in one of the three zones
Chicago, IL	Yes	Yes	Yes	Yes	25% of devices in each of two sub-areas
Denver, CO	Yes	Yes	Yes	Yes	100 of 350 in fleet in 'Opportunity Zones'
Durham, NC	Yes	Yes	-	Yes	20% of devices in certain census tracts
Fort Lauderdale, FL	Yes	-	-	-	-
Minneapolis, MN	Yes	Yes	Yes	Yes	800 in downtown and surrounding neighborhoods; At least 600 in other specified neighborhoods
Nashville, TN	Yes	Yes	Yes	Yes	-
Oakland, CA	-	-	Yes	Yes	At least 50% deployed in "Community of Concern'
Oxford, OH	Yes	Yes	Yes	Yes	No more than 50% in Uptown District
Portland, OR	-	-	Yes	-	Deploy a minimum of 100 or 20% of a fleer (whichever is less) in areas defined within the 2035 Comprehensive Plan
Providence, RI	-	Yes	Yes	Yes	-
Sacramento, CA	-	-	-	Yes	-
San Francisco, CA	-	Yes	Yes	-	-
San Jose, CA	-	-	Yes	Yes	At least 20% must deploy in 'Community of Concern'
St. Paul, MN	Yes	Yes	-	Yes	Minimum of 30% of fleet in 'Areas of Concentrated Poverty where 50% or more of the residents are people of color'
Winston-Salem, NC	Yes	Yes	-	-	-
Washington, D.C.	Yes	Yes	-	-	-

Notes:
-: Denotes information that was not identified in the documents reviewed.
For any jurisdiction listed in Table 1 but not listed in this table, this indicates no relevant requirements were identified in the documents reviewed.

3.5 DISCUSSION

This study reviewed a sample of agency documents, including vender permitting requirements, ordinances, and adopted regulations from 35 local governments (specifically, 33 cities and two counties). The sample pool of the cities ranged in sizes from just under 23,000 people (Oxford, OH) to 2,705,994 (Chicago). The cities were spread around the country, spanning 19 states and the District of Columbia.

Amongst the shared-mobility documents, the most prominent themes include: fees and charges; ridership and data requirements; vehicle specifications and safety concerns; parking and restricted access; and, to a lesser extent, equity concerns. Within those themes were topics that were consistent across the majority of the agencies. For example, it was observed that at least 19 of the 35 jurisdictions include a requirement that shared-mobility operators maintain some form of a customer service line where complaints could be addressed. Although shared across multiple cases, differences emerged and language varied amongst the lines being accessible by time, toll-free, amongst other qualities.

While this paper provides an updated review of requirements from U.S. agencies, extending the Anderson-Hall et al. (2019) review, it is worth noting that many agencies may be looking towards and adopting regulations based on steps taken from other agencies. For example, St. Paul and Denver required venders to submit an MDS format developed by the City of Los Angeles. Other commonalities amongst cities are exemplified in the results throughout this paper. It is not surprising with such a new method and trend in transportation that cities are adopting regulations established in peer cities. One recommendation for cities considering developing their own regulations is to consider the importance of context-sensitive regulations when examining differences across regulations. For one, cities might identify “sister cities” that capture similar local policy, social, and environmental contexts in different ways. For example, cities within the same states have representative legal considerations regarding the types of fees assessed or the vehicle specification requirements—making a same-state sister city a useful comparison. A city that’s approximately the same size or density but in a different part of the region could provide complimentary representation to understand the implications of MUR requirements.

There exists a gap between the research and regulator concerns regarding whether e-scooter programs improve social equity and environmental conditions. However, little research or regulatory frameworks exist to confirm and manage these assumptions. The traffic and emissions generated from the redistribution of e-scooters throughout cities could offset the reductions in vehicle travel facilitated by scooter programs. Social equity is also a concern as e-scooters have the ability to improve access to jobs, goods, and services. Many pilot programs stress or require adherence to minimum unit deployment numbers for underserved and low-income areas. For example, at least 100 e-scooters were required to be deployed in East Portland, an area underserved by transit options (Portland Bureau of Transportation, 2018). Regulations which make the equitable distribution of devices a reality do not appear to exist, or at most, they are infrequently enforced.

E-scooters face similar regulatory gaps to those of e-bikes, and in the early 2000s, Segways. In countries which have adopted alternative mobility devices, including e-scooters, a comprehensive set of national standards for regulating these devices does not exist (Siman-Tov et al., 2017). Gaps in standards and regulations can lead to higher rates of unsafe use, improper parking, and increased rates of injuries among users (Halfon, 2019). Additionally, a general lack of enforcement by both law enforcement and the e-scooter companies themselves does not serve to support proper use and rider safety (Anderson-Hall et al., 2019; National Transport Commission, 2019; Populus, 2018; Portland Bureau of Transportation, 2018). Lastly, it is worth commenting on the speed of which regulations have changed and evolved since the last review of considerations (Anderson-Hall et al., 2019) just a year ago. Micro-mobility technology and services are likely representative of new private services to be expected in the future. The ability for agencies to foster the development of these and other new services and technologies for the benefit of the public will also require agencies to respond faster than they ever have before with regards to both regulations and the evaluation of programs. The adoption of e-scooter—or, more generally, micro-mobility—programs may help cities anticipate the flexibility, speed, and data processing requirements that will be necessary in the transportation landscape of tomorrow.

4.0 SALT LAKE CITY NON-OPTIMAL BEHAVIORS AND INFRASTRUCTURE

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4.1 OVERVIEW

In this part of our study, we are interested in understanding how infrastructure—specifically bike lanes, the presence of light rail, and the size of the facility—relates to observations of non-optimal behaviors for different mode users (e-scooters, bicyclists, pedestrians, and drivers). We developed a paired-site analysis to compare similar facilities and observed rates of non-optimal behaviors across different locations, including behaviors such as signal violations, e-scooting/biking on sidewalks or in vehicle lanes, vehicles encroaching on active traveler spaces, and distracted riding/walking.

With the assistance of the Technical Advisory Committee, we developed the following research questions corresponding with the research objectives:

- Do **bike lanes** correspond with improvements in optimal behavior rates in areas **with and without rail transit**?
- Does the presence of **rail transit** correspond with higher rates of non-optimal behavior **with and without bike lanes**?
- Do **larger facilities** correspond with higher rates of non-optimal behaviors?

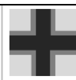
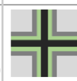
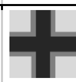
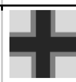
We then identified potential non-optimal behaviors to examine from the literature and categorized each behavior based on whether they are impacted by infrastructure or something else (see Table 17). We expect that some infrastructure might correspond with differences in some types of non-optimal behaviors; these expected outcomes are also specified in Table 18. In this study, we primarily aim to track the non-optimal behaviors that are possibly influenced by infrastructure, but we also include other non-optimal behaviors in our observations, including clustering, two or more passengers riding, and riding with no helmet.

For each research question, we compare data between two sites (differentiated by infrastructure type but controlled by other potential environmental factors) to examine the effect of transportation infrastructure on the rates of non-optimal behaviors. This research design is considered a paired analysis wherein sites are selected based on differentiated characteristics (e.g., presence of bike lanes, rail, or size of facility) and control characteristics (e.g., similar sidewalks, size of lane or intersection, presence of similar signalization). Comparisons between the rates of non-optimal behaviors can then be made by comparing the statistical differences in the rates of non-optimal behaviors across paired locations.

Table 17 Non-Optimal Behaviors Identified in the Literature

Type	No	Factor recorded	Definition	Behavior impacted by infrastructure or something else ("Other")
Scooter User Behaviors	SC1	Riding on sidewalks	Scooter user riding in sidewalks or crosswalks	Infrastructure
	SC2	Riding on vehicle lanes	Scooter user riding on vehicle lanes (not including sharrows) when no bike lane is provided	Infrastructure
	SC3	Signal violation	Scooter user running red lights	Infrastructure
	SC4	Distracted riding	Scooter user using electronic devices or headphones while riding	Infrastructure/Other
	SC5	Cluttering	Scooter not parked properly (e.g., left in a vehicle lane or vehicle parking space, obstructing the movement of pedestrians)	Other
	SC6	Two or more passengers per scooter	Two or more people riding together on one scooter	Other
	SC7	No helmet	Scooter user with no helmet	Other
Bicyclist Behaviors	BK1	Riding on sidewalks	Bicyclist riding in sidewalks or crosswalks	Infrastructure
	BK2	Riding on vehicle lanes	Bicyclist riding on vehicle lanes (not including sharrows) when no bike lane is provided	Infrastructure
	BK3	Signal violation	Bicyclist running red lights	Infrastructure
	BK4	Distracted riding	Bicyclist using electronic devices or headphone	Infrastructure/Other
Pedestrian Behaviors	PE1	Walking not using sidewalks	Pedestrian walking on bike lanes or vehicle lanes	Infrastructure
	PE2	Signal violation	Pedestrian running red lights	Infrastructure
	PE3	Distracted walking	Pedestrian using electronic devices or headphone while walking	Infrastructure/Other
Driver Behaviors	DR1	Signal violation	Driver running red lights	Infrastructure
	DR2	Not yielding	Driver not stopping or slowing down for scooters, bicyclists, pedestrians or other vehicles at conflict points	Infrastructure/Other
	DR3	Taking over other spaces	Driver taking over crosswalk or bike lane space	Infrastructure/Other
Sources: (Cooper et al., 2012; Diependaele, 2019; Dommes et al., 2015; Gillette et al., 2016; Hatfield & Murphy, 2007; Haworth & Schramm, 2019b; Høye, 2018; Klauer et al., 2015; Lyons et al., 2020; PBOT, 2018; Russo et al., 2018; Sparks et al., 2019; Useche et al., 2018; Zhang et al., 2019)				

Table 18 Research Questions, Site Selection, and Expected Results

Research Questions	**Study Site Type**		**Expected Non-Optimal Behavior Rates**			
			Scooter User	**Bicyclist**	**Pedestrian**	**Driver**
1. Do **bike lanes** correspond with improvements in optimal behaviors in areas **without rail transit**?	**Site1** (control)		Higher	Higher	Higher	Higher
	Site2 (treatment)		Lower	Lower	Lower	Lower
2. Do **bike lanes** correspond with improvements in optimal behaviors in areas **with rail transit**?	**Site3** (control)		Higher	Higher	Higher	Higher
	Site4 (treatment)		Lower	Lower	Lower	Lower
3. Does the presence of **rail transit** correspond with higher rates of non-optimal behavior **without bike lanes**?	**Site1** (control)		Higher	Higher	Higher	Higher
	Site3 (treatment)		Lower	Lower	Lower	Lower
4. Does the presence of **rail transit** correspond with higher rates of non-optimal behavior **with bike lanes**?	**Site2** (control)		Higher	Higher	Higher	Higher
	Site4 (treatment)		Lower	Lower	Lower	Lower
5. Do **larger facilities** correspond with higher rates of non-optimal behaviors?	**Site1** (control)		Higher	Higher	Higher	Higher
	Site5 (treatment)		Lower	Lower	Lower	Lower
Image legend: Bike lane Sidewalk Vehicle lane Rail transit						

4.2 DATA & METHODS

This portion of our study produces original data. As such, this section provides an overview of the development of our methods for both data collection and analysis. First, we identified multimodal, non-optimal behaviors that are likely influenced by infrastructure differences in the literature (cited in the last section and summarized below). Second, we developed an observation protocol that enabled us to track as many of these observations as possible. Third, we identified multiple potential data collection locations that align with our research questions in a paired-analysis format. Fourth, after collecting the data, we performed a series of paired-analysis hypothesis tests. The following subsections describe these processes in more detail.

All data in this chapter were collected in Salt Lake City, UT. Salt Lake City has a population and employment density of 1,816 and 5,907 per square mile, respectively, as of 2019, with two major interstate highways, notably wide streets, and multiple public transportation options, such as commuter rail, buses, light rail, and streetcar. The road network in downtown Salt Lake City, where scooter use is concentrated, consists of major arteries and local roads with a speed limit range of 20 to 40 miles per hour, and many downtown road segments include sidewalks and bicycle infrastructure. A light rail system running through the downtown area, from east to west and north to south, provides access to key destinations, such as the University of Utah and the Salt Lake City International Airport.

4.2.1 Observation Protocols

Preliminary observations were conducted in early Spring 2020 to formulate an observation protocol, conduct interrater reliability tests, and train observers. The methods in this study built upon our prior work (Lyons et al., 2020). The initially proposed video data collection method was to record selected intersections from a birds-eye view with a video camera mounted on the third or fourth floor of abutting buildings. This was the approach used in a pilot study completed in Salt Lake City in 2019. However, due to difficulties getting private property owners to allow the research team to mount cameras from their buildings, we developed and tested a more viable approach that couples ground-level video recording with in-person manual counts. In this approach, street-level video cameras are stationed to capture counts of travelers by mode entering the intersection, while our student data collectors capture (non-)optimal behavior frequencies and proportions. This approach limits the need for obtaining rooftop access permission, and it reduces the overall time spent processing the video data.

The actual observations were conducted in the following two pathways. First, trained student observers captured the frequency of each non-optimal behavior (summarized in Table 17) for each mode. This data was collected in real time on location during the data collection period. During these observations, observers also tracked the total number of travelers for e-scooter, bicycle, and pedestrian modes. Second, video camera recordings were collected during the period and post-processed to count the total vehicles entering the intersection during the four-hour period. The higher frequency of vehicle travelers required post-processing of video recordings in order to adequately capture the number of vehicles moving through the intersection. The data collection forms are provided in Appendix A-1.

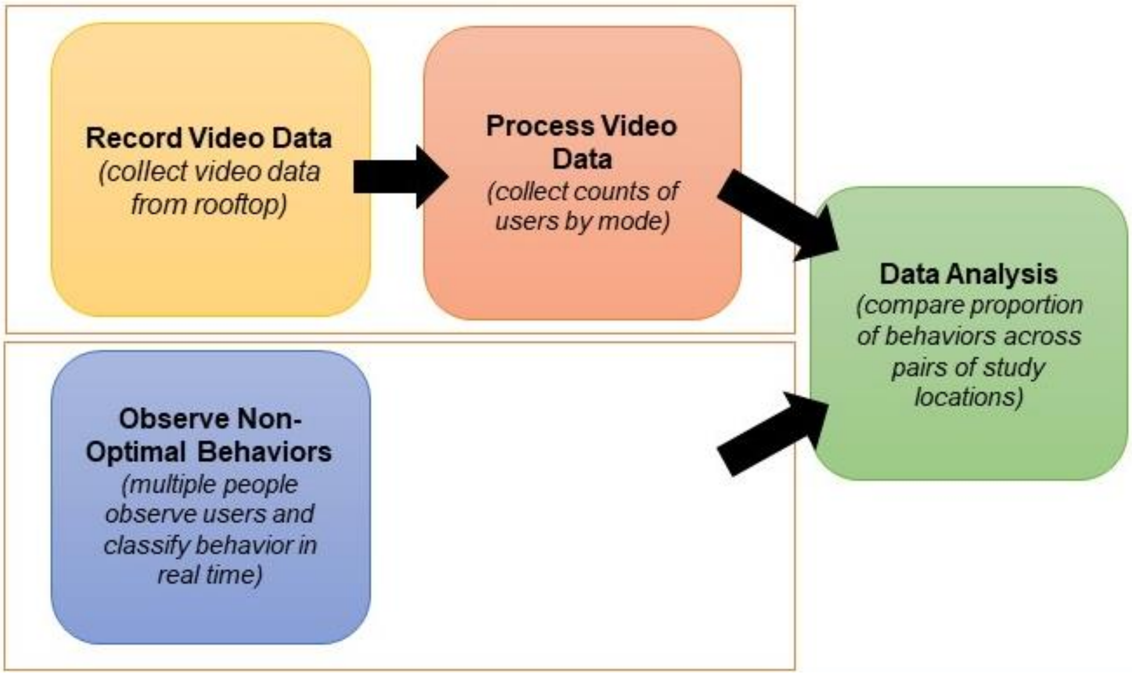


Figure 1 Flowchart of the Data Collection Process

We piloted this approach at 200 S & Main St. in Salt Lake City (see Figure 2). This site has one of the busiest sites in our Salt Lake City sample, and includes rail transit, bike lanes, and a high volume of foot and vehicle traffic. Our initial pilot confirmed that the ground-level video recording method would allow us to capture user counts by mode for directions of travel at the intersection (see Figure 1). Three to four observers (depending on the complexity of the intersection) were trained to capture non-optimal behaviors in person over 15-minute periods at each of the study locations. By observing these behaviors in-person, we were able to capture similar behaviors at 60-70% of the total cost and a fraction of the post-processing time. The video data also served as a tool for validation or quality control.

Similar to our proposed approach, we used interrater reliability testing to determine the quality of data collected and hypothesis tests of proportions to compare the rate of non-optimal behaviors across infrastructure pairs. We collected data at each intersection from 2:00 to 6:00 p.m., a time frame selected in part due to typical daily peaks in e-scooter use and also the peak hour of the facility—based on data provided from other studies or cities (Portland, OR; Tucson, AZ; Washington, D.C.).

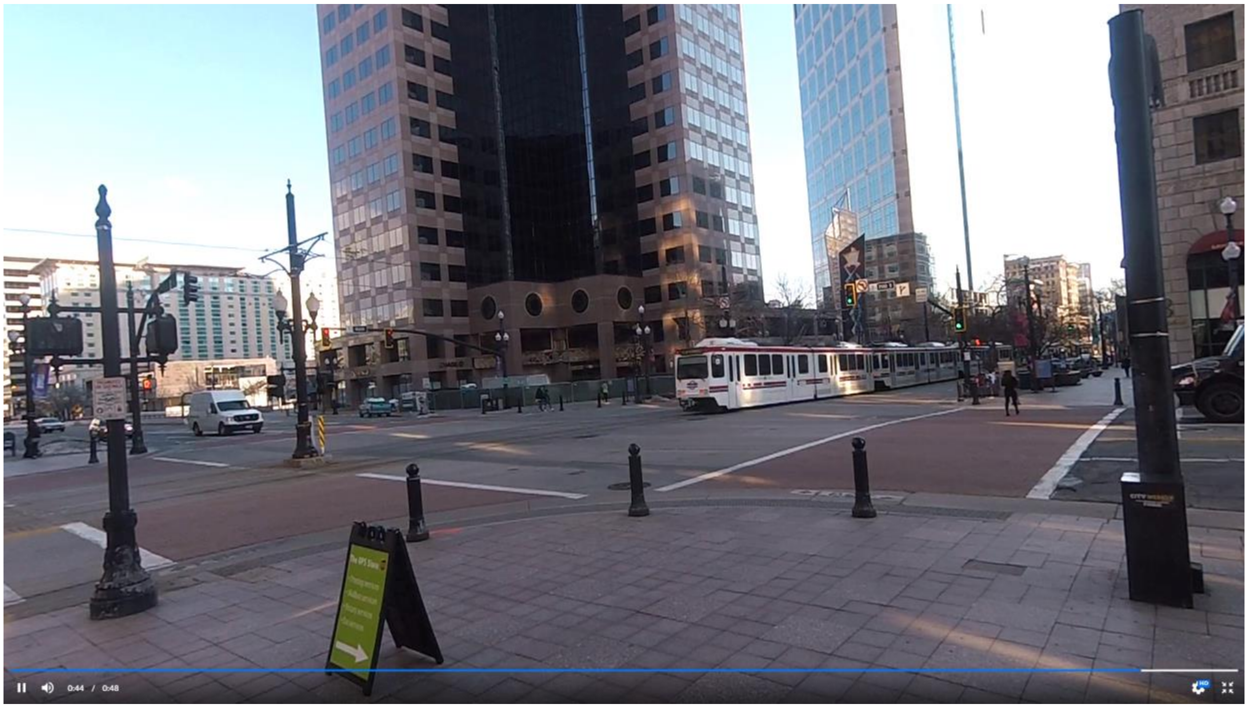


Figure 2 A Screenshot of Video Footage Recorded at 200S and Main St., Salt Lake City, Using GoPro HERO5

4.2.2 Site Selection

Based on our research questions, we then identified potential sites for data collection observations that align with each of the above research questions (see Table 19) and then identified our final study locations (see Table 20). Due to COVID-19 travel restrictions, data collection was first postponed from Spring 2020 to Fall 2020 and then limited to Salt Lake City (reducing inter-state travel). We recollected data at a different Site1 in Spring 2021 after winter weather dissipated because our original observation included unexpectedly low e-scooter usage (likely due to cold weather on the observation date in late Fall 2020).

Table 19 Select Site Characteristics and Preliminary Site Identified

No.	Site characteristics			Site (Plan A)	Site (Plan B)
	Bike lanes	**Rail transit**	**Size**		
SLC1	None	None	Medium	100S 200E	100S 400E
SLC2	4-way	None	Medium	200S 300E	300S 300E
SLC3	None	Rail	Medium	400W & W100S	University Blvd & 200E*
SLC4	4-way	Rail	Medium	200S & Main St	N West Temple & S Temple±
SLC5	None	None	Large	400S & SW Temple	400W & 400S
Tucson1	No sharrows	None	Medium	E 6th St & N Euclid Ave	W Pennington St. & N Stone Ave
Tucson2	4-way sharrows	None	Medium	E Speedway Blvd & N 6th Ave	E University Blvd & N 6th Ave
Tucson3	4-way sharrows	Streetcar	Medium	E University Blvd & N 4th Ave	E Euclid Ave & E University Blvd
Tucson4 (optional)	None	None	Large	Speedway & N Campbell	E Speedway Blvd & N Mountain Ave

Notes:
* Larger roads; ±2-way bike lanes
Controls: All 4-way vehicle intersections, signalized intersection at downtown or urban core, sidewalk, crosswalk, no steep slope

Table 20 Select Site Characteristics

No.	Study site type	Site characteristics	Selected site & date collected	Aerial image
Site1		• 4-way intersection • no bike lanes • no rail transit • medium-size road	300S 400W April 23, 2021[1]	
Site2		• 4-way intersection • 4-way bike lanes • no rail transit • medium-size road	200S 300 E October 12, 2020	
Site3		• 4-way intersection • no bike lanes • rail transit • medium-size road	100S 400W October 19, 2020	
Site4		• 4-way intersection • 4-way bike lanes • rail transit • medium-size road	200S Main St October 14, 2020	
Site5		• 4-way intersection • no bike lanes • no rail transit • larger roads	400 S & S W Temple October 16, 2020	

Notes: All sites are signalized intersection at downtown or urban core with sidewalk, crosswalk and no steep slope.

[1] We recollected data at a different Site1 in Spring 2021 after winter weather dissipated because our original observation included low e-scooter usage.

Image legend: Bike lane Sidewalk Vehicle lane Rail transit

4.2.3 Paired Site Analysis

The paired analysis of study site observations used a hypothesis test of two proportions (Z-test) to compare the statistical differences in proportions of non-optimal behaviors for each mode (see Table 18) based on our hypotheses (summarized in Table 17). Our observations were first summarized as proportions—mode-specific, non-optimal behaviors as a proportion of the total mode-specific count of users during the same data collection period. The null hypothesis (H0) of a test of two proportions is that the non-optimal behavior rates are statistically similar when comparing two intersections—in other words, that there is not enough information to detect a difference between behaviors at different locations. The alternative hypothesis, the one which we are testing, is that there is a statistical difference between non-optimal behavior proportions. The outcome of a hypothesis test is a “p-value,” which describes the level of significance of a statistical difference. A smaller p-value (e.g., p-values < 0.1) indicates the two proportions are statistically different. A larger p-value (e.g., p-values ≥ 0.1) indicates that we do not have enough information to detect a difference in non-optimal behavior rates across different types of intersections. When we detect a large p-value—meaning “no statistical difference”—it is important to remember that this *does not* mean that there is no relationship between infrastructure and non-optimal behaviors. It *does* mean that we did not collect enough information (i.e., sample size) to detect the statistical difference.

An example; In response to Research Question 1, “Do bike lanes correspond with improvements in optimal behaviors in areas without rail transit?”, we can test whether the non-optimal behavior rates at Site2 (treatment; a medium-size intersection with bike lanes) are lower than those at Site1 (control; a medium-size intersection with no bike lanes). Our hypothesis states that the non-optimal behavior “e-scooters riding on the sidewalks” is statistically lower for the site with the bike lanes (Site2 < Site1). We observed 80% of e-scooter users riding on sidewalks at Site1 (N=41 e-scooter users) compared with 35% for Site2 (N=20). After completing the hypothesis test of two proportions, we find a statistically significant difference between rates of e-scooters riding on sidewalks for the location with bike lanes (Site2) compared to the one without (Site1). We then repeat this analysis for each paired location and for every non-optimal behavior identified for each mode. These results and discussion are provided in the following section.

4.3 RESULTS

In this section, we provide an overview of our original data collected, as well as a summary of the paired site analysis results. As there were different numbers of travelers observed at each site during the four-hour observation period, to make a valid comparison among the different sites with a different sample size, we estimated the non-optimal behavior rates by dividing the number of each behavior by the total number of travelers for each mode. Although helmet usage and multi-passenger e-scooter travel are not related to our research questions, we have provided the summary of our observation in this table. Across the sites analyzed, some notably high rates of non-optimal behaviors include 74% total e-scooter users riding on sidewalks and 98% total e-scooters riding without a helmet.

For each of the five research questions and four transportation modes, we have summarized three outcomes of our analysis in Table 21. First, we provide the difference in proportions for the paired sites corresponding to each research question (treatment minus control). Second, we indicate (with an asterisk) whether the difference is statistically significant (p-value < 0.1) using the hypothesis test of two proportions described in the last section. Third, for any significant finding, we have highlighted the cell as either in support of (green) or not in support of (orange) our original hypotheses (see Table 18 for our expected results). In the following subsections, we interpret these results based on the treatment (with/without bike lanes, rail, or comparing the size of facilities) and each transportation mode observed.

Table 21 Summary of Observation: Non-Optimal Behaviors Rates by Site

No.	Behavior Description	Behavior impacted by infrastructure or something else ("Other")	Non-Optimal Behavior Rate					
			Site1 	Site2 	Site3 	Site4 	Site5 	Avg.
Scooter user								
	Sample Size:		**41**	**20**	**28**	**68**	**37**	**38**
SC1	Riding on sidewalks	Infrastructure	80%	35%	82%	76%	97%	74%
SC2	Riding on vehicle lanes	Infrastructure	0%	0%	0%	4%	0%	1%
SC3	Signal violation	Infrastructure	12%	0%	14%	1%	0%	5%
SC4	Distracted riding	Infrastructure/Other	5%	35%	18%	9%	5%	14%
SC5	Cluttering (e.g., not parked properly)	Other	0%	0%	0%	1%	0%	0%
SC6	Two or more passengers per scooter	Other	12%	5%	25%	0%	0%	8%
SC7	No helmet	Other	98%	95%	100%	99%	100%	98%
Bicyclist								
	Sample Size:		**52**	**110**	**35**	**131**	**34**	**72**
BK1	Riding on sidewalks	Infrastructure	42%	21%	60%	43%	85%	50%
BK2	Riding on vehicle lanes	Infrastructure	0%	7%	0%	1%	0%	2%
BK3	Signal violation	Infrastructure	8%	6%	23%	11%	3%	10%
BK4	Distracted riding	Infrastructure/Other	6%	10%	17%	8%	12%	11%
Pedestrian								
	Sample Size:		**187**	**220**	**274**	**249**	**276**	**241**
PE1	Walking not using sidewalks	Infrastructure	1%	2%	0%	3%	4%	2%
PE2	Signal violation	Infrastructure	35%	20%	28%	16%	13%	22%
PE3	Distracted walking	Infrastructure/Other	5%	16%	14%	0%	0%	7%
Driver								
	Sample Size:		**2,796***	**3,250**	**1,761**	**2,970**	**11,612**	**4,898**
DR1	Signal violation	Infrastructure	0%	2%	3%	0%	1%	1%
DR2	Not yielding	Infrastructure	1%	0%	0%	0%	0%	0%
DR3	Taking over other spaces	Infrastructure	1%	8%	3%	2%	0%	3%

Notes:
** As the number of cars for the last one hour was missing due to video battery power shortage, the total number of cars for Site 1 was extrapolated based on the first three-hour vehicle count (2,201) and the proportion of cars for the last hour of another similar site's data (27.04%) collected from our observation sessions (e.g., 2,201 * 1.2704 = 2,796).*
Image legend: Bike lane, Sidewalk, Vehicle lane, Rail transit

Our most significant findings are summarized as follows. We observed lower rates of e-scooter users riding on pedestrian sidewalks when bike lanes were available. For intersections without light rail transit, only 35% of e-scooter users rode on sidewalks when bike lanes were available (versus 80% without bike lanes), a statistically significant difference. E-scooter users were also less likely to violate traffic signals at intersections with bike lanes (1%) compared to those without (14%). At intersections with light rail, sidewalk riding happened at statistically similar rates for intersections with (82% for e-scooters, 60% for cyclists) and without bike lanes (76% for e-scooters, and 43% for cyclists). Similarly, e-scooter users and bicyclists are significantly more likely to use sidewalks on larger roads (six-lane facilities, e-scooter users: 97%, cyclists: 85%) compared with more medium-sized roads (four-lane facilities, e-scooter users: 80%, cyclists: 42%). E-scooter users violated the traffic signal at lower rates on larger roads (six-lane facility: 0%; four-lane facility: 12%), as did pedestrians (six-lane facility: 13%; four-lane facility: 35%). In these observations, we attempted to observe “distracted” behaviors—including using a smartphone and/or listening to music in earbuds. We noted more distracted behaviors on facilities with bike lanes (at non-rail intersections) than those without bike lanes for e-scooters (35% versus 5%), cyclists (10% versus 6%), and pedestrians (16% versus 5%). These behaviors were observed at reduced rates for intersections with light rail present.

4.4 DISCUSSION

The data collection and analysis presented in this chapter provide a replicable method for exploring transportation behaviors among varying intersection treatments, building upon Lyons et al. (2020). Transportation engineers often correlate non-optimal behaviors entirely with users’ conscious decisions to break the rules, but our findings suggest that it may be more important to consider the dynamic ways in which travelers are interacting with a built environment that may or may not be designed with their chosen mode in mind. Forbidding sidewalk riding for e-scooters (or cyclists, for that matter) may not lower the rates of sidewalk riding if there is not enough distance and/or protection from nearby vehicle facilities, particularly when facilities have higher speeds, more vehicle lanes, and/or more complex configurations (such as intersections with light rail tracks). By observing and comparing (non-)optimal behaviors of users on different types of infrastructure, we gain a better understanding about how multimodal users navigate these spaces.

It is worth noting that our observations here are limited to those behaviors that can be observed, and those observable behaviors are not necessarily all equal. The distracted behaviors we measure in this study—using electronic devices or headphones—have been shown to decrease the likelihood that pedestrians will check for traffic before entering a vehicle facility and will start crossing more slowly (Gillette et al., 2016). Although these kinds of distractions have not yet been found to statistically relate to environment characteristics (Gershon et al., 2017; Huemer et al., 2019), this has not yet been studied for e-scooter users.

Some behaviors pose higher risks to different users in the system. While we were not able to capture distracted driving, for example, this behavior presents significantly greater safety risks to other system users. The observations conducted in this analysis help to contextualize behavior with urban form, but we are nonetheless being only truly able to measure distinct and objectively categorized behaviors. There are many more forms of “distraction” that may be measured through other forms of analysis and data collection, such as simulators or surveys. The results from this study should be used with caution. This study was designed to compare behaviors *within* groups of mode users and *across* different facility types. Modal comparisons—such as those aiming at comparing compliance across modes—cannot be made from this data.

5.0 TUCSON E-SCOOTER USER SURVEY

Lead Authors: *Kristina M. Currans; Nicole Iroz-Elardo; and Quinton Fitzpatrick*

5.1 OVERVIEW

While observations of users and uses can provide useful context about how riders in the field interact dynamically with their environs and infrastructure provided, user surveys can complement these observations with more context about the reasons, preferences, and experiences of e-scooter users. In this chapter, we examine the City of Tucson e-scooter pilot program evaluation survey to explore the (a) mode substitution effects of e-scooter users, and (b) the crash experiences of riders in Tucson. This survey was administered by the City of Tucson in the winter of 2019 and 2020 (pre-pandemic) as an opt-in survey for all citizens. A portion of the survey was dedicated to those self-identifying e-scooter users, which is the focus of this chapter.

We are first interested in the substitutive effects of e-scooters in Tucson. New transportation mode options introduce new opportunities for travel and corresponding activities. However, it’s challenging to understand the role of new travel options—such as e-scooters—in our urban environments because trip-making choices depend on a variety of factors, including, but not limited to: demographics; built and natural environments; land use availabilities (mixed uses, densities, destination accessibilities); infrastructure; cultural perspectives and attitudes; alternative modal options and costs; and variations in the temporal or spatial aspects of all characteristics listed before. To understand the use of e-scooters, we must first explore the use and users of e-scooters within the context of existing and alternative travel options. In this survey analysis, we examine the travel characteristics and patterns of e-scooter riders in Tucson to explore how e-scooters have shaped modal substitutions in the existing transportation system and generated new activities (and therefore travel). **In this analysis, we first ask, how are e-scooters substitutes or complements for existing modes? And how does this behavior vary by demographics, trip purposes, and alternative modes available?**

We then turn to reported crash experiences in the City of Tucson survey. While the observations studied in the previous chapter explore non-optimal behaviors as they related to specific infrastructure facilities, in this analysis, we predict the likelihood of experiencing a crash as a function of the demographic characteristics, preferences for riding (including locations, time of day, and other contextual variables), and frequency of e-scooter riding experiences. **In this second analysis, we ask, how do crash experiences correspond with (non-)optimal riding preferences, demographics, and e-scooter riding experiences?**

This chapter is organized as follows. First, we describe the survey collected and analyzed in this chapter, including providing an overview of the sampling demographics compared with Tucson and the nation. Then, we explore the statistical methods used in this analysis before summarizing the results of our (a) mode substitution analysis and (b) crash experiences analysis. Lastly, we provide some summary and discussion about our Tucson survey findings.

5.2 DATA

The survey—developed in partnership with the City of Tucson Department of Transportation (TDOT) for their program evaluation—was conducted on the Qualtrics survey platform and administered through an online link to the survey to the TDOT E-scooter Pilot Program website. The survey was released from November 2019 to February 2020. A press release was issued sharing the website; local council members shared the survey link with their constituents; and several local news stations highlighted the pilot program and information webpage. Because this survey was intended for a program evaluation of all interested community residents, in this evaluation we focus on those respondents who stated that they used e-scooters and provided a complete response. A total of 2,530 community responses were originally collected, 885 of which were identified as e-scooter users to some degree (e.g., something other than a “I have never ridden e-scooters” response). Of those, 743 were determined to be consistent responses with no contradictory answers. A contradictory answer might include one in which respondents select more than one question response that contradicts itself. Or if a respondent listed themselves as having taken a scooter more than once, but wrote in later on that they’ve never ridden an e-scooter.

The survey had three main sections: (A) e-scooter usage information, (B) general preferences and attitudes towards e-scooters and the pilot program, and (C) demographic information about the respondent. In this chapter, we focus on questions that may address or explain the use and users of e-scooters (sections A and C). For the purposes of transferability to other agencies and researchers, we have provided the complete survey instrument in the Appendix A-2.

In the first part of the survey, respondents were asked how frequently they used e-scooters. If they answered that they used them at all, they were then asked a section of questions including: the purpose of the last trip they took; how they accessed the e-scooter (e.g., access mode and travel time to access); and why they took an e-scooter (e.g., for fun, utility). For that trip, respondents were also asked what travel mode they would have taken, had the e-scooter not been available. This question allows us to explore the potential substitutive effects of e-scooter mode availability. Following, respondents were asked to approximate the frequency in times per week of other transportation modes, in general, to meet their transportation needs over the month prior to the survey. This included the following modes: walked, bus/streetcar, car as a driver, car as a passenger, ride share, car share, personal bike, or bike share.

E-scooter users were also asked a few questions about how they prefer to ride e-scooters and their experiences with crashes. First, respondents were asked about how often they prefer to wear a helmet, and how they prefer to ride e-scooters (e.g., on sidewalks, in bike lanes, with vehicle traffic, at night or dusk). Following, respondents were then asked their experiences with crashes while riding e-scooters and the severity of crashes (for those who identified at least one incident).

In terms of demographics (section C), respondents were asked to provide: their age; gender; whether they were living with a disability; income; and highest education. Respondents were also asked to identify in terms of their confidence level while riding a bike. Lastly, respondents were asked whether they held memberships for bike share programs, purchased monthly transit or parking passes, and owned a rideable bike.

A Human-Subject Determination evaluation was conducted (UArizona # 2106881847), and it was determined that a human subjects review was not required for this program evaluation.

5.2.1 Demographic Characteristic of E-scooter Users

Focusing entirely on the e-scooter users in our survey, our Tucson sample was comparatively older on average, and more male, than the overall Tucson and national demographics suggest. E-scooter users from other cities had suggested a younger demographic, on average, but this might be in part related to the likelihood that older individuals may be more likely to go online and opt into a pilot evaluation survey. Males are more likely to ride e-scooters, which is reflected in our sample. Our Tucson sample included a greater proportion of higher-income riders and greater rates of higher educations. The majority of e-scooter use in the City of Tucson is between the University of Arizona, along the 4th Avenue commercial corridor, and within the central business district. E-scooter users, as sampled in this survey, may be disproportionately driven by the employment opportunities in and around this area. A summary of the demographic characteristics collected in the Tucson survey is provided in Table 22, along with comparative summary statistics collected in the American Community Survey (2019, 5-Year Data) for Tucson and the United States.

Table 22 Demographic Characteristics of E-scooter User Survey Respondents Compared with Tucson and United States Demographic Characteristics

	Survey Response			American Community Survey (2019, 5-Year)[1]	
Demographic Characteristic	**E-scooter Users**		**Demographic Characteristic**	**Tucson**	**United States**
	Value	**N**		**Value**	**Value**
Age					
Mean (st. dev.)	38 (12.5)	664			
Median	36	664	Median	33.7	38.1
	Proportion (%)	**Sample Size (N)**		**Proportion (%)**	**Proportion (%)**
Gender			**Sex (18 and over population)**		
Female	38.9	289	Female	50.5	51.5
Male	55.3	411	Male	49.5	48.5
Non-binary	0.7	5			
Prefer not to say	5.1	38			
Income					
Under $10,000	3.6	23	Under $10,000	9.6	6.0
$10,000 to $14,999	2.8	18	$10,000 to $14,999	6.2	4.3
$15,000 to $24,999	6.4	41	$15,000 to $24,999	13.2	8.9
$25,000 to $34,999	7.7	49	$25,000 to $34,999	11.7	8.9
$35,000 to $49,999	15.4	98	$35,000 to $49,999	15.6	12.3
$50,000 to $74,999	21.1	134	$50,000 to $74,999	17.9	17.2
$75,000 to $99,999	13.4	85	$75,000 to $99,999	10.8	12.7
$100,000 to $149,999	17.5	111	$100,000 to $149,999	9.7	15.1
$150,000 to $199,999	6.3	40	$150,000 to $199,999	3.2	6.8
$200,000 or more	3.9	25	$200,000 or more	2.1	7.7
I am retired and/or live on savings	1.8	12			
Prefer not to answer	---	105			
Education			**Education (18 and older)**		
Some high school	1.4	10	<12th grade	14.6	12.1
High school degree	7.2	52	High school graduate	24.6	27.5
Some college	20.6	150	Some college or associates	30.3	23.4
Technical degree (including trade school)	4.4	32	Associates	6.8	7.4
2-year degree	6.3	46			
College degree/4-year degree	28.7	209	Bachelors	15.0	18.7
Some post graduate	6.7	49			
Master's degree (including Law)	18.3	133	Graduate	8.7	10.9
Doctorate	5.8	42			
Prefer not to answer	---	14			

Notes:
Total sample size is 743. There are 570 complete cases when including age, gender, income, and education.
NA: not applicable; na: not available
[1]2019 American Community Survey (5-Year), Age (Table: S0101); Sex, Citizen, 18 and over population (Table: DP05); Income, 2019 inflation-adjusted dollars, household-level (Table: S1901); education, 18 or older (S1501).

Respondents were also asked if they identified as having or living with a disability. Approximately 7% of the respondents identified as having or living with a disability, such as mobility or dexterity (3.5%), visual (0.3%), auditory (0.8%), or other (1.9%). Respondents could identify as having more than one disability, and approximately 4% of the respondents declined to answer.

5.3 METHODS

The cleaned data were first explored using descriptive statistics and plotting. A portion of the descriptive tables and distribution summaries are provided in the results section. Logistic regression analysis was used to address both questions listed in the introduction (i.e., mode substitution and crash experiences). In these regressions, a binary probability was estimated (yes/no outcome) as a function of influencing variables.

For the mode substitution question, the binary outcomes include the modes identified when asked “for your last e-scooter trip, what mode would you have taken if the e-scooter was not available?” Five models were estimated, one for each mode category: no trip would have been taken; active modes; transit modes; shared vehicle modes (including being a passenger in a car); and car modes (driving a vehicle). Each mode substitution was estimated as a function of demographics (gender, age, and income), trip purpose, and alternative modes available. For the crash experience questions, the outcome for the model is “yes” the respondent has experienced an e-scooter crash of some kind.

All demographic variables are represented in these models as categorical dummy variables, thus a “base case” category is selected to represent the base case for which all other coefficients are compared to. For example, if the gender “male” is the base case, the coefficient for “female” is measured as it relates (more or less) to the male observations. Indicators for “trip purpose” and “alternative modes available” were not mutually exclusive and, therefore, the coefficients can be interpreted as the effect when X-option was selected versus when X-option was not selected (no base case comparison required).

Logistic regression coefficients themselves are challenging to interpret. For the purposes of this analysis, we convert all coefficients to the odds ratio, which provides relative probabilities (e.g., higher or lower likelihoods) for which to interpret. An odds ratio of greater than 1.0 indicates a positive relationship between the independent variable and the outcome, analogous to a probability. For example, an odds ratio of 2.27 indicates a 127% increase in the likelihood that an outcome would occur. An odds ratio of less than 1.0 indicates a negative relationship, although the interpretation requires a bit more context. Negative odds ratios are converted into a “percentage less likely” estimation by dividing 1.0 by the odds ratio. For example, an odds ratio of 0.44 means that the outcome is 127% less likely to occur for that indicator (1.0/0.44 = 2.27 ~ 127% less likely). For the purposes of simplification, the percent-more (-less) likely to occur is provided in all regression tables, and negative relationships are highlighted in red text.

For all regressions, we provide an estimate for the amount of variation explained for each regression. For logistic regressions, we use the Nagelkerke R^2 value, a pseudo R^2 approximation used for non-linear regression, analogous to the “OLS R^2” value. We also test for the variance inflation factor (VIF), an indication that independent variables may be too correlated to include together, but we did not note any issues of concern for the regression provided.

5.4 RESULTS

In this section, we provide the results of the analysis, separated into two sections. First, we explore the reasons and purposes of e-scooter use, including regression results for mode-substitution, had e-scooters not been available to respondents on their more recent trip. Second, we examine the crash experiences of respondents, including the relationships between preferences for how riders prefer to travel and their experiences in e-scooter crashes. In both subsections, we first summarize initial survey responses, then present logistic regression findings.

5.4.1 E-scooter User Trip Purpose, Mode Substitution, and Frequency

For the most recent trip the survey respondents recalled, the primary reasons for selecting an e-scooter was that it was “fun” (55%), the “fastest and most reliable option,” and that “parking was difficult at that time/destination” (see Table 23). Interestingly enough, nearly a quarter of respondents stated they took an e-scooter because it was “good for the environment.” Approximately 23% took an e-scooter because it was less expensive than other ways they might get to their destination.

Table 23 Reason for Taking an E-scooter by Proportion of Respondents

Reason for taking an e-scooter	**Proportion (%)**
It was just for fun	54.8
It was the fastest and most reliable option.	37.9
Parking is difficult at that time/destination	30.0
It is good for the environment	24.7
It was less expensive than other ways to get there	23.5
Did not want to get sweaty	12.3
No Bus/Shuttle/Streetcar at that time/destination	11.6
Other	6.7
Do not have a car	4.6

Notes:
Sample size: 738
Respondents could select more than one options.

Respondents were also asked, for the trip most recently taken, what they would have taken if e-scooters had not been available for that trip. We summarize this information along with the stated frequency of e-scooter trips (overall) respondents provided (see Table 24). In this table, we explore the distribution within each substitutive mode shares by the frequency of trips each respondent reported taken. Most frequently, respondents reported that they would have ridden a personal bike if an e-scooter hadn't been available (35.7%); followed by using a vehicle (23.8%); riding a personal e-scooter (14.5%); and taking some sort of ride hailing service (12.4). In both cases, this suggests that the common substitutive methods for ridership in Tucson continue to be vehicle- or active-based substitutions. Approximately 6% of users reported that they would not have taken the trip, suggesting that e-scooters contribute towards generating travel, in some way. While many areas fear e-scooters are taking large public transit and/or bike share trips in Tucson, that appears to be a minor proportion of travel (2.7% and 3.3%, respectively). Far fewer respondents said they would have substituted walking for e-scooters, but this may correspond with the larger block size in Tucson or the higher temperatures in general, compared with other studies in other cities.

Table 24 Proportion of E-scooter Users by their Stated Trip Substitution for Last Trip Taken, Summarized by the Stated Frequency of E-scooter Use

If a shared e-scooter had not been available, how would you most likely have gotten around?	Substitution Type	Reported Frequency of E-scooter Trips (Proportion, %)						Total
		Once	Once/ week	1-2 times/ week	3-6 times/ week	Daily	More than once daily	
Would not have taken the trip	No Trip	2.0	3.3	0.7	0.3	0.0	0.0	**6.3**
Walked	Active	0.1	0.4	0.0	0.0	0.0	0.0	**0.5**
Ridden a personal e-scooter	Active	2.6	7.6	2.4	1.4	0.4	0.1	**14.5**
Ridden a TuGo bike share bike	Active	1.6	1.4	0.3	0.0	0.0	0.0	**3.3**
Ridden a personal bike	Active	14.5	15.2	4.1	1.1	0.7	0.1	**35.7**
Taken a Bus or Streetcar trip	Transit	0.3	1.4	0.8	0.1	0.0	0.1	**2.7**
Taken a taxi, Uber, Lyft, or other ride hailing service	Shared	3.0	5.1	2.3	1.6	0.3	0.1	**12.4**
Ridden as a passenger in a vehicle and dropped off by a friend, family member, or other person	Shared	0.1	0.1	0.1	0.1	0.0	0.3	**0.7**
Driven a personal vehicle, car share vehicle, or other motor vehicle	Vehicle	6.5	9.6	4.5	1.5	1.2	0.5	**23.8**

Notes: Substitution provides classification as used in the models.
Sample size: 738
Substitution type listed was used as aggregation in later models.

Regression Analysis

The mode substitutions were aggregated into similar categories, each pointing to a different impact on the transportation system and potential in increasing or reducing vehicle miles traveled (and, therefore, greenhouse gases). The mode substitution type categories are summarized above in Table 24. Following, for each mode substitution type selected in the hypothetical event that e-scooters were not available, we estimated a logistic regression estimating the relationships with demographics (gender, income, and age of rider), trip purpose, and alternative modes available.

These five regressions are provided in full in Appendix A-5, but for this report we summarize the interpretation of only those coefficients that were significant (including marginally p-values < 0.2). The summary of the five models is provided in Table 25. As explained in the previous methods section, logistic regression coefficients are not easily interpreted on their own. The odds ratio must be calculated, followed by the probabilities that respondents (and their characteristics and trip purposes) might be more (or less) likely to substitute that mode category. In Table 25, these probabilities are summarized in the columns marked "% (-%)" denoting whether that characteristic is more likely (e.g., "%") or less likely (e.g., "(-%)") to substitute that mode. Negative relationships are also highlighted using red text. Gender was not a significant indicator in any mode substitution category, and therefore those variables were removed from this summary. Vehicle ownership was not collected in this survey, and the relationship with mode substitution could not be estimated in these models. However, the 2019 American Community Survey (5-Year, table DP04) estimates that 11.6% (±0.5%) of households in the City of Tucson do not own a vehicle. It's important to note that the correlations between demographics and responses was tested using the VIF, and there were no clear autocorrelation issues across variables tested.

Demographics

Those with higher incomes were more likely to substitute e-scooter trips with vehicles or by not taking a trip at all, compared with lower-income travelers (<$25,000 reported annual incomes). Incomes of greater than $50,000 were 122-144% less likely to want to substitute their e-scooter travel with active modes, and between 223-300% less likely to substitute with transit modes of travel, compared with the base case, households with less than $25,000 in reported income. Riders older than 60 years of age were over 900% more likely to substitute with transit, and approximately 200% less likely to substitute with a shared vehicle mode (like ride share), compared with riders aged younger than 30 years. This category of self-reporting riders was small, however, and should be interpreted with caution (N: 40 respondents). Access to e-scooters is greater near the university, and riders between the ages of 40-49 years of age were 292% more likely to take transit as a substitute and 127% less likely to take not trip at all, compared with riders of less than 30 years of age. The proportion of respondents in this survey had higher degrees of education than the general public, and they may reflect university employees with higher incomes.

For those who reported they would have taken transit, demographics contributed roughly half of the variation explained (e.g., psudo-R^2 values). This suggests that demographics are the most important indicator for those considering substituting transit with e-scooters.

Trip Purpose

Riders reporting that they would have taken no trip if the e-scooters weren't available were 194% less likely to report a work-based trip purpose—reflecting the necessity of work travel—but 20% more likely if they reported a school-based trip. School-based travel may be more flexible here, including non-essential trips like studying, visiting office hours or labs outside of required times, skipping school activities, or even an increased used on internet-based school activities (pre-pandemic).

Similarly, those taking the e-scooter to travel to restaurants were 61% more likely to report a "no trip" mode substitution, had e-scooters not been available. Overall, approximately 26% of respondents reported going to restaurants during their last e-scooter trip, and of those, 18% said they would not have taken the trip had e-scooters not been available. This suggests that e-scooters fill a gap in economic-generating activities like restaurant travel. Restaurants may include convenience food (coffee, bars, food trucks) or sit-down restaurants; more research is necessary to estimate the role of e-scooters in economic-generating activities. Comparatively, those who reported they would have substituted a vehicle for travel were more likely to have been traveling for work or shopping errands, possibly pointing to both the convenience of vehicle travel and the need to carry items during the trip. Those taking more recreational trips (restaurants, fun, shopping/errands, or sightseeing) were less likely to want to substitute trips for active travel modes.

For the models estimating mode substitutions including no trip, active travel, and shared or personal vehicle options, the trip purpose contributed just over half of the variation explained. This indicates that trip purpose may be a more important contributor to explaining mode substitutions, compared with demographics and alternative modes available. For those who suggested they would have taken transit, trip purpose contributed roughly a quarter of the variation explained—suggesting that demographics were a more important contributor to predicting a transit substitution.

Alternative Modes Available

Not surprisingly, those who had a working personal bike were 79% more likely to substitute an active mode and 83% less likely to substitute a shared vehicle. This might suggest that, although shared e-scooters require money to ride, they might have a role in substituting away from personal vehicle travel for some trips and may still be more attractive than shared vehicles (e.g., ride share options). Those with a monthly transit pass were over 300% more likely to want to substitute a transit trip. It was interesting, however, that those with a monthly parking pass at their employers were 49% more likely to want to substitute an active mode of travel and 52% less likely to want to substitute a vehicle mode. Although the sample size of this analysis did not permit it, we hypothesize that the interactive effects of trip purpose and alternative modes available might point to the counterintuitive relationship. In other words, e-scooter trips are more frequently used for non-mandatory travel; travelers interested in e-scooters also tend to be more multimodal in nature for non-work travel; and therefore, the more recreational trip purposes point to more active mode substitute if e-scooters were not available.

Alternative modes available explain away roughly a quarter of the variation controlled for (e.g., pseudo-R^2) in the transit mode substation model, suggesting that trip purpose and alternative modes available are still not as important as demographics for predicting transit/e-scooter substitutive behaviors. However, vehicle ownership was not included in the survey or regression analysis; this may be another important indicator in predicting mode substitutions.

Table 25 Probability Summary of Logistic Regression Predicting Substitutive Trip, if E-scooters Were Not Available on Last Trip Taken

Substitutive Mode Option:	**No trip**			**Active**			**Transit**			**Shared Vehicle**			**Car**		
Odds Ratio and %- More (or Less) Likely: / **Significant Variables:**	**Odds Ratio**	**% (-%)**		**Odds Ratio**	**% (-%)**		**Odds Ratio**	**% (-%)**		**Odds Ratio**	**% (-%)**		**Odds Ratio**	**% (-%)**	
Income															
Less than $25,000 (base case)	---	---		---	---		---	---		---	---		---	---	
$25,000 - $49,999	2.49	149	*	0.55	(82)	*									
$50,000 - $74,999	2.54	154	*	0.42	(138)	***	0.28	(257)	.				1.89	89	.
$75,000 - $99,999				0.41	(144)	**	0.25	(300)	.				1.94	94	.
Greater than $100,000				0.45	(122)	**	0.31	(223)	.				2.27	127	**
Retired or living off savings															
Age															
Less than 30 (base case)	---	---		---	---		---	---		---	---		---	---	
30-39							2.85	185	.						
40-49	0.44	(127)	*				3.92	292	*						
50-59										0.36	(178)	**			
Greater than 60							10.26	926	**	0.33	(203)	.			
Trip Purpose															
Go to or from work	0.34	(194)	**										2.12	112	***
Go to or from a bus/streetcar stop							3.08	208	*						
Go to or from school	1.20	20	*	0.44	(127)	*									
Social and/or entertainment activities										2.09	109	***			
Go to or from restaurants	1.61	61	.	0.61	(64)	**									
Just for fun				0.73	(37)	.				0.56	(79)	**	1.92	92	***
Shopping or errands				0.61	(64)	*							1.57	57	.
Site seeing				0.61	(64)	*									
Alternative Modes Available															
Bike that is currently in rideable				1.79	79	***				0.55	(82)	**			
Membership with TuGo Bikeshare															
Monthly transit pass with SUNTran transit							4.18	318	**						
Monthly parking pass with your employer				1.49	49	.							0.66	(52)	.

*Notes: '.'p<0.2 "marginal significance"; *p<0.1; **p<0.05; ***p<0.01; This table provides the odds ratio summaries for all models shared in the Appendix A-5. Only significant variables are indicated. The role of "gender" was not statistically significant in any of the summarized models.*

5.4.2 Crash Experiences and Riding Preferences

In the second part of our analysis, we explore the respondent's self-reporting of crash experiences. For our e-scooter user respondents (summarized in Table 26), 81.6% of users reported never having crashed or nearly crashed on shared e-scooters in Tucson. Approximately 10.7% of riders reported *nearly* crashing into an object, pedestrian, or vehicle at some point in time. For those users who reported at least one crash experience, slightly more respondents reported crashing into parked vehicles (3.5%), objects or streetcar tracks (3.8%) than crashing into a pedestrian (2.4%) or a moving vehicle (1.6%). Overall, the most frequent type of crash included just falling over or crashing without other entities involved (7.3%). This is, of course, self-reported experiences, and it is likely that more respondents may have added near crashes or just falling over than reported.

Table 26 Self-Reported Crash Experiences – Proportion of E-scooter Riders

Has any of the following ever happened to you when using a shared e-scooter in Tucson?	Proportion (%)
Crashed with a pedestrian	2.4
Crashed into a parked vehicle or object	3.5
Crashed with a moving vehicle	1.6
Crashed crossing the streetcar tracks	3.8
Crashed or fell off the scooter	7.3
Nearly crashed into an object, pedestrian, or vehicle	10.7
None of the above	81.6

Note: N=741. Respondents could select more than one option.

We also asked for the severity of crash experiences (summarized in Table 27). It is worth noting that the total proportion that reported never experiencing a crash was slightly greater in Table 6 than Table 5 (83.3% versus 81.5%), suggesting some degree of inconsistency in responses. Based on the severity categories below, this may account for a missing category in the survey instrument—something between "had minor scraps" and "have never fall" (e.g., "no injury during fall"). For all those reporting at least one crash, 76% reported having minor issues with limited medical attention. Respondents could select more than one option, as they may have had more than one crash experience to report. While the vast majority of experiences appear to be "minor," this does not provide enough information to determine whether some types of crashes (e.g., with a pedestrian or moving vehicle) were the ones to require more attention.

Table 27 Result of E-scooter Crashes, Proportion Distribution for E-scooter Riders

As a result of a fall or crash when riding a shared e-scooter, have you:	Proportion of Total (%)	Proportion of those who reported at least one crashed (%)

Required same day medical attention at an urgent care or hospital	2.2	16.7
Required medical attention 1-3 days after the crash with your regular doctor, urgent care, or hospital	0.9	7.3
Had minor scrapes or bruises that required no more medical attention than a bandage	9.9	76
I've never fallen or crashed riding a shared e-scooter	83.3	NA

Notes: N=741. Respondents could select more than one option.

In this survey, we also inquire about the types of e-scooter riding preferences (summarized in Table 28). We asked respondents "how [they] prefer to ride" and listed a number of contextual characteristics, some of which were analogous to the non-optimal behaviors observed in chapter Salt Lake City Non-Optimal Behaviors and Infrastructure. Overwhelming, respondents reported that they prefer to ride either on bike lanes (68%) or sidewalks (40.8%), with the direction of automobile travel (51.6%). Only about a third noted preferring to travel slower than 15 miles per hour. Most travelers like to ride in and around downtown Tucson (49.8%) where most of the density and activities occur, and only 11.5% noted an interest in traveling around the University of Arizona campus.

Table 28 Preferences for Riding E-scooters – Proportion of E-scooter Users

How do you prefer to ride…?	**Proportion (%)**
On the sidewalk	40.8
In bike lanes	68.0
In the street with cars	17.5
On bike or shared use paths	44.9
On off-street paths	16.6
On residential and low traffic streets	46.2
During the day	47.6
In the dark, early morning or the evening	18.2
While wearing a helmet	13.0
With other e-scooter users	25.2
With bicyclists	10.7
Against the direction of automobile traffic	4.2
With the direction of automobile traffic	51.6
Crossing the street in the pedestrian crosswalk	25.4
Crossing the street mid-block	4.0
Crossing the street using vehicular traffic lane	9.9
Coming to a complete stop for stop signs	43.2
Coming to a complete stop for red traffic lights	46.8
On the University of Arizona campus	11.5
In and around downtown Tucson	49.8
Slower than 15 miles per hour	28.3

Notes: N=741. Respondents could select more than one option.

There appears to be a disconnect between reported preferences for helmet use and observed helmet use. Although 13% of e-scooter users reported preferring to travel with a helmet (Table 28), nearly 27% of respondents indicated they sometimes, usually, or always wear a helmet (Table 29). In our observations around the same time period, in Tucson only 2% of riders were observed wearing helmets (Appendix A-4), similar to the Salt Lake City observations (Chapter 4.0).

Table 29 Helmet Use for (A) Reported Helmet Use in Tucson Survey and (B) Observed Helmet Use in Salt Lake City and Tucson Sample

(A) Reported Helmet Use	Proportion (%)	Sample Size
Always	7.8	57
Usually	5.6	41
Sometimes	7.3	53
Rarely	8.1	59
Never	71.3	521

(B) Observed Helmet Use	Proportion using Helmets (%)	Observed Scooter Users
Salt Lake City (Chapter 4)	2	194
Tucson (Appendix A-4)	2	98

Regression Analysis

We then examine the likelihood that a respondent experienced a crash (regardless in the type of crash and/or severity) with demographic characteristics (gender, income, and age), their preferences for how they ride, and the frequency of riding experiences. This regression is summarized in Table 30 below, with the full regression results provided in Appendix A-5, Table 39. Similar in interpretation to the mode substitution models, our interpretation relies on the odds ratio and the estimate for the percentage more (or less) likely to have experienced a crash.

Demographics

While gender and income is not a significant predictor of crash experiences, age is. Respondents who were 40-49 or 50-59 years of age were 108% and 257% less likely to report a crash experience, respectively, compared with riders who were less than 30 years of age. This is consistent with some prior research that points to less risk taking and crash incidents for older individuals, compared with younger, as explored in earlier chapters. This does not suggest, however, that older individuals have lower crash severity or lower crash rates (per mile traveled or exposure), as explored in Iroz-Elardo & Currans (2021).

Reported Riding Behavior Preferences

In terms of reporting riding preferences, those who reported preferring to ride on a sidewalk were 151% more likely to have reported experiencing a crash, while those who road in bike lanes were 52% less likely to have experienced a crash. In neither case do we ask whether sidewalks or bike lanes are available to the rider (or where during the crash experienced). Riders interested in riding during darker hours were 140% more likely to experience a crash. This may correspond with the types of trips that occur during the dark, including riskier behaviors. Similarly, those who prefer to cross the street mid-block were 272% more likely to have experienced a crash, which may correspond with both riskier behaviors and the difficulties of traveling across some of the more major facilities along the larger block size grid. Those who prefer to travel with other e-scooter users were 127% less likely to have experienced a crash, possibly pointing to the more cautious behavior of group travelers or the benefits of riding in platoons of travelers.

Frequency of Riding

Those who reported traveling at least once a week (as of taking the survey) were less likely to have experienced a crash compared with those who only rode once, but that relationship declines as more trips are taken and more exposure to potential crash increases. In Iroz-Elardo & Currans (2021), the authors note that more experiences may lessen the crash risk, improving e-scooter riding skills. However, more ridership also increases risk. We are unable to unpack the relationship between the exposure of riding and crash rates with this survey analysis.

Table 30 Logistic Regression Estimating Crash Experiences as a Function of Demographics, Riding Preferences, and Experience

	Coef.	Odds Ratio	%-More (or Less) Likely	
Intercept (Constant)	-0.64	0.53	(89)	.
Gender				
Male (basecase)	---	---	---	
Female	-0.13	0.88	(14)	
Non-binary	0.02	1.02	2	
Income				
Less than $25,000 (basecase)	---	---	---	
$25,000 - $49,999	-0.34	0.71	(41)	
$50,000 - $74,999	-0.09	0.92	(9)	
$75,000 - $99,999	-0.34	0.71	(41)	
Greater than $100,000	-0.32	0.73	(37)	
Retired or living off savings	0.05	1.05	5	
Age				
Less than 30 (basecase)	---	---	---	
30-39	-0.23	0.79	(27)	
40-49	-0.74	0.48	(108)	*
50-59	-1.27	0.28	(257)	**
Greater than 60	-0.15	0.86	(16)	
How do you prefer to ride…?				
On the sidewalk	0.92	2.51	151	***
In bike lanes	-0.42	0.66	(52)	.
In the street with cars	0.17	1.18	18	
On bike or shared use paths	-0.28	0.75	(33)	
On off-street paths	0.01	1.01	1	
On residential and low traffic streets	0.05	1.05	5	
During the day	-0.23	0.79	(27)	
In the dark, early morning or the evening	0.88	2.40	140	**
While wearing a helmet	-0.13	0.88	(14)	
With other e-scooter users	-0.81	0.44	(127)	**
With bicyclists	-0.24	0.78	(28)	
Against the direction of automobile traffic	-0.13	0.88	(14)	
With the direction of automobile traffic	-0.16	0.86	(16)	
Crossing the street in the pedestrian crosswalk	-0.03	0.97	(3)	
Crossing the street mid-block	1.31	3.72	272	**
Crossing the street using vehicular traffic lane	0.12	1.12	12	
Coming to a complete stop for stop signs	-0.23	0.80	(25)	
Coming to a complete stop for red traffic lights	0.46	1.58	58	
On the University of Arizona campus	-0.59	0.55	(82)	
In and around downtown Tucson	-0.11	0.90	(11)	
Slower than 15 miles per hour	0.14	1.15	15	
Frequency of E-scooter Use				
Only Once (basecase)	---	---	---	
Less than once a week	-0.95	0.39	(156)	***
1-2 times per week	-0.86	0.42	(138)	*
3-6 times per week	-0.90	0.41	(144)	.
Daily (at least once a day)	-0.54	0.59	(69)	
Pseudo R2 (Nagelkerke)	0.2			
Observations	569			
Log Likelihood	-201			
Akaike Inf. Crit.	476			

5.5 SUMMARY AND DISCUSSION

In this chapter, we explore the findings from an e-scooter user survey conducted in Tucson (in winter of 2019 and 2020, prior to the COVID-19 pandemic). We first examine the relationship between the substitutive effects of e-scooters and rider demographics, trip purposes, and alternative modes available. We then explore the reported crash experiences of riders, their preferred e-scooter riding behavior, and frequency of riding.

A substantial portion of e-scooter riding in Tucson appears to be supporting more recreational travel, including generating more trips for restaurant travel that would not have otherwise happened. E-scooter trips that are substituting for transit travel are more frequent for those with lower incomes or who are older than 30 years of age, but especially for those older than 60. For transit/e-scooter mode substitutions, income and age matter more than trip purposes or alternative modes available (e.g., more variation explained through demographics). For e-scooter substitutions with active modes, shared or vehicle modes, or no-trip-taken activities, trip purpose matters substantially more. Gender does not play a significant role in mode substitutive behaviors in our Tucson study. Given that more discretionary or recreational travel (including social, entertainment, restaurants, fun trips, shopping/errands, sightseeing) make up a greater proportion of e-scooter use in Tucson, it is surprising that most of those trip purposes correspond with significantly less likelihood that respondents would substitute active modes. For fun trips or shopping/errand trips, it's more likely that respondents will opt to take a personal vehicle.

In terms of crash experiences, older respondents (40-60 years old) were much less likely to have experienced a crash compared with younger riders (<30 years of age). Those who prefer riding on sidewalks were more likely to have experienced a crash of some kind, while those who prefer riding on bike lanes were less likely. As explored in Chapter 4.0 (Salt Lake City Non-Optimal Behaviors and Infrastructure), we observed more riders selecting to ride on the sidewalk when bike lanes were present. However, when riders were near larger roadways, we also observed more sidewalk-riding behavior, even with bike lanes present. This may point to concerns about proximity to vehicles, particularly along faster moving or larger facilities. Overall, we see correlations between behaviors determined to be more risk-taking (crossing mid-block, riding in the dark) and crash experiences. Respondents were also less likely to have experienced a crash if they reported riding more than once a week (compared to only once), but that likelihood decreased with more experience riding. In any case, the reported use of helmets (21% at least some of the time and 13% while riding) far outweighs our observations in Salt Lake City (2%, Chapter 4.0) or Tucson (2%, Appendix A-4).

In combination, this analysis contributes to the larger conversations about how the introduction of e-scooters in Tucson shapes ridership and use of existing facilities. More information from more cities with varying urban landscapes will certainly shape our understanding about underlying travel behavior decisions, including how trade-offs between modes are made and how riding behaviors might influence crashes and safety risks. In the following chapter, we explore the lessons derived from our review of the literature and regulations, our observations on behaviors across different infrastructure types, and our survey analyses.

6.0 LESSONS AND CONCLUSIONS

In this study, we use a two-pronged approach to explore the uses of e-scooters in two urban environments: Salt Lake City, UT, and Tucson, AZ. In the first approach, we build upon the methods of Lyons et al. (2020) to observe and characterize multimodal (non-)optimal behaviors at intersections in Salt Lake City. In the second approach, we explore the mode substitution effects of e-scooters and the relationship between crash experiences and preferences for riding e-scooters based on a survey collected by the City of Tucson in the Winter of 2019/2020.

In Tucson, when considering the modal substitution of trips for e-scooters, e-scooter trips appear to generate new restaurant activities. Similarly, e-scooters in Tucson appear to have stronger relationships substituting for active travel modes than for less environmentally friendly modes—including shared (ride share, passenger travel) and personal vehicles (drivers). Moreover, when considering the modal-substitution effect of e-scooters in Tucson, the trip purpose and activities matter more when generating new trips, or substituting for active or vehicle modes of travel, compared with demographics and alternative modes available.

One of our most notable findings from Salt Lake City suggests that e-scooter users (and cyclists) are more likely to use sidewalks on larger facilities and when light rail is present, regardless of the availability of bike lanes. Comparatively speaking, our survey in Tucson indicated that when respondents reported preferring to ride on a sidewalk, they were 151% more likely to have reported experiencing a crash, while those who road in bike lanes were 52% less likely to have experienced a crash. However, we don't ask whether sidewalks or bike lanes are available to the rider (or where they were during the crash) in this survey. The causation is unclear—it may be that more inexperienced e-scooter users are more prone to crashes and also more likely to ride on sidewalks, or that the sidewalk riding might increase the likelihood of a crash (e.g., uneven pavement, access management with steep curbs). Similarly, those who prefer to cross the street mid-block were 272% more likely to have experienced a crash, which may correspond with both riskier behaviors and the difficulties of traveling across some of the more major facilities along the larger block-size grid. Those who prefer to travel with other e-scooter users were 127% less likely to have experienced a crash, possibly pointing to the more cautious behavior of group travelers or the benefits of riding in platoons of travelers. In any case, the reported use of helmets (21% at least some of the time and 13% while riding) far outweighs our observations in Salt Lake City (2%, Chapter 4.0) or Tucson (2%, Appendix A-4).

Across both studies, we identify concerns about already-constrained curb space competition and concerns about proximity (and/or lack of protection) from larger or faster-moving vehicle facilities. The status quo allocation of transportation infrastructure in the U.S. is increasingly challenged by new micro-mobility modes and use—including those not studied in this report, such as: ride hailing (pick-up and drop-offs) and e-commerce deliveries (ranging from truck to passenger vehicle to drone urban freight).

While providing multimodal infrastructure does matter, perceived risk of facilities that provide inadequate separation from larger and bigger automobile facilities may outweigh the use of “appropriate” facilities in the travel behavior decision making process. This suggests that more “optimal” behaviors are likely to occur not where permitted, but where infrastructure provided is actually, as perceived to be, safe.

7.0 REFERENCES

Anderson-Hall, K., Bordenkircher, B., O'Neil, R., & Smith, C. S. (2019). Governing Micro-Mobility: A Nationwide Assessment of Electric Scooter Regulations (paper: 19-05267). *19-05267*, 18.

Austin Department of Transportation. (2018). *Notice of Proposed Rule No. R161-18.09* (p. 14) [Rule]. City of Austin.

Austin Public Health. (2019). *Dockless Electric Scooter-Related Injuries Study*. Epidemiology and Disease Surveillance Unit; Epidemiology and Public Health Preparedness Division; Austin Public Health.

Badeau, A., Carman, C., Newman, M., Steenblik, J., Carlson, M., & Madsen, T. (2019). Emergency department visits for electric scooter-related injuries after introduction of an urban rental program. *The American Journal of Emergency Medicine*, *37*(8), 1531–1533. https://doi.org/10.1016/j.ajem.2019.05.003

Baltimore City Department of Transportation. (2018). *Dockless Vehicle Committee Work Plan* (p. 2) [Work Plan]. City of Baltimore.

Basky, G. (2020). Spike in e-scooter injuries linked to ride-share boom. *Canadian Medical Association Journal*, *192*(8), E195–E196. https://doi.org/10.1503/cmaj.1095848

Brown, A., Klein, N., Thigpen, C., & Williams, N. (2019). Impeding access: The frequency and characteristics of improper scooter, bike, and car parking. *Transportation Research Interdisciplanary Perspectives*, 11.

Center for Disease Control and Prevention. (2017). *2015, United States: Unintentional Pedestrian Deaths and Rates per 100,000*. National Vital Statistics Systems, National Center for Health Statistics (NCHS) and the National Center for Injury Prevention and Control, U.S. Department of Health and Human Services. https://webappa.cdc.gov/sasweb/ ncipc/mortrate10_us.html

Centers for Disease Control and Prevention. (2019, October 24). *National Syndromic Surveillance Program (NSSP)*. https://www.cdc.gov/nssp/index.html

Charlotte Department of Transportation. (2018). *Bike Share Permit Requirements* (p. 15) [Permit Requirements]. City of Charlotte.

Chester, M. (2019, January 28). It's a Bird…It's a Lime…It's Dockless Scooters! But Can These Electric-Powered Mobility Options Be Considered Sustainable Using Life-Cycle Analysis? *Chester Energy and Policy*. https://chesterenergyandpolicy.com/2019/01/28/its-a-bird-its-a-lime-its-dockless-scooters-but-can-these-electric-powered-mobility-options-be-considered-sustainable-using-life-cycle-analysis/

Circella, G., Lee, Y., & Alemi, F. (2019). *Exploring the Relationships among Travel Multimodality, Driving Behavior, Use of Ridehailing and Energy Consumption* (p. 45) [Research Report]. National Center for Sustainable Transportation.

City of Albuquerque. (2018). *City of Albuquerque—Interoffice Memorandum—Bill No. C/S O-18-29; Enactment No. O-2018-021* (p. 9) [Ordinance].

City of Albuquerque. (2019). *Shared Active Transportation Program Permit and Agreement Form* (p. 12) [Permit and Agreement].

City of Atlanta. (2019). *Ordinance 18-O-1322* (p. 19) [Ordinance].

City of Baltimore. (2019). *Unofficial Reprint to Show Context of Amendments Proposed by Department of Transportation—Council Bill 19-0324* (p. 18) [Ordinance].

City of Boise. (2018). *Stationless Bicycle Share Programs—Chapter 5-11* (p. 12) [Program Requirements].

City of Chicago. (2019). *City of Chicago Requirements for Scooter Sharing Emerging Business Permit Pilot Program* (p. 13) [Permit Requirements].

City of Cincinnati. (2018). *City of Cincinnati An Ordinance No. 292-2018* (p. 4) [Ordinance].

City of Cincinnati, Ohio. (2018). *Interim Operating Agreement for Shared Active Transportation—Contract no. 233-95x7720* (p. 14) [Operating Agreement]. Bird Rides, Inc.

City of Dallas. (2018). *Ordinance No. 30936: Dockless Vehicle Permit* (p. 15) [Ordinance].

City of Detroit. (2018). *Compliance by Users and Operators of Dockless Electric-Assisted Scooters with Selected Provisions of the Detroit City Code* (p. 8) [Memorandum of Interpretation].

City of Durham. (2018a). *City of Durham Shared Active Transportation System—Permit Application* (p. 6) [Permit Application].

City of Durham. (2018b). *Ordinance to Regulate the Operation of Shared Active Transportation Systems* (p. 10) [Ordinance]. https://durhamnc.gov/3219/Shared-Active-Transportation

City of Fort Lauderdale. (2018). *Ordinance NO. C-18-16* (p. 14) [Ordinance].

City of Greensboro. (2018). *Standup Electric Scooter Share Permit Requirements* (p. 5) [Program Requirements].

City of Indianapolis. (2018). *City-County General Ordinance No. 49, 2018; Proposal No. 120, 2018—Chapter 905—Shared Mobility Operator* (p. 8) [Ordinance].

City of Long Beach. (2018). *Shared e-Scooter Pilot Program* (p. 28) [Pilot Requirements].

City of Lubbock. (2018). *Ordinance No. 2018-O0117* (p. 19) [Ordinance].

City of Memphis. (2018). *Shared Mobility Ordinance No. XXX, Memphis* (p. 4) [Ordinance].

City of Miami. (2018). *Chapter 8: BICYCLES, SKATEBOARDS, SCOOTERS AND OTHER SIMILAR DEVICES* (p. 11) [Ordinance].

City of Minneapolis. (2018). *Mobility Data Methodology and Analysis* (p. 7) [Documentation]. City of Minneapolis.

City of Minneapolis. (2019). *City selects operators for motorized foot scooter pilot program* (p. 1) [Press Release].

City of Oakland. (2018). *Ordinance No. XXXX - Establish Regulations and New Permits to Operate and Park Dockless Bike and Scooter Sharing Programs in the Public Right of Way* (p. 8) [Ordinance].

City of Oxford. (2018). *Interim Bicycle and E-scooter Sharing System Permit Program* (p. 5) [Permit Requirements].

City of Raleigh. (2018). *Proposed Master Right of Way Encroachment Agreement* (p. 4) [Agreement].

City of Sacramento. (2018). *Chapter 5.18 SHARED-RIDEABLE BUSINESSES* (p. 10) [Operating Agreement].

City of San Diego. (2018a). *Draft Chapter 8, Article 3: Alternative Transportation. Division 3: Shared Mobility Devices* (p. 12) [Rules].

City of San Diego. (2018b). *Shared Dockless Mobility Devices: Proposed Regulations* (p. 20) [Presentation].

City of San Jose. (2018). *Shared Micro-Mobility Program and Regulatory Framework* (p. 18) [Memorandum].

City of Scottsdale. (2018). *City Council Report: Community mobility* (p. 78) [Ordinance].

City of St. Louis. (2019). *St. Louis City Ordinance 65138—Board Bill No. 186[00]* (p. 4) [Ordinance].

City of St. Paul. (2019). *2019 SCOOTER SHARING PROGRAM APPLICATION GUIDELINES* (p. 14) [Application Guidelines].

City of Virginia Beach. (2011). *Appendix J. City Codes Applicable to Bikeways and Trails* (p. 16) [City Code].

City of Winston-Salem. (2019). *Winston-Salem Shared Micromobility System Permit Application.pdf* (p. 32) [Permit Application].

Clewlow, R. (2018). The Micro-Mobility Revolution. *Populus*. https://medium.com/populus-ai/the-micro-mobility-revolution-95e396db3754

Cooper, J., Schneider, R., Ryan, S., & Co, S. (2012). Documenting targeted behaviors associated with pedestrian safety. *Transportation Research Record*, *2299*(2299), 1–10. https://doi.org/10.3141/2299-01

Denver Public Works. (2019a). *Denver Dockless Mobility Pilot Program Dynamic Fleet Sizing Policy* (p. 1) [Permit Requirements].

Denver Public Works. (2019b). *Denver Dockless Mobility Program Pilot Interim Report* (p. 17) [Pilot Report].

Department of City Planning. (2019). *Shareable Dockless Mobility Devices* (p. 11) [Study Presentation]. City of Atlanta.

Department of Public Services. (2018). *ORD2539-2018 Summary of Changes in Title 21—Traffic Code* (p. 17) [Ordinance]. City of Columbus.

Department of Public Works. (2018). *Regulation Governing the Placement and Operation of Electric Scooters on a Pilot Basis in the City of Providence* (p. 5) [Memorandum of Interpretation]. City of Providence.

Department of Transportation. (2018). *Shared Micro-Mobility Permit Administrative Regulations* (p. 6) [Permit Requirements]. City of San Jose.

Department of Transportation. (2019). *TERMS AND CONDITIONS FOR THE PUBLIC RIGHT-OF-WAY OCCUPANCY PERMIT* (p. 17) [Operating Agreement]. District of Columbia.

Diependaele, K. (2019). Non-compliance with pedestrian traffic lights in Belgian cities. *Transportation Research Part F: Traffic Psychology and Behaviour*, *67*, 230–241. https://doi.org/10.1016/j.trf.2016.11.017

Dill, J. (2019). The e-scooter gender gap. *Jennifer Dill, Ph.D.* https://jenniferdill.net/2019/02/01/the-e-scooter-gender-gap/

District of Columbia. (2018). *Permit Application Instructions Dockless Sharing Vehicles 2019 Permit* (p. 8) [Permit Application].

Dommes, A., Granié, M. A., Cloutier, M. S., Coquelet, C., & Huguenin-Richard, F. (2015). Red light violations by adult pedestrians and other safety-related behaviors at signalized crosswalks. *Accident Analysis and Prevention*, *80*, 67–75. https://doi.org/10.1016/j.aap.2015.04.002

Espinoza, W., Howard, M., Lane, J., & Van Hentenryck, P. (2019). Shared E-scooters: Business, Pleasure, or Transit? *ArXiv:1910.05807 [Cs]*. http://arxiv.org/abs/1910.05807

Fang, K., Steele, J., Hunter, J. J., & Hooper, A. M. (2018). *Where Do Riders Park Dockless, Shared Electric Scooters? Findings from San Jose, California* (p. 5) [Research Report]. San Jose State University.

Garcia-Colberg, M. (2019). *Transit and Micro-Mobility (Bikeshare, Scooter-share, etc)* [Unpublished Report]. https://rip.trb.org/view/1584713

Gershon, P., Zhu, C., Klauer, S. G., Dingus, T., & Simons-Morton, B. (2017). Teens' distracted driving behavior: Prevalence and predictors. *Journal of Safety Research*, *63*, 157–161. https://doi.org/10.1016/j.jsr.2017.10.002

Gillette, G., Fitzpatrick, K., Chrysler, S., & Avelar, R. (2016). Effect of distractions on a pedestrian's waiting behavior at traffic signals: Observational study. *Transportation Research Record*, *2586*(1), 111–119. https://doi.org/10.3141/2586-13

Goodwin, A., Kirley, B., Sandt, L., Hall, W., Thomas, L., O'Brien, N., & Summerlin, D. (2013). *Countermeasures That Work: A Highway Safety Countermeasures Guide for the State Highway Safety Offices—7th Edition* (p. 388) [DOT HS 811 727]. National Highway Traffic Safety Administration, U.S. Department of Transportation. http://www.nhtsa.gov/staticfiles/nti/pdf/811727.pdf

Griffee, J., Currans, K. M., Lyons, T., & Fitzpatrick, Q. (2019). Scooting into a New Era: A Review of Agency Regulations on Shared E-Scooter Programs. *Working Paper*.

Halfon, J. (2019). A Lawyer Explains Why Electric Scooter Laws Don't Work. *CityLab*. https://www.citylab.com/perspective/2019/06/electric-scooters-dockless-regulations-liability-helmet-laws/592861/

Hatfield, J., & Murphy, S. (2007). The effects of mobile phone use on pedestrian crossing behaviour at signalised and unsignalised intersections. *Accident*

Analysis and Prevention, *39*(1), 197–205. https://doi.org/10.1016/j.aap.2006.07.001

Haworth, N. L., & Schramm, A. (2019a). Illegal and risky riding of electric scooters in Brisbane. *Medical Journal of Australia*, *211*(9), 412–413. https://doi.org/10.5694/mja2.50275

Haworth, N. L., & Schramm, A. (2019b). Illegal and risky riding of electric scooters in Brisbane. In *Medical Journal of Australia* (Vol. 211, Issue 9, pp. 412–413). John Wiley and Sons Inc. https://doi.org/10.5694/mja2.50275

Herrman, M. (2019). *A comprehensive guide to electric scooter regulation practices* (p. 71). Kansas State University.

Hollingsworth, J., Copeland, B., & Johnson, J. X. (2019). Are e-scooters polluters? The environmental impacts of shared dockless electric scooters. *Environmental Research Letters*, *14*(8), 084031. https://doi.org/10.1088/1748-9326/ab2da8

Høye, A. (2018). Bicycle helmets – To wear or not to wear? A meta-analyses of the effects of bicycle helmets on injuries. *Accident Analysis & Prevention*, *117*, 85–97. https://doi.org/10.1016/J.AAP.2018.03.026

Huemer, A. K., Gercek, S., & Vollrath, M. (2019). Secondary task engagement in German cyclists – An observational study. *Safety Science*, *120*, 290–298. https://doi.org/10.1016/j.ssci.2019.07.016

Injury Surveillance Working Group 8 (ISW8). (2017). *Consensus Recommendations for Pedestrian Injury Surveillance*. Safe States Alliance. https://pedevalguide.safestates.org/assets/resource-center/tools/Consensus%20Recommendations%20for%20Pedestrian%20Injury%20Surveillance%20ISW8.pdf

Iroz-Elardo, N., & Currans, K. M. (2021). Injury Burden of Introducing E-Scooters: A Review of E-Scooter Injury Studies Using Retrospective Review of Emergency Department Records, 2015–2019. *Transportation Research Record: Journal of the Transportation Research Board*, *August*. https://doi.org/10.1177/03611981211032216

James, O., Swiderski, J., Hicks, J., Teoman, D., & Buehler, R. (2019). Pedestrians and E-Scooters: An Initial Look at E-Scooter Parking and Perceptions by Riders and Non-Riders. *Sustainability*, *11*(20), 5591. https://doi.org/10.3390/su11205591

Johnson, J. (2019). Are Shared Scooters Good for the Planet? Only If They Replace Car Trips. *CityLab*. https://www.citylab.com/transportation/2019/08/are-shared-scooters-good-planet-only-if-they-replace-car-trips/595387/

Klauer, C., Dingus, T. A., Neale, V. L., Sudweeks, J. D., & Ramsey, D. J. (2015). *The Impact of Driver Inattention on Near-Crash/Crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study Data*.

Kobayashi, L. M., Williams, E., Brown, C. V., Emigh, B. J., Bansal, V., Badiee, J., Checchi, K. D., Castillo, E. M., & Doucet, J. (2019). The e-merging e-pidemic of e-scooters. *Trauma Surgery & Acute Care Open*, *4*(1). https://doi.org/10.1136/tsaco-2019-000337

Lazo, L. (2019). The CDC is studying e-scooter injuries. *The Washington Post*. https://www.washingtonpost.com/transportation/2019/03/15/cdc-is-studying-e-scooter-injuries/?utm_term=.f9e58b68aaaa

Lyons, T., Choi, D., & Ameli, H. (2018). *Safety and Perception of a Protected Bicycle Intersection, Salt Lake City, UT* [Interim Report]. Utah Department of Transportation; Salt Lake City Corporation.

Lyons, T., Choi, D., Ameli, S. H., & Park, K. (2019). *Safety and Nonoptimal Usage of a Protected Bicycle Intersection: A Before-and-after Case Study in Salt Lake City, UT*. Working Paper.

Lyons, T., Choi, D., Park, K., & Ameli, S. H. (2020). Safety and Nonoptimal Usage of a Protected Intersection for Bicycling and Walking: A Before-and-After Case Study in Salt Lake City, Utah. *Sustainability 2020, Vol. 12, Page 9195*, *12*(21), 9195. https://doi.org/10.3390/SU12219195

Mancuso, K. (2019). The Rise of Electric Scooter Regulations. *The Regulatory Review*. https://www.theregreview.org/2019/01/03/mancuso-electric-scooter-regulations/

Mathew, J. K., Bullock, D. M., Liu, M., Li, H., & Seeder, S. (2019). *Analysis of E-Scooter Trips and Their Temporal Usage Patterns*. 7.

Mitchell, G., Tsao, H., Randell, T., Marks, J., & Mackay, P. (2019). Impact of electric scooters to a tertiary emergency department: 8-week review after implementation of a scooter share scheme. *Emergency Medicine Australasia*, 1742-6723.13356. https://doi.org/10.1111/1742-6723.13356

Montgomery County. (2019). *Memorandum of Understanding with Participating Company* (p. 15) [Memorandum of Understanding].

Morano, L., Pindyck, T., Ballard, S. B., Anand, A., Zane, D., Tisdale, A., Peterson, A., Sauber-Schatz, E., & Taylor, J. (2019). Characterization of Dockless Electric Scooter Related Injury Incidents—Austin, Texas, September–November, 2018. *Epidemic Intelligence Service*, 110.

Moreau, H., de Jamblinne de Meux, L., Zeller, V., D'Ans, P., Ruwet, C., & Achten, W. M. J. (2020). Dockless E-Scooter: A Green Solution for Mobility? Comparative Case Study between Dockless E-Scooters, Displaced Transport, and Personal E-Scooters. *Sustainability*, *12*(5), 1803. https://doi.org/10.3390/su12051803

Multnomah County Health Department. (2018). *Scooter-related injuries in Multnomah County July-November 2018* (p. 4) [Research Report]. https://www.portlandoregon.gov/transportation/article/709715

Namiri, N. K., Lui, H., Tangney, T., Allen, I. E., Cohen, A. J., & Breyer, B. N. (2020). Electric Scooter Injuries and Hospital Admissions in the United States, 2014-2018. *JAMA Surgery*. https://doi.org/10.1001/jamasurg.2019.5423

National Center for Statistics and Analysis. (2016). *2015 Motor Vehicle Crashes: Overview* (Traffic Safety Facts: Research Note DOT HS 812 318). National Highway Traffic Safety Administration, U.S. Department of Transportation. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812318

National Transport Commission. (2019). *Barriers to the safe use of innovative vehicles and motorised mobility devices* (p. 45) [Issue Paper]. Melbourne, Australia.

https://www.ntc.gov.au/Media/Reports/(67C382BE-5673-11A6-8B64-86816071EC58).pdf

PBOT, P. B. of T. (2018). *2018 E-Scooter Findings Report Contents*.

Populus. (2018). *The Micro-Mobility Revolution: The Introduction and Adoption of Electric Scooters in the United States* (p. 18) [Research Report]. Populus. https://research.populus.ai/reports/Populus_MicroMobility_2018_Jul.pdf

Portland Bureau of Transportation. (2018). *2018 E-Scooter Findings Report* (p. 36) [Pilot Report]. https://www.portlandoregon.gov/transportation/article/709719

Russo, B. J., James, E., Aguilar, C. Y., & Smaglik, E. J. (2018). Pedestrian behavior at signalized intersection crosswalks: Observational study of factors associated with distracted walking, pedestrian violations, and walking speed. *Transportation Research Record*, *2672*(35), 1–12. https://doi.org/10.1177/0361198118759949

Salt Lake City Corporation. (2018). *License Agreement with Licensee* (p. 15) [License Agreement].

San Francisco Municipal transportation Agency. (2018). *SFMTA Powered Scooter Share Program Permit Application* (p. 18) [Permit Application].

Sandt, L., & Harmon, K. (2018). *Dockless Electric Kick Scooter Systems: What we know and don't know* (p. 28) [Research Report].

Schlaff, C. D., Sack, K. D., Elliott, R.-J., & Rosner, M. K. (2019). Early Experience with Electric Scooter Injuries Requiring Neurosurgical Evaluation in District of Columbia: A Case Series. *World Neurosurgery*, *132*, 202–207. https://doi.org/10.1016/j.wneu.2019.08.237

Shared Use Mobility Learning Center. (2019). *Search by Mode: Scootershare*. https://learn.sharedusemobilitycenter.org/search/

Sikka, N., Vila, C., Stratton, M., Ghassemi, M., & Pourmand, A. (2019). Sharing the sidewalk: A case of E-scooter related pedestrian injury. *The American Journal of Emergency Medicine*. https://doi.org/10.1016/j.ajem.2019.06.017

Siman-Tov, M., Radomislensky, I., Israel Trauma Group, & Peleg, K. (2017). The casualties from electric bike and motorized scooter road accidents. *Traffic Injury Prevention*, *18*(3), 7. https://doi.org/10.1080/15389588.2016.1246723

Smart Transportation and Urban Transit. (2019). *Smart Cities Dive*. https://www.smartcitiesdive.com/topic/transportation/

Smith, C. S., & Schwieterman, J. P. (2018). *E-Scooter Scenarios: Evaluating the Potential Mobility Benefits of Shared Dockless Scooters in Chicago* (p. 32) [Research Report]. https://trid.trb.org/view/1577726

Sparks, A. M., Fessler, D. M. T., & Zinsser, M. (2019). *Exploring the Roles of Conformity, Hazard, and Convenience in Risk Mitigation Decisions: An Observational Study of Helmet Use Among Bicyclists and E-Scooter Riders in Los Angeles During Two Natural Experiments*. https://doi.org/10.31234/OSF.IO/GSPBM

Trivedi, B., Kesterke, M. J., Bhattacharjee, R., Weber, W., Mynar, K., & Reddy, L. V. (2019). Craniofacial Injuries Seen With the Introduction of Bicycle-Share Electric

Scooters in an Urban Setting. *Journal of Oral and Maxillofacial Surgery*, *77*(11), 2292–2297. https://doi.org/10.1016/j.joms.2019.07.014

Trivedi, T. K., Liu, C., Antonio, A. L. M., Wheaton, N., Kreger, V., Yap, A., Schriger, D., & Elmore, J. G. (2019). Injuries Associated With Standing Electric Scooter Use. *JAMA Network Open*, *2*(1), e187381–e187381. https://doi.org/10.1001/jamanetworkopen.2018.7381

U.S. Census Bureau. (2017). *American FactFinder—Community Facts: Portland, Oregon 2017 ACS*. https://factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml

Useche, S., Montoro, L., Alonso, F., & Oviedo-Trespalacios, O. (2018). Infrastructural and Human Factors Affecting Safety Outcomes of Cyclists. *Sustainability 2018, Vol. 10, Page 299*, *10*(2), 299. https://doi.org/10.3390/SU10020299

Williams, J. (2004). *Motorized Scooters and Other Low-Power Vehicles* (p. 5) [Issue Paper]. Minnesota House of Representatives.

Zhang, F., Mehrotra, S., & Roberts, S. C. (2019). Driving distracted with friends: Effect of passengers and driver distraction on young drivers' behavior. *Accident Analysis & Prevention*, *132*, 105246. https://doi.org/10.1016/J.AAP.2019.07.022

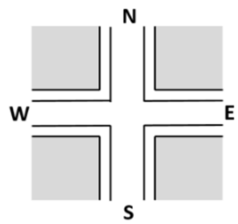
8.0 APPENDICES

The following materials are documented in the Appendices, as follows:

- APPENDIX A-1 SUPPLEMENTARY MATERIALS – NON-OPTIMAL BEHAVIOR
- APPENDIX A-2 SUPPLEMENTARY MATERIALS – TUCSON USER SURVEY
- APPENDIX A-3 TUCSON E-SCOOTER PARKING OBSERVATION REPORT (FEB. 6, 2021)
- APPENDIX A-4 TUCSON USER OBSERVATION STUDY (FEB. 6, 2020)
- APPENDIX A-5 TUCSON USER SURVEY – FULL REGRESSION RESULTS

APPENDIX A-1

SUPPLEMENTARY MATERIALS – NON-OPTIMAL BEHAVIOR

NON-OPTIMAL BEHAVIOR STUDY	Site#/Location:______________ Observed streets: Observer locations: Camera locations:		Observer name:_____________ Date: ______________________ Day of week:________________ Weather: ___________________ Start time: _________________ End time: _________________

E-scooter User Behaviors		1st 15min	2st 15min	3rd 15min	4th 15min	Total
1	Riding on sidewalks (e.g., sidewalks, crosswalks)					
2	Riding on auto. travel lanes (not including sharrows)					
3	Signal violation (e.g., ran red lights)					
4	Cluttering (e.g., not parked properly)					
5	Distracted riding (e.g., using electronic devices or headphone)					
6	Two or more passengers per scooter					
7	No helmet					

Pedestrian Behaviors		Tally				Total
1	Walking not using sidewalks (e.g., bike lanes, auto. travel lanes)					
2	Signal violation (e.g., was in street when light turned red)					
3	Distracted walking (e.g., using electronic devices or headphone)					

Bicyclist Behaviors		Tally
1	Riding on sidewalks (e.g., sidewalks, crosswalks)	
2	Riding on auto. travel lanes (not including sharrows)	
3	Signal violation (e.g., ran red lights)	
4	Distracted riding (e.g., using electronic devices or headphone)	

APPENDIX A-2

SUPPLEMENTARY MATERIALS – TUCSON USER SURVEY

The following is the survey instrument deployed in the TDOT E-scooter Pilot Program Evaluation Survey.

Q1 The City is seeking input from **community residents** regarding Tucson's Electric-Scooter (E-scooter) Pilot Program. In this survey, you will be asked questions about your experiences of e-scooter use, perspectives on the management and operations of the program, and some personal information.

Q2 What is your home ZIP code? <text>

Q3 How often do you ride e-scooters? (Select one)

- I have never ridden e-scooters (1)
- I have only ridden once (2)
- Occasionally, but less than once per week (3)
- 1-2 times per week (4)
- 3-6 times per week (5)
- Daily (6)
- More than once per day (7)

SECTION (A)

<If "I HAVE NEVER RIDDEN E-SCOOTERS" is selected, skip to Q16>

Q4 Thinking about the last e-scooter trip you took, what was the primary reason you took the trip? (Multiple choice)

- Go to or from work (1)
- Go to or from a bus/streetcar stop (2)
- Go to or from school (3)
- Social and/or entertainment activities (4)
- Go to or from restaurants (5)
- Just for fun (9)
- Shopping or errands (6)
- Site seeing (7)
- Other (8) <text entry>

Q5 Thinking of the last e-scooter trip you took; how did you get to the e-scooter that you rode? *(Select all that apply)*

- Walked (1)
- Rode a SunTran Bus (2)
- Rode a SunVan Shuttle (3)
- Rode the SunLink Streetcar (4)
- Drove a personal vehicle, car share vehicle, or other motor vehicle (5)
- Taken a taxi, Uber, Lyft, or other ride hailing service (6)
- Ridden as a passenger in a vehicle and dropper off by a friend, family member, or other person (7)
- Rode a TuGo bike share bike (8)
- Rode a personal bike (9)
- Other (please specify) (10) <text entry>

Q6 Approximately how many minutes did you have to travel to get to the last e-scooter that you took?

- 0-5 minutes (1)
- 5-10 minutes (2)
- More than 10 minutes (3)
- I do not remember (4) <text entry>

Q7 Still thinking about your most recent e-scooter trip. Why did you choose to take an e-scooter? *(Select all that apply)*

- It was the fastest and most reliable option. (1)
- It was less expensive than other ways to get there (2)
- Did not want to get sweaty (3)
- Parking is difficult at that time/destination (4)
- No Bus/Shuttle/Streetcar at that time/destination (5)
- It is good for the environment (6)
- Do not have a car (7)
- It was just for fun (8)
- Other (please specify) (9) <text entry>

Q8 Think about your last ride on an e-scooter in Tucson. If a shared e-scooter had not been available, how would you most likely have gotten around?

- Would not have taken the trip (1)
- Walked (2)
- Taken a Bus or Streetcar trip (3)
- Driven a personal vehicle, car share vehicle, or other motor vehicle (4)
- Taken a taxi, Uber, Lyft, or other ride hailing service (5)
- Ridden as a passenger in a vehicle and dropped off by a friend, family member, or other person (6)
- Ridden a personal e-scooter (7)
- Ridden a TuGo bike share bike (8)
- Ridden a personal bike (9)

Q9 Think about how you have traveled, in general, over the last month. Approximately, how often have you done each of the following to meet your transportation needs:

	7+ times per week (1)	3-6 times per week (2)	1-2 times per week (3)	Less than once per week (4)	Never (5)
Walked (1)	☐	☐	☐	☐	☐
Took Bus/Streetcar (2)	☐	☐	☐	☐	☐
Drove a car (3)	☐	☐	☐	☐	☐
Road as a passenger in a car (4)	☐	☐	☐	☐	☐
Took Rideshare (e.g., Taxi, Uber, Lyft) (5)	☐	☐	☐	☐	☐
Took Carshare (e.g., Zipcar) (6)	☐	☐	☐	☐	☐
Biked using a personal bicycle (7)	☐	☐	☐	☐	☐
Biked using TuGo bike share (8)	☐	☐	☐	☐	☐

Q10 How often do you wear a helmet when riding an e-scooter?

- Never (1)
- Rarely (2)
- Sometimes (3)
- Usually (4)
- Always (5)

Q11 How do you prefer to ride or use e-scooters? *(Select all that apply)*

- On the sidewalk (1)

- In bike lanes (2)
- In the street with cars (3)
- On bike or shared use paths (4)
- On off-street paths (like The Loop) (5)
- On residential and low traffic streets (6)
- During the day (7)
- In the dark, early morning or the evening (8)
- While wearing a helmet (9)
- With other e-scooter users (10)
- With bicyclists (11)
- Against the direction of automobile traffic (12)
- With the direction of automobile traffic (13)
- Crossing the street in the pedestrian crosswalk (14)
- Crossing the street mid-block (15)
- Crossing the street using vehicular traffic lane (16)
- Coming to a complete stop for stop signs (17)
- Coming to a complete stop for red traffic lights (18)
- On the University of Arizona campus (19)
- In and around downtown Tucson (20)
- Slower than 15 miles per hour (21)
- Other (please specify) (22) <text entry>

Q12 Has any of the following ever happened to you when using a shared e-scooter in Tucson? *(Select all that apply)*

- Crashed with a pedestrian (1)
- Crashed into a parked vehicle or object (2)
- Crashed with a moving vehicle (3)
- Crashed crossing the streetcar tracks (4)
- Crashed or fell off the scooter (without running into anything else) (5)
- Nearly crashed into an object, pedestrian, or vehicle (6)
- None of the above (7)

Q13 As a result of a fall or crash when riding a shared e-scooter, have you:

- Required same day medical attention at an urgent care or hospital (1)
- Required medical attention 1-3 days after the crash with your regular doctor, urgent care, or hospital (2)
- Had minor scrapes or bruises that required no more medical attention than a bandage (3)
- I've never fallen or crashed riding a shared e-scooter (5)

Q14 Do you have or use any of the following? *(Select all that apply)*

- Bike that is currently in rideable (decent to good condition) (1)

- Membership with TuGo Bikeshare (2)
- Monthly transit passes with SUNTran transit (3)
- Monthly parking pass with your employer (4)
- None of the above (5)

Q15 Which statement best describes the type of bicycle rider that you are?

- I am a confident bicycle rider, and I will ride on nearly any type of road. (1)
- I am a confident but cautious bicycle rider, and I only ride on bike friendly roads and residential streets. (2)
- I am cautious but interested bicycle rider, and I ride infrequently on bike paths and residential streets. I would ride more with better conditions or options. (3)
- I do not normally ride bicycles. (4)
- I am unable to ride a bicycle. (5)

SECTION (B)

<ALL RESPONDENTS GET THESE QUESTIONS>

Q16 in general, to what extent do you approve or disapprove of the E-Scooter Pilot Program in Tucson?

- Strongly approve (1)
- Moderately approve (2)
- Neither approve nor disapprove (3)
- Moderately disapprove (4)
- Strongly disapprove (5)

Q17 As a **community resident**, how satisfied are you with the following situations involving interactions with e-scooters in Tucson:

	Extremely dissatisfied (1)	Somewhat dissatisfied (2)	Somewhat satisfied (4)	Extremely satisfied (5)	Not applicable (3)
While you were walking on sidewalks (1)	☐	☐	☐	☐	☐
While you were walking or biking on an off-street path (2)	☐	☐	☐	☐	☐
While you were biking in bike lanes (3)	☐	☐	☐	☐	☐

Q18 Have you ever reported an improperly parked e-scooter? If so, please think about your most recent report.

- Yes, and it was moved within 2 hours of my report. (1)
- Yes, and it was moved within 2-8 hours of my report. (2)
- Yes, and it was moved more than 8 hours after my report. (3)
- Yes, but I'm not aware of whether or not the e-scooter was ever moved. (4)
- No, I have never reported an improperly parked e-scooter. (5)

Q19 If you have contacted customer service for either e-scooter company, please rate your experience with either company's <u>customer service:</u>

	Dissatisfied (1)	Somewhat Dissatisfied (2)	Neither satisfied nor dissatisfied (3)	Somewhat Satisfied (4)	Satisfied (5)	I have never contacted customer service. (6)
Bird (1)	☐	☐	☐	☐	☐	☐
Razor (2)	☐	☐	☐	☐	☐	☐

Q20 In your opinion, what changes would make Tucson's Pilot Program better or more effective? *(Select all that apply)*

- More e-scooters available (1)
- More designated places to park e-scooters (3)
- Lower cost (4)
- Easier access to helmets (5)
- Free helmets (6)
- Better pavement quality on city streets (7)
- Safer places to ride (protected bike lanes, off-street paths) (8)
- Longer battery life (9)
- Better design of e-scooters (more stable, better lighting, etc.) (10)
- E-scooters on the University of Arizona campus (14)
- None of these changes would improve the Tucson Pilot Program (11)
- Other (please specify) (12) <text entry>

Q21 How likely are you to recommend shared e-scooters to a friend?

- Extremely likely (1)
- Very likely (2)
- Somewhat likely (3)
- Not so likely (4)
- Not at all likely (5)

SECTION (C)

<START RESPONDENT INFORMATION BLOCK>

Q22 In what year were you born?

Year (1)	▼ 1900 (1) ... 2009 (110)

Q23 What gender do you identify with?

- Male (1)
- Female (2)
- Transgender (3)
- Non-binary (4)
- Do not know (5)
- Prefer not to answer (6)

Q24 Do you identify with having or living with a disability?

- No (1)
- Yes, mobility or dexterity (walking, climbing stairs) (2)
- Yes, visual (blind, low vision) (3)
- Yes, deaf or hard-of-hearing (4)
- Yes, speech or communication (5)
- Yes, other (please specify) (6) <text entry>
- Prefer not to answer (7)

Q25 Approximately what was your household's annual income for 2018?

- Under $10,000 (1)
- $10,000 to $14,999 (2)
- $15,000 to $24,999 (3)
- $25,000 to $34,999 (4)
- $35,000 to $49,999 (5)
- $50,000 to $74,999 (6)
- $75,000 to $99,999 (7)
- $100,000 to $149,999 (8)
- $150,000 to $199,999 (9)
- $200,000 or more (10)
- I am retired and/or live on savings (11)
- Prefer not to answer (12)

Q26 What is your highest level of education?

- Some high school (1)
- High school degree (2)
- Some college (3)
- Technical degree (including trade school) (4)
- 2-year degree (5)
- College degree/4-year degree (6)
- Some post graduate (7)
- Master's degree (8)
- Doctorate (9)
- Other (please specify) (10) <text entry>

Q27 Do you have any additional feedback or recommendations regarding Tucson's E-Scooter Pilot Program? <Open response, text entry>

APPENDIX A-3

TUCSON E-SCOOTER PARKING OBSERVATION REPORT (FEB. 6, 2020)

Lead Authors: Kristina Currans; Nicole Iroz-Elardo; and Quinton Fitzpatrick

A draft of this report (appendix) was circulated to support early decision making in Tucson regarding the permitting program.

INTRODUCTION

On January 24 2020, eight student researchers systematically walked all streets within four districts in Tucson, AZ. to capture a snapshot of how electric scooters (e-scooters) were parked. For an hour and a half, four teams of two searched their designated districts to find and capture any parked e-scooter using photographs. Afterwards, researchers classified them into three broad categories: well-parked, questionably parked, and improperly parked. This short report summarizes the findings of this e-scooter parking study.

METHODS

Four districts were selected based on the estimated shared e-scooter use and known popular travel routes leading between the University of Arizona campus to downtown, along the streetcar line (see Figure 3). (Note that the University of Arizona campus has a no-park geofence area. After our data collection, we also learned that one vendor had temporarily geofenced a no-park area along Fourth Avenue.)

Eight students were hired to take photographs of parked e-scooters in each of the four districts during a 90-minute period on Friday, January 24 between 7:00 p.m. and 8:30 p.m. This data collection was developed concurrently with an e-scooter observation study. The time period was selected, in part, to capture scooters during the peak period of e-scooter use. Earlier time periods may have disproportionately overrepresented staged e-scooter pods - typically occurring overnight or early in the morning - and thus would not adequately reflect how everyday users park e-scooters. The students were trained in capturing photos of parked e-scooters within their parking context. Afterwards, the pictures were categorized into three tiers of parking: well parked, questionably parked, and improperly parked. The questionably parked category represented either: (a) disagreement in the rules of what constitutes a well parked (or improperly parked) scooter, or (b) issues with understanding enough context in the photo to classify it confidently. Example photos from each category are provided in Table 1.

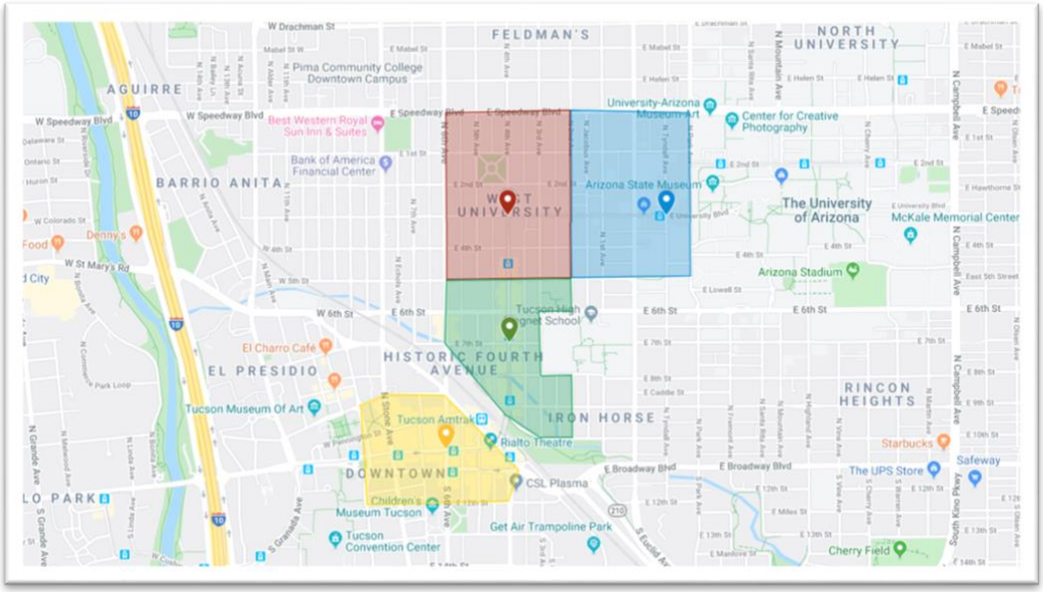
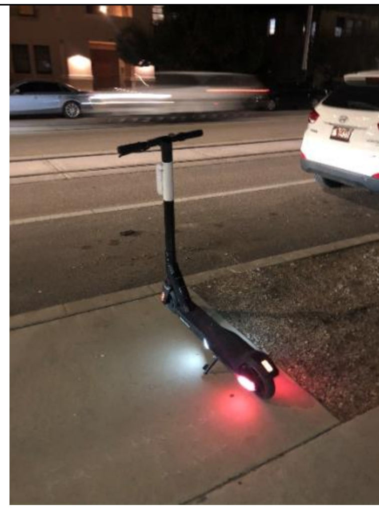
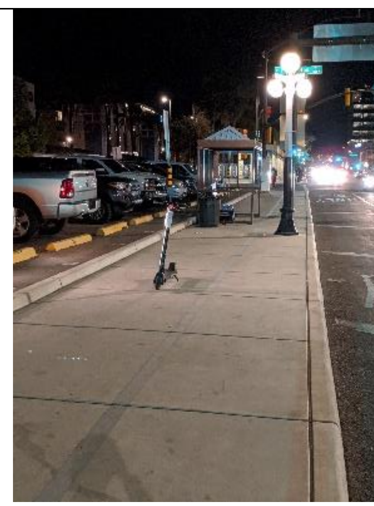


Figure 3 Four Study Areas in Tucson, AZ

Table 31 Examples of Parked E-Scooters Categories

	Well Parked	Questionably Parked	Improperly Parked
a)			
	“Staged” parking	Parked on a pathway, but the photo does not provide enough information to identify if it is someone’s walkway.	Parked on sidewalk, leaning on private fence.
b)			
	Parked in designated e-scooter parking zone	Scooter possibly obstructing walkway	Scooter blocking sidewalk

RESULTS

The research team collected 145 photos accounting for 292 parked e-scooters within the study area. The City of Tucson estimates that approximately 672 e-scooter vehicles were available within the city during the study period. We estimate that we observed 43% (N=292) of total e-scooters in the city and roughly a third were observed within the downtown observation area during our study period. Table 2 displays the total counts and proportions of well parked, questionably parked, and improperly parked e-scooters from each observation location. Of the 292 total parked e-scooters observed, 76% of all e-scooters were well parked; 17% were improperly parked; and approximately 7% were questionably parked. With additional clarifications, we may be able to better classify questionably parked vehicles to better match proper or improper parking as defined by the City of Tucson.

Table 32 Count of Parked E-Scooters

Observation Area	Well Parked			Questionably Parked	Improperly Parked	Total Count
	Appears Staged by Vender	Does not Appear Staged by Vender	Total			
Park and University	4	22	26	2	12	40
Proportion	10%	55%	65%	5%	30%	
4th Avenue and University	37	13	50	1	12	63
Proportion	59%	21%	79%	2%	19%	
4th Avenue and 7th Street	48	21	69	5	10	84
Proportion	57%	25%	82%	6%	12%	
Congress and 6th Avenue	48	30	78	12	15	105
Proportion	46%	29%	74%	11%	14%	
Total Count	137	86	223	20	49	292
Total Proportion	47%	29%	76%	7%	17%	

DISCUSSION AND CONCLUSIONS

Our research team made several anecdotal observations that are worth noting during this process. Questionably parked e-scooters—those that may be improperly or appropriately parked—were often in front of red curbs, but outside of designated e-scooter parking zones. Another common questionable parking trend was e-scooters in plazas or near bicycle racks with low pedestrian traffic. Improperly parked scooters included scooters placed on their side on the ground, or those placed into bushes or fences in or near the sidewalk or public right-of-way. Many of the well-parked scooters appeared “staged” by the venders (47% overall), but that may also be an artifact of users mimicking already staged groups of scooters by adding theirs to the line.

It is important to note that this observation period represents a cross section of parked e-scooters during a peak day of use (Friday). The parking behaviors of e-scooter users may vary greatly each day. Because one vender was geofencing a no-park zone along Fourth Avenue during the study period, we have not separated out the results by vender. Each vender has their own mechanisms and programs to educate chargers and riders about properly parking scooters within the city's guidelines; it is likely that the parking of scooters might vary by vendor. Finally, the study area had several new designated parking zones for e-scooters; parking behaviors may vary greatly in neighborhoods without designated parking zones.

HUMAN-SUBJECTS REVIEW

The University of Arizona Institutional Review Board determined this study to not meet the definition of Human Subjects Research by 45 CFR 46.102(e), and therefore, no Human Subjects Review was required (Protocol Number: 2001270380).

APPENDIX A-4

TUCSON USER OBSERVATION STUDY (FEB. 6, 2020)

Lead Authors: Kristina Currans; Nicole Iroz-Elardo; and Quinton Fitzpatrick

A draft of this report (appendix) was circulated to support early decision making in Tucson regarding the permitting program.

INTRODUCTION

On the evening of January 24 2020, eight students observed electric scooter (e-scooter) users in Tucson, AZ. The purpose of this study was to understand how e-scooter users were riding and operating the technology during a City of Tucson pilot period running from September to March. Specifically, we aimed to gather more information about: (a) helmet use; (b) scooter type; (c) location of riding on infrastructure (e.g., sidewalk, bike lane, with vehicle traffic); and (d) other observable behaviors (e.g., riding two people per scooter, children riders, swerving). This short report summarizes the results of these efforts.

METHODOLOGY

Four locations were chosen for observation (see Figure 4): University and Park, University and Fourth Avenue, Fourth Avenue and 9th Street, and Congress and 6th Street. These locations were selected based on their proximity in and around the most common e-scooter use corridors using data provided to the city by the permitted vendors under a data reporting requirement. Two time periods for observation were selected: the evening peak hour of the facilities (5-7 p.m.) and a nighttime hour (10-11 p.m.). Also based on aggregated data provided to the city by the vendors, we determined e-scooter use to be highest in the evening, and especially later at night on Fridays. We included a second hour of observation during the evening peak (5-7 p.m.) to increase our sample of observed scooter users and check to see if late-night behavior is substantially different from commute-time behavior.

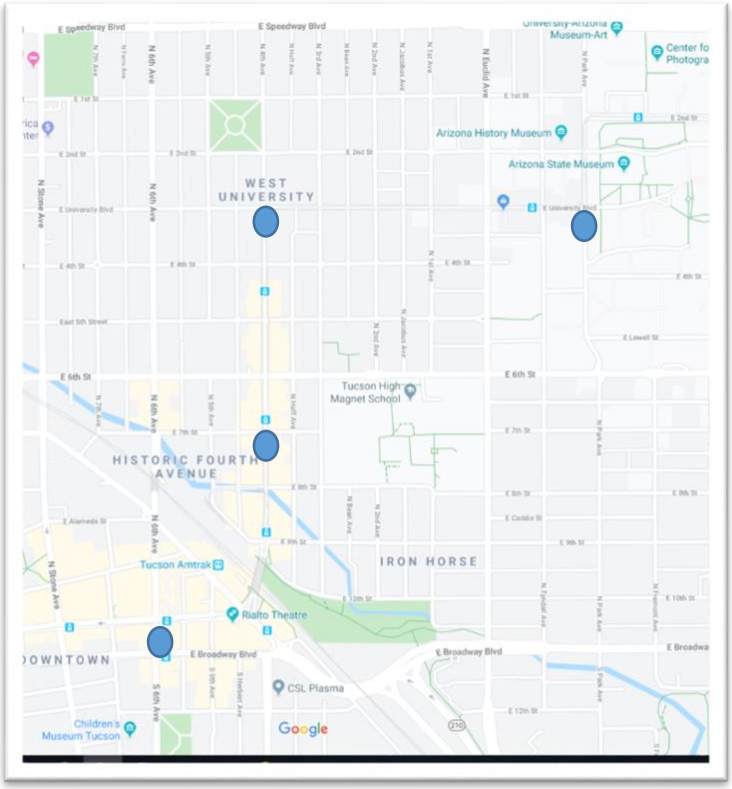


Figure 4 Map of the Study Area (Downtown, 4th Avenue and University Boulevard in Tucson, AZ)

Four teams of two student researchers were placed at the four selected intersections to record e-scooter observations. For each e-scooter user observed, the researchers at each location recorded:

- the direction of travel approaching the intersection (east and west or north and south),
- the time of observation, the riding location (street, bike lane, or sidewalk),
- the type of e-scooter being ridden (Bird, Razor, or standing Razor),
- helmet use,
- the speed of the rider (if possible to record),
- and whether there were two riders on a single scooter.

During the training, we provided examples of additional pertinent behaviors we suspected would be unusual, but we would like to have captured notes such as whether the user was carrying items from a shopping trip (e.g., groceries); if the user was clearly a child or minor; or whether the user appeared visibly intoxicated.

RESULTS

We observed 98 e-scooter users across the four locations and two time periods. It is feasible that we captured some e-scooters twice if they were traveling along the streetcar line and thus through multiple study areas. The City of Tucson also estimated that approximately 227 shared e-scooter trips where taken during the three-hour study period; thus, we estimate that we observed a maximum of 43% of e-scooter trips. However, because we did not collect information about the riders themselves in order to track them on their trip, we cannot confirm definitively the proportion of trips observed.

Bird or Razor. Of the 98 total observed users during the study period, approximately 90% of the riders were using Bird e-scooters and 10% were using Razor e-scooters (approximate 5% standing e-scooters and 5% e-scooters with a seat). The City of Tucson estimated that approximately 60% of the shared e-scooter fleet available during the study period were Bird e-scooters. After the data collection, we learned that Razor had temporarily blocked users from parking within the Fourth Avenue district; this accounts for the discrepancy between the proportions of scooter venders at our observation locations. Because of this, we pooled the two vendors for all additional analyses.

Sidewalks, Bike Lanes, Sharrows, and Streets. Table 1 below summarizes the 98 observations relative to where the user was riding the e-scooter. All locations have sharrows – a portion of the street where bicyclists (and e-scooters) and vehicular traffic are expected to share space. Across all locations, 64% of e-scooters were observed riding appropriately in the bike lane or sharrows.

E-scooters are instructed not to ride on the sidewalk; however, 36% of e-scooters were observed riding on the sidewalk. Most notably, we observed higher rates of sidewalk riding at the locations with higher vehicle volumes and sharrows (e.g., no bike lanes, thus requiring mixing of e-scooter and vehicular traffic). In areas with slower automobile speeds, we observed more correct riding in sharrow spaces (than on sidewalks). At locations with dedicated bike lanes, we observed less sidewalk riding overall.

Table 33 Where On the Sidewalk/Street Did They Ride?

Location and Time	Sidewalk	Bike Lane	Sharrow	Street (Auto/Streetcar Only)
Park and University				
N/S: Sidewalk/Bike lane/Street; E/W: Sidewalk/Sharrow				
5-7PM	4	5	3	0
10-11PM	4	1	3	0
Proportion	40%	30%	30%	0%
University and 4th Ave				
N/S: Sidewalk/Sharrow; E/W: Sidewalk/Sharrow*				
5-7PM	0	8	5	---
10-11PM	0	12	1	---
Proportion	0%	77%	23%	---
4th Ave and 7th St.				
N/S: Sidewalk/Sharrow; E/W: Sidewalk/Street (low-volume sharrow)				
5-7PM	1	---	6	---
10-11PM	4	---	11	---
Proportion	23%	---	59%	---
5th/6th Ave and Congress				
N/S: Sidewalk/Sharrow; E/W: Sidewalk/Sharrow (one-way traffic only)				
5-7PM	10	---	0	---
10-11PM	12	---	8	---
Proportion	73%	---	27%	---
Location and Time	Sidewalk	Bike Lane	Sharrow	Street
Total Observations	35	26	37	0
Proportion	36%	27%	38%	0%

Notes:

---: Infrastructure not available in this location.

* One direction had a bike lane, but only for turning purposes. Otherwise, through traffic should be observed on a sharrow.

Green bike boxes were not counted as bike lanes in this exercise.

Helmets. Two riders (2% out of 98 observations) were observed wearing a helmet. In previous studies, low helmet use on e-scooters has been reported, including 2% of injured emergency room patients in Austin, TX (Austin Public Health, 2019) and 10% of users observed in Portland, OR (Portland Bureau of Transportation, 2018). While the City of Tucson's vendor permit specifies that e-scooters will be instructed to wear helmets, it is notable that Arizona does not legally require adult cyclists or motorcyclists to wear helmets.

Two riders per e-scooter Additionally, two e-scooters were observed with two riders using the scooter at the same time (2%). One e-scooter was identified as a seated Razor and the other as a Bird scooter.

Speed. Two observation teams had speed radar detectors on hand for two of the four locations. However, this equipment was not adequately capturing speeds of e-scooter users, particularly after dark. Generally, the observation teams noted that most e-scooter users were operating at lower speed in most areas. This appeared to be due to (a) more complex multimodal configurations and activity or (b) rougher pavement.

DISCUSSION

This short study aimed to systematically capture e-scooter rider behavior for one evening in Tucson. During the 5-7 p.m. and 10-11 p.m. periods on Friday, January 24 2020, we observed 98 e-scooter users entering the four study intersections. Only two users were wearing helmets, and two of the e-scooters observed had more than one rider on them.

The four observation locations selected were along the streetcar line from the University of Arizona campus, through the University Boulevard and Fourth Avenue commercial districts, and into downtown Tucson. These locations were selected, in part, because of their consistently high traffic rates for e-scooters. However, it is possible that some of the e-scooter users observed were double-counted by teams at intersections further along the observation route. Future observations might capture each location across several time periods and days, or on separate days and times.

While 90% of the observations we observed were Bird e-scooter riders, the number of currently deployed e-scooters for each company (and the corresponding utilization rate) was estimated by the city to be 60% Bird and 40% Razor. We believe the discrepancy is due to a parking geofence set up by Razor at the time of observation. However, it is feasible that users from either company may have different rates of compliance, depending on the educational programs implemented by either vender.

In future data collections, determining if a rider was riding against the flow of traffic—such as riding in a bike lane, but against the expected flow of bike traffic—may help identify another observable risky riding behavior. Anecdotally, the research team did not note many occurrences of this type of behavior, but it was also not captured in our original data collection form. Moreover, similar future studies should aim to develop location-specific and infrastructure configuration-sensitive data collection forms to assist student observers in the data collection.

HUMAN-SUBJECTS REVIEW

The University of Arizona Institutional Review Board determined this study to not meet the definition of Human Subjects Research by 45 CFR 46.102(e), and therefore, no Human Subjects Review was required (Protocol Number: 2001270380).

APPENDIX A-5

TUCSON USER SURVEY – FULL REGRESSION RESULTS

Table 34 Logistic Regression on "I wouldn't take a trip if E-scooter wasn't available on last trip"

	Coef.	Odds Ratio	More (or Less) Likely (%)	P-value	
Intercept	-2.678	0.07		0.00	***
Gender					
Male (basecase)	---	---	---	---	
Female	0.213	1.24	24	0.43	
Non-binary	*na*	*na*	*na*	*na*	
Income					
Less than $25,000 (basecase)	---	---	---	---	
$25,000 - $49,999	0.914	2.49	149	0.07	*
$50,000 - $74,999	0.932	2.54	154	0.07	*
$75,000 - $99,999	0.72	2.06	106	0.21	
Greater than $100,000	0.46	1.58	58	0.39	
Retired or living off savings	0.357	1.43	43	0.78	
Age					
Less than 30 (basecase)	---	---	---	---	
30-39	-0.304	0.74	(35)	0.38	
40-49	-0.815	0.44	(127)	0.09	*
50-59	0.263	1.3	30	0.52	
Greater than 60	0.144	1.15	15	-1.09	
Trip Purpose					
Go to or from work	-1.089	0.34	(194)	0.03	**
Go to or from a bus/streetcar stop	0.179	2.4	140	0.70	
Go to or from school	0.873	1.2	20	0.06	*
Social and/or entertainment activities	-0.217	0.81	(23)	0.45	
Go to or from restaurants	0.479	1.61	61	0.11	.
Just for fun	0.314	1.37	37	0.25	
Shopping or errands	0.356	1.43	43	0.34	
Site seeing	0.277	1.32	32	0.43	
Alternative Modes Available					
Bike that is currently in rideable	-0.125	0.88	(14)	0.65	
Membership with TuGo Bikeshare	0.103	1.11	11	0.88	
Monthly transit pass with SUNTran transit	0.086	1.09	9	0.87	
Monthly parking pass with your employer	-0.346	0.71	(41)	0.41	
Pseudo R2 (Nagelkerke)		0.10			
Observations		566			
Log Likelihood		-204			
Akaike Inf. Crit.		456			

*Notes: "."p<0.2, marginal significance; *p<0.1; **p<0.05; ***p<0.01*

The contribution of "trip purpose" indicators contributes half of the total Pseudo R2.

na: No available, too small sample size for this outcome.

Table 35 Logistic Regression on Taking an Active Mode if E-scooter Wasn't Available on Last Trip

	Coef.	Odds Ratio	More (or Less) Likely (%)	P-value	
Intercept	0.555	1.74		0.10	
Gender					
Male (basecase)	---	---	---	---	
Female	-0.078	0.92	(9)	0.68	
Non-binary	*na*	*na*	*na*	*na*	
Income					
Less than $25,000 (basecase)	---	---	---	---	
$25,000 - $49,999	-0.592	0.55	(82)	0.07	*
$50,000 - $74,999	-0.872	0.42	(138)	0.01	***
$75,000 - $99,999	-0.901	0.41	(144)	0.02	**
Greater than $100,000	-0.798	0.45	(122)	0.02	**
Retired or living off savings	-0.644	0.53	(89)	0.44	
Age					
Less than 30 (basecase)	---	---	---	---	
30-39	0.206	1.23	23	0.40	
40-49	0.033	1.03	3	0.91	
50-59	0.078	1.08	8	0.80	
Greater than 60		0.68	(47)	0.41	
Trip Purpose					
Go to or from work	-0.207	0.81	(23)	0.44	
Go to or from a bus/streetcar stop	-0.198	0.82	(22)	0.58	
Go to or from school	-0.814	0.44	(127)	0.06	*
Social and/or entertainment activities	-0.128	0.88	(14)	0.45	
Go to or from restaurants	-0.492	0.61	(64)	0.02	**
Just for fun	-0.314	0.73	(37)	0.10	.
Shopping or errands	-0.488	0.61	(64)	0.08	*
Site seeing	-0.49	0.61	(64)	0.09	*
Alternative Modes Available					
Bike that is currently in rideable	0.581	1.79	79	0.00	***
Membership with TuGo Bikeshare	-0.134	0.87	(15)	0.79	
Monthly transit pass with SUNTran transit	-0.129	0.88	(14)	0.71	
Monthly parking pass with your employer	0.401	1.49	49	0.12	.
Pseudo R2 (Nagelkerke)		0.12			
Observations		566			
Log Likelihood		-361			
Akaike Inf. Crit.		770			

*Notes: "."p<0.2, marginal significance; *p<0.1; **p<0.05; ***p<0.01*

The contribution of "trip purpose" indicators contributes nearly 0.07 out of 0.12 of the Pseudo R2.

na: No available, too small sample size for this outcome.

Table 36 Logistic Regression on Taking a Transit Mode if E-scooter Wasn't Available on Last Trip

	Coef.	Odds Ratio	More (or Less) Likely (%)	P-value	
Intercept	-3.738	0.02		0.00	***
Gender					
Male (basecase)	---	---	---	---	
Female	0.476	1.61	61	0.34	
Non-binary	*na*	*na*	*na*	*na*	
Income					
Less than $25,000 (basecase)	---	---	---	---	
$25,000 - $49,999	-0.385	0.68	(47)	0.59	
$50,000 - $74,999	-1.265	0.28	(257)	0.14	.
$75,000 - $99,999	-1.386	0.25	(300)	0.16	.
Greater than $100,000	-1.168	0.31	(223)	0.15	.
Retired or living off savings	*na*	*na*	*na*	*na*	
Age					
Less than 30 (basecase)	---	---	---	---	
30-39	1.046	2.85	185	0.16	.
40-49	1.366	3.92	292	0.09	*
50-59	0.629	1.88	88	0.53	
Greater than 60	2.328	10.26	926	0.03	**
Trip Purpose					
Go to or from work	-1.039	0.35	(186)	0.34	
Go to or from a bus/streetcar stop	1.126	3.08	208	0.10	*
Go to or from school	-0.047	0.95	(5)	0.97	
Social and/or entertainment activities	-0.213	0.81	(23)	0.70	
Go to or from restaurants	-0.175	0.84	(19)	0.79	
Just for fun	0.118	1.13	13	0.83	
Shopping or errands	-1.054	0.35	(186)	0.34	
Site seeing	0.369	1.45	45	0.61	
Alternative Modes Available					
Bike that is currently in rideable	-0.219	0.8	(25)	0.67	
Membership with TuGo Bikeshare	*na*	*na*	*na*	*na*	
Monthly transit pass with SUNTran transit	1.43	4.18	318	0.03	**
Monthly parking pass with your employer	0.646	1.91	91	0.36	
Pseudo R2 (Nagelkerke)		0.19			
Observations		566			
Log Likelihood		-72			
Akaike Inf. Crit.		192			

*Notes: "."p<0.2, marginal significance; *p<0.1; **p<0.05; ***p<0.01*
The contribution of "trip purpose" indicators contributes nearly 0.04 out of 0.19 of the Pseudo R2.
The contribution of "alternative modes available" indicators contributes nearly 0.04 out of 0.19 of the Pseudo R2. na: No available, too small sample size for this outcome.

Table 37 Logistic Regression on Taking a Shared Mode if E-scooter Wasn't Available on Last Trip

	Coef.	Odds Ratio	More (or Less) Likely (%)	P-value	
Intercept	-1.662	0.19		0.00	***
Gender					
Male (basecase)	---	---	---	---	
Female	0.009	1.01	1	0.97	
Non-binary	*na*	*na*	*na*	*na*	
Income					
Less than $25,000 (basecase)	---	---	---	---	
$25,000 - $49,999	-0.098	0.91	(10)	0.83	
$50,000 - $74,999	0.404	1.5	50	0.36	
$75,000 - $99,999	0.505	1.66	66	0.29	
Greater than $100,000	0.449	1.57	57	0.31	
Retired or living off savings	1.538	4.66	366	0.18	
Age					
Less than 30 (basecase)	---	---	---	---	
30-39	-0.083	0.92	(9)	0.79	
40-49	-0.246	0.78	(28)	0.51	
50-59	-1.029	0.36	(178)	0.03	**
Greater than 60	-1.117	0.33	(203)	0.18	.
Trip Purpose					
Go to or from work	0.136	1.15	15	0.69	
Go to or from a bus/streetcar stop	-0.393	0.68	(47)	0.41	
Go to or from school	0.123	1.13	13	0.80	
Social and/or entertainment activities	0.737	2.09	109	0.01	***
Go to or from restaurants	0.192	1.21	21	0.48	
Just for fun	-0.584	0.56	(79)	0.03	**
Shopping or errands	0.053	1.05	5	0.88	
Site seeing	0.128	1.14	14	0.71	
Alternative Modes Available					
Bike that is currently in rideable	-0.59	0.55	(82)	0.02	**
Membership with TuGo Bikeshare	0.675	1.96	96	0.28	
Monthly transit pass with SUNTran transit	0.108	1.11	11	0.82	
Monthly parking pass with your employer	0.057	1.06	6	0.87	
Pseudo R2 (Nagelkerke)	0.11				
Observations	566				
Log Likelihood	-236				
Akaike Inf. Crit.	519				

*Notes: "."p<0.2, marginal significance; *p<0.1; **p<0.05; ***p<0.01*
The contribution of "trip purpose" indicators contributes nearly 0.07 out of 0.11 of the Pseudo R2.
na: No available, too small sample size for this outcome.

Table 38 Logistic Regression on Taking a Vehicle Mode if E-scooter Wasn't Available on Last Trip

	Coef.	Odds Ratio	More (or Less) Likely (%)	P-value	
Intercept	-2.104	0.12		0.00	***
Gender					
Male (basecase)	---	---	---	---	
Female	-0.122	0.89	(12)	0.58	
Non-binary		*na*	*na*	*na*	
Income					
Less than $25,000 (basecase)	---	---	---	---	
$25,000 - $49,999	0.498	1.65	65	0.23	
$50,000 - $74,999	0.636	1.89	89	0.13	.
$75,000 - $99,999	0.665	1.94	94	0.15	.
Greater than $100,000	0.819	2.27	127	0.05	**
Retired or living off savings	0.532	1.7	70	0.59	
Age					
Less than 30 (basecase)	---	---	---	---	
30-39	-0.245	0.78	(28)	0.40	
40-49	0.231	1.26	26	0.48	
50-59	0.213	1.24	24	0.55	
Greater than 60	0.606	1.83	83	0.23	
Trip Purpose					
Go to or from work	0.754	2.12	112	0.01	***
Go to or from a bus/streetcar stop	-0.02	0.98	(2)	0.96	
Go to or from school	0.279	1.32	32	0.51	
Social and/or entertainment activities	-0.214	0.81	(23)	0.35	
Go to or from restaurants	0.214	1.24	24	0.39	
Just for fun	0.654	1.92	92	0.00	***
Shopping or errands	0.452	1.57	57	0.13	.
Site seeing	0.188	1.21	21	0.53	
Alternative Modes Available					
Bike that is currently in rideable	-0.188	0.83	(20)	0.39	
Membership with TuGo Bikeshare	-0.019	0.98	(2)	0.97	
Monthly transit pass with SUNTran transit	-0.579	0.56	(79)	0.21	
Monthly parking pass with your employer	-0.415	0.66	(52)	0.19	.
Pseudo R2 (Nagelkerke)	0.10				
Observations	566				
Log Likelihood	-288				
Akaike Inf. Crit.	624				

*Notes: "."p<0.2, marginal significance; *p<0.1; **p<0.05; ***p<0.01*

The contribution of "trip purpose" indicators contributes nearly 0.06 out of 0.10 of the Pseudo R2.

na: No available, too small sample size for this outcome.

Table 39 Logistic Regression Estimating Crash Experiences as a Function of Demographics, Riding Preferences, and Experience

	Coef.	Odds Ratio	More (or Less) Likely (%)	P-value	
Intercept (Constant)	-0.637	0.53	(89)	0.182	.
Gender					
Male (basecase)	---	---	---	---	
Female	-0.127	0.88	(14)	0.657	
Non-binary	0.023	1.02	2	0.988	
Income					
Less than $25,000 (basecase)	---	---	---	---	
$25,000 - $49,999	-0.344	0.71	(41)	0.421	
$50,000 - $74,999	-0.086	0.92	(9)	0.848	
$75,000 - $99,999	-0.339	0.71	(41)	0.485	
Greater than $100,000	-0.32	0.73	(37)	0.453	
Retired or living off savings	0.048	1.05	5	0.965	
Age					
Less than 30 (basecase)	---	---	---	---	
30-39	-0.233	0.79	(27)	0.499	
40-49	-0.736	0.48	(108)	0.094	*
50-59	-1.269	0.28	(257)	0.021	**
Greater than 60	-0.147	0.86	(16)	0.823	
How do you prefer to ride…?					
On the sidewalk	0.919	2.51	151	0.003	***
In bike lanes	-0.417	0.66	(52)	0.196	.
In the street with cars	0.17	1.18	18	0.66	
On bike or shared use paths	-0.282	0.75	(33)	0.365	
On off-street paths	0.011	1.01	1	0.981	
On residential and low traffic streets	0.049	1.05	5	0.884	
During the day	-0.231	0.79	(27)	0.455	
In the dark, early morning or the evening	0.875	2.4	140	0.032	**
While wearing a helmet	-0.131	0.88	(14)	0.802	
With other e-scooter users	-0.813	0.44	(127)	0.043	**
With bicyclists	-0.243	0.78	(28)	0.667	
Against the direction of automobile traffic	-0.129	0.88	(14)	0.834	
With the direction of automobile traffic	-0.155	0.86	(16)	0.654	
Crossing the street in the pedestrian crosswalk	-0.033	0.97	(3)	0.927	
Crossing the street mid-block	1.314	3.72	272	0.041	**
Crossing the street using vehicular traffic lane	0.117	1.12	12	0.824	
Coming to a complete stop for stop signs	-0.228	0.8	(25)	0.579	
Coming to a complete stop for red traffic lights	0.458	1.58	58	0.304	

On the University of Arizona campus	-0.589	0.55	(82)	0.281	
In and around downtown Tucson	-0.107	0.9	(11)	0.744	
Slower than 15 miles per hour	0.144	1.15	15	0.684	
Frequency of E-scooter Use					
Only Once (basecase)	---	---	---	---	
Less than once a week	-0.951	0.39	(156)	0.003	***
1-2 times per week	-0.862	0.42	(138)	0.058	*
3-6 times per week	-0.901	0.41	(144)	0.163	.
Daily (at least once a day)	-0.535	0.59	(69)	0.52	
Pseudo R2 (Nagelkerke)	0.2				
Observations	569				
Log Likelihood	-201				
Akaike Inf. Crit.	476				

*Notes: '.' p<0.2 "marginal significance" *p<0.1; **p<0.05; ***p<0.01*