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Perspectives on e-scooters use: A multi-year cross-sectional approach to understanding e-scooter travel behavior in Portland, Oregon

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ABSTRACT

Unique travel behavior patterns are observed as shared electric scooters (e-scooters) provided by private operators expand into U.S. cities. Three separate years of e-scooter ridership survey data from the Portland Bureau of Transportation's E-scooter Pilot Programs were analyzed to ascertain the multi-year cross-sectional and demographic characteristics of e-scooter riders. A binary logistic regression model, descriptive statistics, and multiple regression model are used to analyze e-scooter mode substitution, trip purposes, and travel distance from 2018 to 2020 in Portland, Oregon. Since the introduction of e-scooter in 2018, respondents have been less likely to use their previous transportation, and especially vehicle trips were consistently replaced with e-scooter trips during three different periods of analysis. In 2020, utilitarian trips, work/school trips, and trips for accessing transit stop replaced recreation trips as the primary trip purpose. The travel distance model shows that e-scooters can help to reduce vehicle miles traveled (VMT) by replacing car and ride-hail/taxis trips. With the result of this research, this study supports shared e-scooters as a viable transportation mode in the future that can achieve several policy goals, such as climate change, congestion, first/last mile connector to transit, and equity.

Keywords: e-scooter, travel behavior, micromobility, shared transportation

1 Introduction

Shared electric scooters (e-scooters) are becoming an integral part of urban transportation networks. The North American Bikeshare and Scootershare Association (NABSA) estimated that of the 128 million unique trips on shared micromobility in North America (bike, e-bike, and scooter) in 2021, nearly 49% were on shared e-scooters (NABSA, 2022; SAE, 2019). Though the COVID-19 pandemic contributed to a reduction in the number of providers and e-scooter use starting in 2020, at least 110 cities had shared systems by the end of 2021 (Bureau of Transportation Statistics, 2022). While e-scooters are largely provided by private mobility companies, cities and other public agencies are increasing their role in the provision of e-scooters through regulations and permitting programs. This is often motivated by visible issues and conflicts (e.g., e-scooters blocking sidewalks). However, cities are also seeing e-scooters as a tool to achieve other policy objectives, including reducing carbon and other emissions, congestion and increasing mobility options for residents, particularly those currently underserved by transit and other modes (Active Transportation Alliance, 2019; Los Angeles Department of Transportation, 2020; Portland Bureau of Transportation, 2020; Seattle Department of Transportation, 2022).

With more cities making efforts to incorporate e-scooters into their transportation system, research is necessary to assess whether e-scooters can help achieve larger policy objectives by lowering private vehicle trips (Dias et al, 2021; Hardt and Bogenberger, 2019). Nonetheless, only six of the 203 articles on shared micromobility services were on travel behavior and trip purpose, leading the authors to call for more research on scooter rider behavior (Elmashhara et al., 2022). Understanding why people choose to use a shared e-scooter, how often the use the e-scooter for certain trips, and what modes they are displacing, particularly how these decisions change over time, is a growing knowledge-base but still is in the early stages.

The aims of this paper are to examine whether shared e-scooters can help cities achieve goals of reducing emissions and providing mobility options to replace vehicle trips, particularly for underserved populations. Emission reductions can occur if e-scooters are replacing trips that would have been made using more polluting modes. Greater reductions are likely if e-scooters are a mobility option for common types of trips (e.g., commuting, shopping, etc.), and reductions are dependent upon the distance of the trips replaced. These shifts might also help address concerns over congestion. Regarding the second policy objective, micromobility services have been critiqued as primarily serving people who are male, white, higher-income, and younger, though there is some limited evidence that e-scooters might be serving people of color and lower-income individuals better than bike share (Dill and McNeil, 2021). In addition, e-scooters could improve mobility by providing quicker connections to transit for longer trips or by substituting for modes that may be more costly (e.g., taxis and ride-hailing) or time-consuming (e.g., transit).

To examine these topics, the analysis uses data from surveys of Portland e-scooter users conducted over three time periods (Fall 2018, Fall 2019, and Winter 2020). The multi-year data allows us to also explore whether changes are occurring over time that would indicate greater (or lesser) likelihood of achieving the policy goals in the future. We examine the goal of improved mobility by analyzing e-scooter use by income, race, gender, and age. Since shared e-scooters are a new modal technology, early adopters may behave differently than users at later stages of the technology diffusion (Flores and Jansson, 2021). The analysis adds to the small but growing body of research based on data from users of e-scooters (Bozzi and Aguilera, 2021). Though not without its limitations, survey-based user data can provide insights related to mode substitution, trip purpose, and equitable mobility more completely than analyses based on anonymous vehicle trip data.

By analyzing the behavior and demographics of e-scooter users, this research is expected to reveal whether the scooter share can achieve policy goals and will provide insights to municipal transportation planners and decision makers in developing better policies and permitting procedures. For example, some cities, like Portland, are including provisions in operator agreements to help ensure more equitable access to e-scooters in lower-income neighborhoods and areas not as well served by transit or other mobility services (NACTO, 2020). Our findings also reveal what role e-scooters can play in the context of mobility-as-a-service (MaaS), where users can rely on a range of shared services integrated with transit, thus reducing the need for private vehicle ownership.

2 Literature review

Shared e-scooters are part of the fast-growing field of micromobility (Dias et al., 2021). The rise of e-scooters appeared around the time of the dockless bike share (Lazo, 2018; Schmitt, 2018). Shared e-scooters are one micromobility option used to improve urban transportation systems through increased mobility, decreased emissions, and decreased automobile use (Dias et al, 2021; Hardt and Bogenberger, 2019; Seebauer, 2015), but what niche they fill is yet to be determined (Tuncer et al., 2020). This new mode is undergoing increased scrutiny due to the proliferation throughout the world, but with the limited understanding of its impacts on travel behavior, urban planning, and safety. The overt emphasis on the e-scooter travel behavior related to public safety (Nisson et al., 2020), parking behaviors (Hemphill et al, 2022; Thigpen et al., 2020), and pedestrian conflict (Sikka et al., 2019) is oftentimes overly stressed compared to the massive negative externalities associated with private urban car ownership and dependency (Blincoe et al., 2015; Parry et al., 2007). Within the field of micromobility, e-scooters share several similarities with bike share and are sometimes operated by the same companies (Hirsch et al., 2019). Bike share research methodology and data are often used as an analogy to study e-scooter travel behavior (Mckenzie, 2019). While early studies can benefit from the groundwork laid by bike share, bike share research does not fully capture the unique travel behaviors and attributes produced by e-scooter travel behavior. Additionally, e-scooter markets and operations are private sector enterprises that are influenced by market forces. Market fluctuation may impact mode choice stability due to the companies' ability to exit the market whenever they feel it is appropriate based on market demands (Theen, 2020).

Equal and equitable access to newer transportation technologies is imperative for a more just transportation system. Several e-scooter companies attempt to address this issue by providing discounted rates for qualified riders from low-income, underserved communities (Petersen, 2019). Furthermore, companies are often required to equitably distribute e-scooters beyond "desired" ridership locations, such as neighborhoods with lower socioeconomics and further away from the city center (Portland Bureau of Transportation, 2018). Micromobility services have been critiqued as primarily serving people who are younger, male, and white (Bai and Jiao, 2020; Fitt and Curl, 2019; Laa and Leth, 2020), though there is some limited evidence how e-scooters might be serving people of color and lower-income populations better than bike share (Dill and McNeil, 2021). Interestingly, e-scooters appear to have high adoption rates for those who never tried biking or bike share in the past and are less physically active (Reck and Axhausen, 2021).

Research shows that e-scooters may substitute for private motor vehicle travel, as well as for walking, bicycling and public transportation (McQueen et al, 2022). Micromobility literature illustrates the local modal shifts of ridership from more conventional modes to new mobility, such as e-scooters (Fitt and Curl, 2019; Laa and Leth, 2020; Lee et al., 2021; Mathew et al., 2019; Portland Bureau of Transportation, 2020; Seebauer, 2015). Since micromobility can potentially diversify our mobility options, it is important to understand the nuances of e-scooters travel behavior and how these devices could be used to shift people's modes for specific trips. A particular interest is in how scooter and bike share help enhance first and last mile connections to transit. Understanding travel behavior of e-scooter users is a crucial step to developing safer, more inclusive and equitable micromobility networks, infrastructure and shared systems. (Laa and Leth, 2020). Recent e-scooter research shows promising results with some studies indicating a degree of mode shift away from private vehicles and improved air quality metrics (Fitt and Curl, 2019; Mathew et al., 2019; Portland Bureau of Transportation, 2020; Schuller and Aboukrat, 2019; Seebauer, 2015). However, other researchers found e-scooter trips can replace non-motorized modes, such as walking, bicycling, and public transportation (Fitt and Curl, 2019; Portland Bureau of Transportation, 2020; Yang et al., 2021).

During the initial introduction in several cities, shared e-scooter ridership tended to be for fun and recreation trips (Bai et al., 2021; Fitt and Curl, 2019; Portland Bureau of Transportation, 2020). However, e-scooter ridership shifted away from leisure/fun to convenience and more utilitarian purposes. Laa and Leth (2020) found e-scooters are used for work/education trips more than shopping or leisure trips in Vienna. In New Zealand cities e-scooter riders who made more than one prior trip not only for fun but also for work, social engagement, and shops or supermarkets (Fitt and Curl, 2019). However, Mathew et al. found e-scooters in Indianapolis are not an effective morning commute option (Mathew et al., 2019). Understanding how people use e-scooters and how they can be used for more utilitarian purposes is still understudied. One specific trip purpose for e-scooter use promoted by cities and operators is for first/last mile transit connections. Lee et al. (2021) found e-scooters encourage public transit use by providing service for short-distance access/egress trips to public transit. Roughly 20% of short-distance travel used e-scooters instead of other transportation modes, including taxi substitution (Lee et al., 2021). Finally, the rate of e-scooter access/egress to public transportation increases as the travel distance of transit increases (Lee et al., 2021), meaning there is an elasticity between e-scooter availability and public transit trip distances. In particular, most e-scooter riders used e-scooters for short-distance travel (Bai and Jiao, 2020; Bai et al., 2021; Jiao and Bai, 2020; Lee et al., 2021; Mathew et al., 2019).

The literature suggests, (1) e-scooter riders are more likely to substitute walking, transit, and car trips with e-scooter trips, (2) the primary trip purpose of e-scooters shifted from fun/recreation to commuting/utilitarian as scooter deployment as matured and (3) e-scooter riders are more likely to use e-scooters for short-distance travel. Despite growing e-scooter-related research, there have been few studies focused on travel behaviors of e-scooter users due to the short commercialization period and the limitations of data acquisition. There are limitations since the current published literature usually reports descriptive statistics instead of exploring potential correlations between e-scooter ridership behaviors and ridership variables. Additionally, most studies covered only a particular year, which makes it difficult to examine e-scooter travel pattern changes over time. These research gaps are areas which this study seeks to address.

3 Data and methodology

3.1 Data

Beginning in July 2018, the Portland Bureau of Transportation (PBOT) permitted several e-scooter companies to operate a fixed number of e-scooters for a 120-day pilot program to examine the potential impact on the urban environment. The first pilot lasted from July to November 2018, and included Lime, Bird and Skip as the first e-scooter operators. Following the pilot, the PBOT released a comprehensive report detailing and studying the pilot program (Portland Bureau of Transportation, 2018). The following year, a second pilot program was announced and implemented starting April 2019, with five companies permitted to operate. However, in March 2020 several companies ended or suspended service due to the COVID-19 pandemic, and PBOT restricted scooter usage during the nighttime in May 2020 due to racial justice protests. Some services returned in the summer, and PBOT has gradually eliminated restrictions to return to normal service in 2022.

Working with the e-scooter operators, PBOT surveyed e-scooter users at three different times in 2018, 2019, and 2020. The surveys were distributed to all individuals with an account with at least one of the scooter operators, but the total number of users for each time period is unknown. The surveys conducted in 2018 and 2019 took place during similar periods between September and October. Whereas, in 2020, the survey took place in the late winter season from February 24 to March 23. It should be noted that impacts due to COVID-19 had not gone into effect in Portland during the winter 2020 survey period. After PBOT collected the surveys, the surveys were anonymized and partially cleaned before being given to the researchers.

All three surveys covered e-scooter users' travel behaviors in Portland, such as trip purpose, mode shift, frequency of using e-scooter, as well as demographic of respondents. The surveys in 2019 and 2020 asked about e-scooter policy-related questions, like knowledge of provided service plans (e.g., low-income pricing plan, options for non-smartphone users), parking knowledge and behavior, and knowledge of e-scooter laws. Unlike 2018, the 2019 and 2020 surveys include questions related to the most recent trip, such as travel distance and the motivation of using e-scooters for the most recent trip.

The survey data required significant cleaning and reorganizing for a proper multi-period cross-sectional analysis. First, some survey respondents were excluded from our analysis. The surveys captured both residents and non-residents, residents are defined as respondents who worked or lived in Portland. Since this research aims to find out how e-scooters, as a new mobility mode, affects Portland travel behavior by understanding residents' travel behavior, non-resident responses were excluded from our analysis. Non-resident or tourist travel behavior can be very different from resident use both in trip purpose, mode choice and the mode shift caused by using an e-scooter. In addition, the survey was sent to anyone who had signed up to use the service, not necessarily only people who had taken a ride on an e-scooter. Therefore, there were some respondents who indicated in one question that they never used e-scooters, but responded to the e-scooter travel behavior questions. We omitted these responses because of this inconsistency. Secondly, there were differences in some question-and-answer wording between the three survey years. Due to the discontinuity between questions asking similar inquiries, this research compared each question and available responses between three time periods and used similar questions and responses as best as possible to run a proper analysis. For example, available responses for gender and income questions in 2019 and 2020 are more diverse and specific than in 2018. After data cleaning, the number of useable survey responses were 3,293 in 2018, 1,604 in 2019, and 560 in 2020.

3.2 Analysis Methods

The survey responses were used to investigate changes in users' travel behavior due to the availability of e-scooters. This study aims to find out what socio-economic and travel behavior factors affect the e-scooter mode substitution, trip purpose, and travel distance. A general cross tabulation of several demographics and ridership behavior was used to generate descriptive statistics and identify possibly significant characteristics to use e-scooter. This study examines the data using binary logistic regression and multinomial logit model (MNL) models for trip purpose, travel distance and mode substitution to address how people were using shared e-scooters and whether e-scooters can be a more attractive transportation mode than other transportation modes.

To examine changes in *mode substitution*, we used the survey question, "Since first using shared e-scooters, how has your use of the following [travel] options changed?" The travel mode options included walking, transit, driving a car, carpool or ride as a passenger, ride hail (including transportation network companies "TNC" and taxi), carsharing (e.g., Zipcar), personal bike, BIKETOWN bike share, and personal e-scooter. There were three possible responses for each mode option: less often, about the same, more often. Since this analysis aims to find out whether e-scooters can be more attractive than other transportation modes in mode substitution model, this study classified three available responses to this question into a dichotomy. To determine what kind of e-scooter users were less likely to use their previous transportation mode since they used e-scooters, we then estimated a binary logistic regression model with 1= less often and 0= same or more often. Because the question asked about change for each mode overall (not for a specific trip), a single respondent could indicate that they decreased the use of several modes, one mode, or no modes. Therefore, we estimated separate models for each mode. Among the sample respondents, 68.3% responded that they used at least one of the other transportation modes less frequently after using the e-scooter, while 31.7% said they used the same amount or more frequently (Table 1). The dependent variable of models for each mode is defined as frequency changes in using each mode since using e-scooters. This study developed the models with several independent variables based on the literature reviews and the model fits: socio-economic (e.g., age, gender, race, and individual annual income) and travel behavior variables (e.g., trip frequency, and primary trip purpose). This study used the same independent variables to compare models for each mode.

To understand *trip purpose*, we used the top three rank responses for trip purpose from the question, “How do you normally use an e-scooter?” To simplify our analysis, we grouped the primary trip purposes into four categories: *work and school*, *utilitarian*, *fun/recreation*, and *accessing transit stops* to streamline analysis. Utilitarian trips included social/entertainment with specific destination, shopping and errands, restaurant, to/from work meeting/appointment, and exercise. Fun/recreation trips indicate trips for moving around freely without any specific destination. Due to the data limitations, we only present descriptive statistics and chi-square tests for the trip purpose by socio-demographic characteristics. We developed a multinomial logit model (MNL) for the trip purpose, but the model fit was too poor. To improve the model fit, we reclassified trip purposes, market segmentation by year, and included interaction variables. The model has not adequate to explain the association between variables and trip purpose since the model still produced a lack of model fit, however it was the best that could be with the available data and to ensure some continuity through the data sets.

Our analysis of e-scooter *trip distances* uses a question included on the 2019 and 2020 surveys that asked the user about their most recent e-scooter trip. The survey questionnaire asked for the person’s app ride history for this question, which included the distance recorded by the e-scooter. Therefore, the trip distance data are likely more accurate than data from a question relying on the respondent’s memory. The travel distance range of the responses is 0.01 to 25.00 miles, though we treated trip distances over 10 miles as outliers (n=2). With a sufficient sample size, this research assumes these trips across all respondents provide a good representation of all e-scooter trips. The distribution of trip distances is shown in Figure 1.

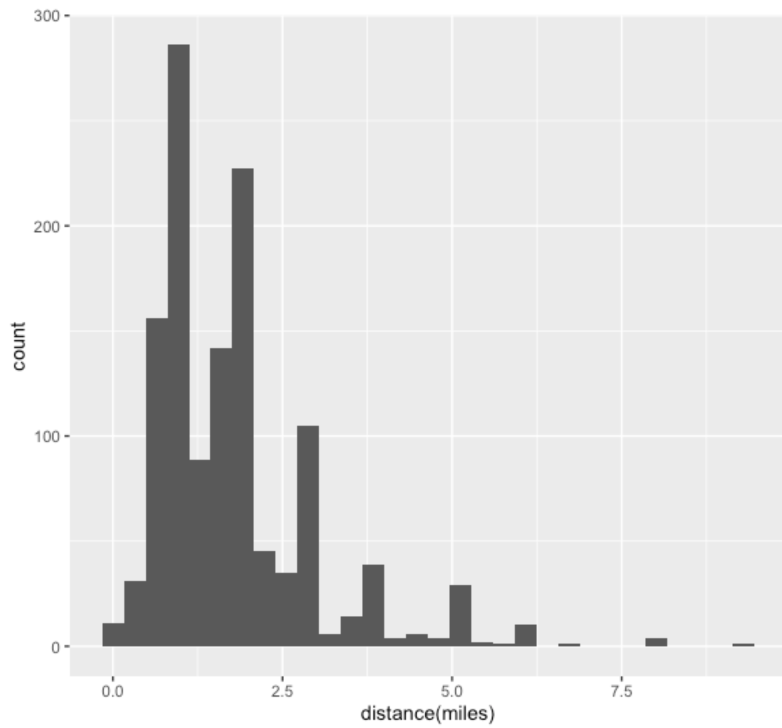

Figure 1. Travel distance (miles) distribution of sample

In addition to descriptive analysis, we developed a regression model with trip distance as the dependent variable to examine how the distance of e-scooter users has changed over time. Table 1 provides descriptive information on variables for the model. We used a generalized linear regression model with negative binomial distribution with log-link since the distance variable is discrete with non-integer values, but not normally distributed (Figure 1). Based on the literature review, we considered several independent variables in two categories: socio-economic factors (e.g., age, gender, race, and individual annual income) and travel behavior factors such as trip frequency and primary trip purpose. The trip information was based on the most recent trip and trip variables of mode replacement and motivation. Mode replacement represents the alternative transportation mode if an e-scooter had not been available for the last trip. Motivation variables for the most recent e-scooter trip were collected in multiple choice responses which allows the motivation variables to be treated as dummy variables. To find out what factors affect the distance of a recent e-scooter trip, this research compared F-statistic and R2 changes by adding each variable group. The model including all socio-economic, travel behavior, and the most recent e-scooter trip variable groups had the highest F-statistic for change in R2 when adding each variable group to the travel distance model of the most recent e-scooter trip.

Because we had travel distance data for the most recent trip based on ride history from the app, we used this data to estimate a change in vehicle miles traveled (VMT) as a result of using e-scooters. To do so, we summed the travel distance of users who responded that they would have used a motor vehicle (solo driving, carpool, carshare and TNCs/taxi) if an e-scooter had not been available for the trip. This estimation cannot represent the exact reduction in VMT since e-scooter trips do not mirror exactly a vehicle trip, especially if it is not on the roadway. Nonetheless, with the sum of travel distance of users who replaced their travel with e-scooter, this research can be expected to support the policy goal that e-scooter have the potential to reduce VMT and traffic congestion.

Table 1. Variables included in the models

Variables	Description	Mode substitution model n=3514	Trip distance model n=1248
Dependent Variables			
Reduction in using other modes	Since first using a shared e-scooter, how has your use of the following options changed? Dummy variable: 1= less often 0= same or more often	% less often Car: 49.9% (n=1755) Walk: 15.8% (n=555) Transit: 19.0% (n=669) TNCs (transportation network companies)/taxi: 59.4% (n=2088) Micromobility (personal bike, BIKETOWN, personal e-scooter, skateboard): 31.1% (n=1093)	
Trip distance	Distance of the most recent e-scooter trip based on the app (miles)		Mean: 1.8 miles (std. dev.=1.2)
Independent Variables			
Year	The year of conducting the survey	2018: 63.0% 2019: 27.6% 2020: 9.4%	2019: 74.1% 2020: 25.9%
Socio-economic factors			
Age group	Millennials (18-35), GenX (35-55), Boomer (55+)	Millennials: 53.4% GenX: 41.5% Boomer: 5.1%	Millennials: 53.4% GenX: 41.7% Boomer: 4.9%
Gender	Male, Female	Male: 65.3% Female: 34.7%	Male: 67.1% Female: 32.9%
Race	White / Black, Indigenous, and People of Color (BIPOC)	White: 80.4% BIPOC: 19.6%	White: 82.1% BIPOC: 17.9%
Annual individual income	Low income (less than $30K), Middle income (between $30K and $75K), High income (more than $75K)	Low income: 20.1% Middle income: 41.0% High income: 38.9%	Low income: 17.0% Middle income: 40.3% High income: 42.7%
Travel behavior			
Frequency of e-scooter use	Less than weekly, Weekly (1-6x per week), Daily (more than 1x per day)	Less than weekly: 60.2% Weekly: 36.3% Daily: 3.5%	Less than weekly: 58.9% Weekly: 37.5% Daily: 3.6%
Trip purpose	Work/School, Utilitarian, Fun/Recreation, Accessing transit stops	Work/school: 21.8% Utilitarian: 46.2%	Work/school: 23.0% Utilitarian: 50.6%

Variables	Description	Mode substitution model n=3514	Trip distance model n=1248
	Utilitarian trips include social/entertainment with specific destination, shopping and errands, restaurant, to/from work meeting/appointment, and exercise	Fun/recreation: 25.2% Accessing transit stops: 6.9%	Fun/recreation: 18.5% Transit stop: 7.9%
Travel behavior related to the most recent e-scooter trip			
Mode replacement	If an e-scooter had not been available for your last trip, how would you have made that trip?		Walking: 40.9% Transit: 10.4% Car (driving, carpool, and carshare): 16.8% TNCs/taxi: 24.7% Micromobility: 7.1%
Recent motivation_fast	Dummy variable equal to 1 for the reason to take an e-scooter for the most recent trip is that it was the fastest and most reliable and 0 for not		60.7%
Recent motivation_cost	Dummy variable equal to 1 for the reason to take an e-scooter for the most recent trip is that it was less expensive than other ways to get there and 0 for not		33.5%
Recent motivation_nosweat	Dummy variable equal to 1 for the reason to take an e-scooter for the most recent trip is that I didn't want to get sweaty and 0 for not		18.1%
Recent motivation_noparkin g	Dummy variable equal to 1 for the reason to take an e-scooter for the most recent trip is that parking was difficult or not convenient and 0 for not		26.8%
Recent motivation_fun	Dummy variable equal to 1 for the reason to take an e-scooter for the most recent trip is that it was just for fun and 0 for not		28.9%
Recent motivation_transit	Dummy variable equal to 1 for the reason to take an e-scooter for the most recent trip is that transit was not convenient and 0 for not		30.1%
Recent motivation_nocar	Dummy variable equal to 1 for the reason to take an e-scooter for the most recent trip is that I don't have a car and 0 for not		15.5%

Note: The difference in sample number between the travel distance model and other models is caused by excluded 2018 surveys for the travel distance model since travel distance-related questions were not asked in 2018.

4 Results

4.1 Mode substitution

The launch of new transportation modes can impact mode choice by providing additional transportation options for people. The data from the three surveys showed that the introduction of e-scooters caused some change in the frequency of use by travel modes. In general, the majority of respondents' travel choices had not changed because of e-scooters deployment. Figure 2 presents the response rate for the use of mode by 'less often.' Some users used driving, carpool, and ride-hail (TNC/taxi) less often compared to other modes, indicating it is possible for e-scooters to influence the mode shift of vehicle trips.

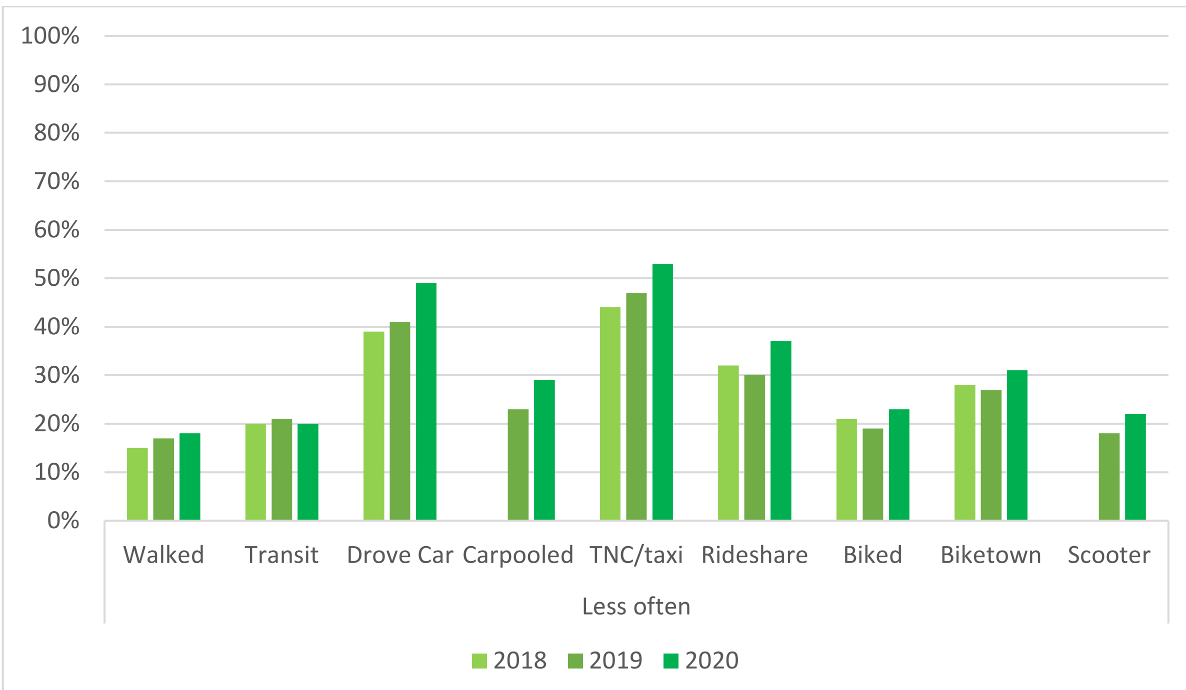

Figure 2. Reported changes in the use of travel modes since the start e-scooter pilot program (2018-2020)

When asked if an e-scooter had not been available, respondents reported how they would have made that specific trip. For shorter distances between 0 to 1.99 miles, e-scooter trips tend to replace walk trips (74.6%), car trips (46.0%), and TNC/taxi trips (49.5%). At a longer distance (2 to 4.99 miles), 51.9% of e-scooter trips replace transit trips. The average distance traveled by e-scooter in 2019 and 2020 were respectively 1.91 miles and 1.63 miles. This shows that people were more likely to use an e-scooter as a mode substitution for relatively short-distance.

This study used a binary logistic regression model to investigate each transportation mode (Table 2). The p-values for chi-square of the likelihood ratio test for each transportation mode are less than 0.05, indicating that predictors are associated with reducing the frequency of other transportation modes since the availability of e-scooters to residents.

The results of the mode substitution model (Table 2) show over the time period that Millennials, Black, Indigenous, and People of Color (BIPOC), low-income, weekly and daily users, and utilitarian trips are more likely to switch to an e-scooter from their previous transportation modes. Since the introduction of e-scooters in 2018, e-scooter users used some transportation modes less often, especially car and TNCs/taxi, indicating e-scooters can substitute some vehicle trips. The frequency changes of car, TNCs/taxi and other "micromobility" modes (personal bike, BIKETOWN, personal e-scooter, skateboard) in 2020 are significant, while only transit and TNCs/taxi usage in 2019 are significant. While the greatest reductions in use were related to car and TNCs/taxi modes, e-scooter users were also more likely to change from walking and transit to using an e-scooter in 2020 compared to 2018.

Exploring socio-economic variables, GenXers and Boomers are less likely to shift from their previous mode preference to using an e-scooter than Millennials, and the results of GenXers for mode substitution model are statistically significant for all modes while the results of Boomers are statistically significant only for TNCs/taxi. Most gender differences are negligible for each mode, except other micromobility devices, where men are 1.36 times less likely to use micromobility after starting to use e-scooters than women. BIPOC riders are more likely to substitute to an e-scooter from car, transit and micromobility devices than white riders. Low-income riders are more likely to change their usage pattern for all transportation modes given the use of an e-scooter. However, middle-income riders are significantly less likely to substitute walking and micromobility modes and high-income riders are significantly less likely to change walking, transit and micromobility usage compared to low-income riders. These results can be interpreted that e-scooter can be a more attractive transportation mode, especially for low-income groups.

Frequent e-scooter riders are more likely to switch to an e-scooter from other modes compared to people who use e-scooter less than weekly. Compared to "less than weekly" users, "weekly" users are more than 2 times likely and "daily" users are more than 4 times likely to use e-scooter for all transportation modes. Among the transportation modes, TNCs/taxi is the least frequently used transportation mode since the availability of e-scooters, indicating that "weekly" and "daily" users are over 4 times and 12 times more likely to reduce using TNCs/taxi than "less than weekly" users. The results show that daily and weekly e-scooter users are less likely to use other transportation modes since starting to use an e-scooter.

Respondents who use e-scooters for work/school trips are significantly less likely to use car, walk, use transit, and taxi/TNCs compared to someone that primarily uses an e-scooter for fun/recreational trips. Among the various transportation modes, commuters are most likely to change their transportation modes from walking to an e-scooter. Utilitarian e-scooter riders are significantly less likely to use car and TNC/taxi over potential micromobility trips. People who use an e-scooter for utilitarian purposes have the largest change in TNCs/taxi usage, indicating that approximately 66% increase in the probability of reducing TNCs/taxi usage since first using the e-scooters. Similar to utilitarian trips, people who use an e-scooter to get to transit stops also tend to reduce using other transportation modes except transit rather than recreational users, and only transit and TNCs/taxi usage are significant for respondents using e-scooter to get to transit stops. People who used TNCs/taxi for accessing transit stops are more likely to use an e-scooter to get to transit stops than other modes since starting to use the program.

Table 2. Results of binary logistic regression model for each transportation mode (less often=1)

	Car[1]		Walk		Transit		TNCs/taxi		Micromobility[2]	
	Estimate (SE†)	Odds ratio	Estimate (SE)	Odds ratio	Estimate (SE)	Odds ratio	Estimate (SE)	Odds ratio	Estimate (SE)	Odds ratio
Constant	-0.60^{***} (0.11)	0.55	-2.18^{***} (0.16)	0.11	-1.73^{***} (0.14)	0.18	-0.25^{*} (0.11)	0.78	-1.02^{***} (0.12)	0.36
Year 2018 (base)										
Year 2019	0.12 (0.08)	1.12	0.14 (0.11)	1.15	0.25^{*} (0.10)	1.29	0.27^{**} (0.09)	1.31	0.07 (0.09)	1.07
Year 2020	0.28^{*} (0.13)	1.32	0.02 (0.17)	1.02	0.10 (0.16)	1.10	0.37^{**} (0.14)	1.45	0.29^{*} (0.13)	1.34
Socio-economic Variable										
Age Millennials (base)										
GenX	-0.25^{**} (0.08)	0.78	-0.31^{**} (0.11)	0.73	-0.44^{***} (0.10)	0.64	-0.47^{***} (0.08)	0.63	-0.49^{***} (0.09)	0.61
Boomer	-0.22 (0.17)	0.80	-0.17 (0.23)	0.84	-0.26 (0.23)	0.77	-0.60^{***} (0.17)	0.55	-0.17 (0.18)	0.85
Gender: Male	0.01 (0.08)	1.01	0.12 (0.11)	1.13	0.07 (0.10)	1.07	-0.10 (0.08)	0.91	0.31^{***} (0.08)	1.36
Race: BIPOC	0.18^{*} (0.09)	1.20	0.13 (0.12)	1.14	0.31^{**} (0.11)	1.36	0.16 (0.10)	1.17	0.59^{***} (0.09)	1.80
Individual Annual Income Low income (base)										
Middle income	-0.06 (0.10)	0.94	-0.33^{**} (0.12)	0.72	-0.15 (0.11)	0.86	-0.16 (0.10)	0.86	-0.31^{**} (0.10)	0.73
High income	-0.07 (0.11)	0.93	-0.31^{*} (0.13)	0.74	-0.59^{***} (0.13)	0.55	-0.07 (0.11)	0.94	-0.50^{***} (0.11)	0.60
Travel Behavior Variable										
Frequency Less than weekly (base)										
Weekly	1.20^{***} (0.08)	3.33	0.87^{***} (0.10)	2.40	0.90^{***} (0.10)	2.46	1.47^{***} (0.09)	4.36	0.71^{***} (0.08)	2.04
Daily	1.91^{***} (0.24)	6.76	1.47^{***} (0.21)	4.35	1.45^{***} (0.21)	4.25	2.54^{***} (0.34)	12.69	1.39^{***} (0.20)	4.01
Trip purpose Fun/recreation (base)										
Work/school	0.22 (0.11)	1.24	0.58^{***} (0.15)	1.79	0.44^{***} (0.13)	1.56	0.39^{***} (0.12)	1.47	0.06 (0.12)	1.06
Utilitarian	0.24^{**} (0.09)	1.27	0.25 (0.14)	1.28	-0.01 (0.12)	0.99	0.51^{***} (0.09)	1.66	0.01 (0.10)	1.01
Accessing transit stops	0.23 (0.16)	1.26	0.17 (0.22)	1.19	-0.67^{**} (0.23)	0.51	0.36^{*} (0.16)	1.43	0.15 (0.16)	1.16
AIC	4515.64		2905.67		3164.41		4213.49		4099.76	
BIC	4601.95		2991.97		3250.71		4299.79		4186.06	
Log Likelihood	-2243.82		-1438.83		-1568.20		-2092.75		-2035.88	
Deviance	4487.64		2877.67		3136.41		4185.49		4071.76	
McFadden R2	0.0788		0.0614		0.0832		0.1181		0.0654	
Adj. McFadden R2	0.0730		0.0523		0.0750		0.1122		0.0590	

Note: n=3514, $^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$, † Standard Error

[1]Car includes drive a car, carpool or ride as a passenger, carshare (Zipcar or Car2go/ShareNow)

[2]Micromobility includes personal bike, BIKETOWN bike, personal e-scooter (excludes shared e-scooters)

4.2 Trip purpose

With three periods of survey data, this study has been able to examine how the travel purpose for using an e-scooter has changed. By analyzing trip purpose, our research wanted to address if e-scooters could be used more regularly for essential trips, not just for leisure trips. In addition, by classifying accessing to transit stops as a separate trip purpose, we can see to what extent e-scooters can work as a first/last mile connector to transit.

Table 3 shows the descriptive statistics between socio-demographic/travel behavior variables and each trip purposes: work/school, utilitarian, fun/recreation, and accessing transit stops. Our research combined several trip purposes into utilitarian trips, including social/entertainment, shopping, eating out, a work-related meeting/appointment, and exercise. The chi-square test for each independent variable was used to determine whether there was a significant difference between the characteristics of respondents and trip purposes, and all independent variables of respondents had a statistically significant impact trip purpose.

Over time, e-scooter trips for utilitarian trips and accessing transit stops increased, while trips for fun/recreational purposes decreased. Utilitarian trips made up the majority of top trip purposes overall years with combined several trip purposes, 44% in 2018, 47% in 2019 and 59% in 2020. E-scooter riders' primary trip purpose was fun/recreation during 2018 and 2019, but the primary purpose shifted to utilitarian, work/school and accessing transit stops for 2020. By 2020, the percentage of fun/recreation trips decreased from 29% in 2018 to 9%, while work/school trips increased to 23% from 22% and trips for accessing transit stops increased to 9% from 6%. The decrease in the use of e-scooters for fun/recreation could be partly due to the timing of the 2020 survey.

Millennials were more likely to use e-scooter for work/school and fun/recreational trips than GenXers and Boomers. On the other hand, GenXers and Boomers were more likely to use e-scooter to get to transit stops than Millennials. Females tend to use an e-scooter for fun/recreation purposes more than males. The proportions of BIPOC riders that use an e-scooter for work/school, fun/recreation, and accessing to transit stop were higher than White riders. The low-income category was more likely to make e-scooter trips for commuting and fun/recreation trips than the middle and high-income categories. Daily riders primarily used an e-scooter for work/school, while less than weekly riders were more likely to use an e-scooter for fun/recreation.

Figure 3 presents the primary trip purpose by demographic groups, which combines data from the three survey periods. In general, most demographic groups use e-scooters for utilitarian trips, except daily users. Daily users are more likely to use an e-scooter on work/school trips than utilitarian trips. Riders who used e-scooters for work/school were more likely to be male, Black, Indigenous, and People of Color (BIPOC), Millennials (18-35), low and middle income, and daily users. Whereas, riders making fun/recreation trips were more likely to be female and less than weekly users. BIPOC, Millennials (18-35), and low-income groups tend to use e-scooter not only for work/school but also for fun/recreation.

For the demographic groups by survey period, race and frequency of use were statistically significant for the primary trip purpose. Figure 4 highlights the differences of the primary trip purpose for race and frequency users by each survey period. Although not all the results are not presented in the paper, all demographic groups in 2018 displayed significance. Where in 2019 only age was not significant and gender, age, and income were not significant in 2020.

Table 3. Descriptive statistics and the results of the chi-square test of socio-demographic/travel behavior of respondents

Variables	Trip Purpose				P-Value
	Work/School (%)	Utilitarian (%)	Fun/Recreation (%)	Accessing transit stops (%)	
Year					
2018	21.9	43.7	28.3	6.2	<.001
2019	21.1	47.4	23.5	7.9	
2020	23.0	59.2	9.1	8.8	
Age					
Millennials	23.1	43.2	28.1	5.7	<.001
Gen X	20.4	49.3	22.0	8.2	
Boomer	19.1	52.3	20.2	8.4	
Gender					
Male	24.0	47.1	21.8	7.1	<.001
Female	17.7	44.4	31.5	6.5	
Race					
White	21.2	48.3	23.7	6.7	<.001
BIPOC	24.0	37.5	31.1	7.6	
Individual Annual Income					
Low income	24.3	34.8	34.8	6.2	<.001
Middle income	23.3	43.3	25.9	7.5	
High income	18.8	55.1	19.5	6.6	
Frequency					
Less than weekly	13.3	47.5	33.2	6.0	<.001
Weekly	32.6	45.6	13.3	8.6	
Daily	55.3	29.3	9.8	5.7	

Note: Utilitarian trips include social/entertainment with specific destination, shopping and errands, restaurant, to/from work meeting/appointment, and exercise.

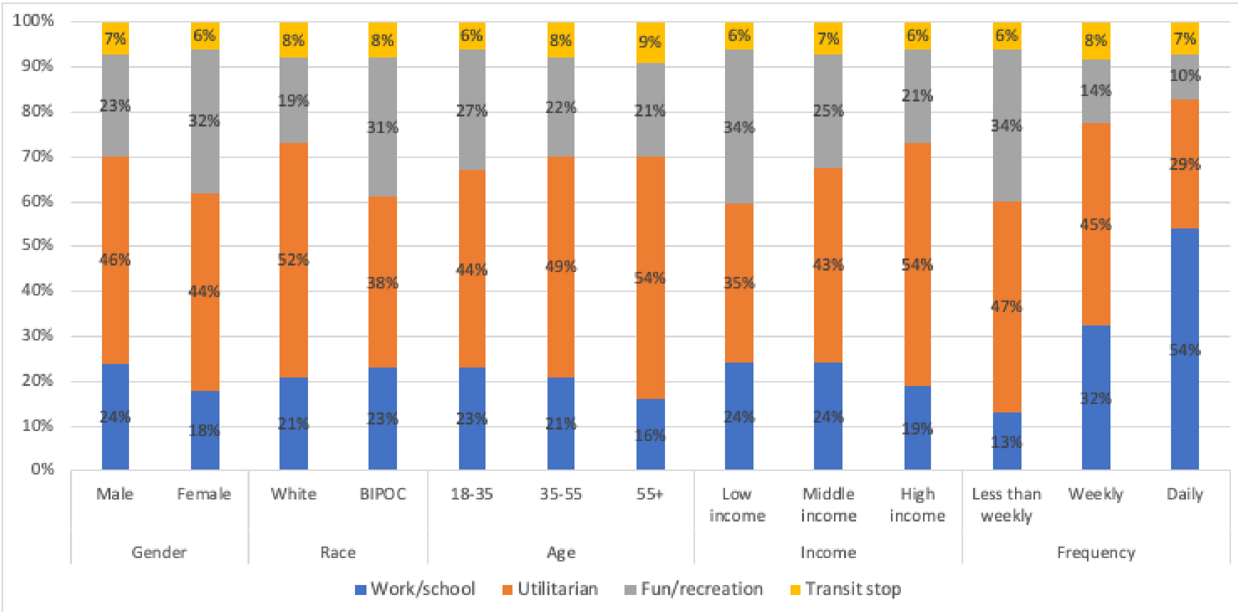

Figure 3. Primary trip purpose by demographic groups: combined 2018-2020 data

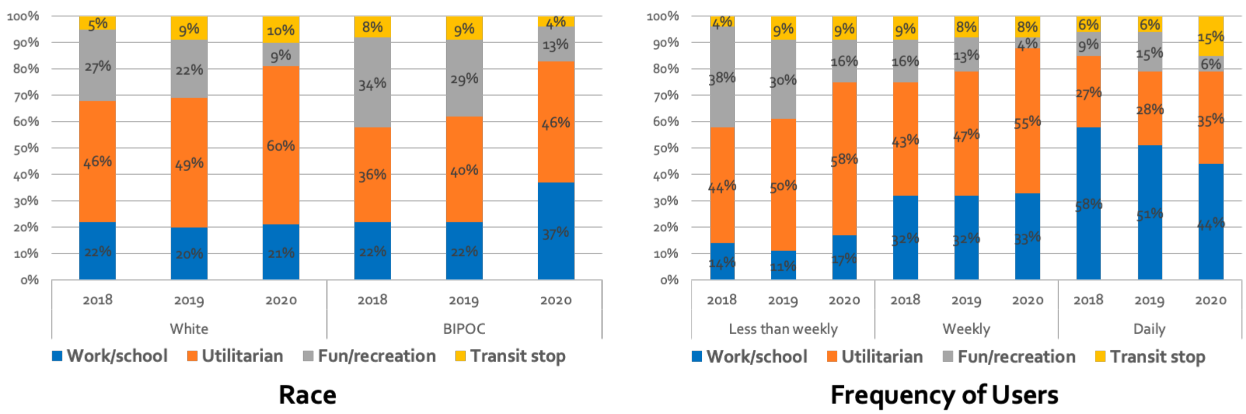

Figure 4. Primary trip purpose for race and frequency users by each year

4.3 Travel distance

This research conducted a multiple regression model with the travel distance data from the 2019 and 2020 surveys to examine how the distance traveled by e-scooter users has changed over time periods and whether e-scooters can help to reduce the vehicle miles traveled (VMT) by replacing vehicle trips. Table 4 shows the estimates of a generalized linear regression model with negative binomial distribution for the most recent e-scooter trip distance. The generalized linear regression model shows the significance ($\chi^2(23) = 139.55$, $p < 0.001$). The model shows that middle income, people who had walked, and the reason to take an e-scooter for the most recent trip (it's "*fast*" and "*just for fun*") are significantly associated with the travel distance of the most recent e-scooter trip. In 2020, people rode e-scooters shorter distances than in 2019. Contrary to the expectation, age, gender, race, frequency, and trip purpose are not statistically significant associated with the travel distance after controlling for other variables.

The results illustrate that people who would have walked for their most recent trip are less likely to travel longer distances by e-scooter than people who would have used a car. There are both negative and positive relationships between travel distances and the reason to use e-scooters. E-scooter riders who chose e-scooters because it is "fast" are more likely to travel short distances (coefficient=-0.11), while e-scooter riders who used the e-scooter for "fun" are more likely to travel longer distances (coefficient=0.16). It appears that e-scooter riders who choose the mode because it is "fast" aim to access their destination as soon as possible and an e-scooter can be competitive for a shorter trip. E-scooter users who use the mode for "fun" might travel without any specific destination or for recreational purposes and they enjoy travel itself, so they might have longer travel distances.

With travel distance and mode replacement questions for the most recent e-scooter trip, this research can calculate how much e-scooters can reduce VMT with the most recent e-scooter trip distance from the user's apps. This calculation is an estimate of reduced VMT since e-scooter users can travel on roads, paths and sidewalks and may sometimes not follow one-way streets, unlike vehicles. The model shows e-scooters have replaced 1,079 miles from car and TNCs/taxis trips averaging 2.08 miles per car or TNCs/taxis trip.

Table 4. Generalized linear regression model with negative binomial distribution predicting distance of e-scooter trips

	Estimate	Std. Error
Constant	0.92***	(0.09)
Year: 2020	-0.15**	(0.05)
Socio-economic Variable		
Age Millennials (base)		
GenX	0.03	(0.05)
Boomer	0.12	(0.10)
Gender: Male	0.09	(0.05)
Race: BIPOC	0.04	(0.06)
Individual Annual Income Low income (base)		
Middle income	-0.15*	(0.06)
High income	-0.10	(0.07)
Travel Behavior Variable		
Frequency Less than weekly (base)		
Weekly	0.00	(0.05)
Daily	0.15	(0.11)
Trip purpose Fun/recreation (base)		
Work/school	-0.04	(0.07)
Utilitarian	-0.07	(0.06)
Transit stops	-0.12	(0.10)
Variables Related to the Most Recent E-scooter Trip		
Mode Replacement Car (base)		
Walked	-0.45***	(0.06)
Transit	-0.09	(0.08)
TNCs and taxi	-0.09	(0.06)
Micromobility	-0.13	(0.09)
The reason to take e-scooter		
Recent motivation_fast	-0.11*	(0.05)
Recent motivation_cost	0.07	(0.05)
Recent motivation_nosweat	-0.08	(0.06)
Recent motivation_noparking	-0.08	(0.05)
Recent motivation_fun	0.16**	(0.05)
Recent motivation_transit	-0.01	(0.05)
Recent motivation_nocar	-0.03	(0.06)
Log Likelihood	-1837.578	
Deviance	861.52	
McFadden R2	0.14	

Note: n=1248, ***p < 0.001; **p < 0.01; *p < 0.05

5 Discussion

The introduction of e-scooters in Portland provides residents with more mobility options. After analyzing three different time periods of e-scooter ridership survey data and demographic data, it appears e-scooters are shifting from a novelty or recreational vehicle to a viable mode of transportation that enhances Portland's transportation network. At the beginning of the e-scooter operations in Portland, similar demographics and e-scooter travel behavior were observed between Portland and other cities like Austin, San Francisco, and Santa Monica (Austin, City of, 2018; San Francisco Municipal Transportation Agency, 2019; Santa Monica, City of, 2019A, 2019B). E-scooter riders were more likely to be young, middle/high-income, white men with and who were less than weekly riders (Austin, City of, 2018; San Francisco Municipal Transportation Agency, 2019; Santa Monica, City of, 2019A, 2019B). While there are observable similarities between cities and their e-scooter ridership behavior, the differences might be due to the built environment, availability to safe infrastructure and weather conditions. Huo et al. (2021) found e-scooter ridership in Portland, Minneapolis, Kansas City, Austin, and Louisville positively correlates with population density, employment density, intersection density, land use, and bus stop density. Additionally, Huo et al. (2021) found an elasticity between bicycle trail density (1%) and e-scooter ridership (1.18%). We can surmise that transit and bicycle infrastructure have the ability to support and encourage e-scooter ridership. Portland's transportation network is rich with public transit and bicycle facilities, which may contribute to the ridership shift towards utilitarian and commuting trips. The logistic regression model for mode substitution (Table 2) suggests that the introduction and commercialization of e-scooter can affect the mode substitution. This is not to say that Portland and other cities that want to encourage using e-scooters do not need more infrastructure for micromobility users, including lanes, separated paths and parking (Guo and Zhang, 2021; Zakhem and Smith-Colin, 2021). More than likely, the increase in safe infrastructure and policies that encourage proper use of e-scooters and connections to transit will increase the use of e-scooters.

By analyzing the survey data, this research finds e-scooters were used for commuting and convenience trips as well as for alternative transportation over the early stages of deployment in Portland. Compared to Millennials, GenXers and Boomers are less likely to change the frequency of their transportation mode, implying that e-scooters could be a viable transportation alternative for Millennials who are familiar with smartphones and tech-based transportation and feel e-scooters are easy to use (Ratan et al., 2021). Since the introduction of e-scooters, BIPOC riders used e-scooters as an additional travel option and shifted from car and transit trips. Since several e-scooter companies offer discounted pricing for low-income residents (Portland Bureau of Transportation, 2020), e-scooters can be a more attractive transportation mode compared to more expensive options, walking or even personally-owned bicycles. Though e-scooters are substituting transit trips, particularly among BIPOC and lower-income riders, this could be interpreted to expanding travel options which might be quicker and more direct. The areas of travel behavior and mode substitution certainly needs more investigation.

The mode choice changes produced by the introduction of e-scooters may potentially reduce automobile use, especially for weekly and daily users and utilitarian e-scooter riders, which have a higher probability of using an e-scooter instead of vehicles (car, TNCs/taxi). There are some signs that some users were seeing e-scooters as a viable daily travel mode. Compared to other cities this relationship is unique (6t-bureau de recherche, 2019; Krier et al., 2021), where this relationship between regular and occasional riders and modal shift has not been established. People who use an e-scooter for accessing transit stops are less likely to change to transit usage, and maybe even increases transit usage, compared to people who use e-scooter for fun/recreation. The use of e-scooters vs other modes to connect to the first/last mile of the transit system needs further analysis and more in-depth data collection.

This study illustrates some shifts in travel behavior, from novelty (fun/recreational trips) towards utilitarian purposes, including work and school commutes. This trip purpose shift could be a result of e-scooters losing their novelty and imbedding themselves as part of the urban transportation network. Besides the utilitarian trip, *fun/recreation* was the top trip purpose in 2018 (Table 3), similar to what was seen in Austin and Santa Monica (Austin, City of, 2018; Santa Monica, City of, 2019A, 2019B). Two years after introducing e-scooters, there is a shift to using e-scooters more for *work/school* and the *utilitarian* trips (Table 3). It should be noted again that the results may be influenced by time surveys where administered. Though the 2020 survey took place during late winter, the population might represent an active segment of the user population. We would expect with any of the micromobility modes fluctuations of use throughout the year, because of weather, some individuals still find utility in the mode for daily or weekly use. With increasing accessing transit stops with e-scooters over time, e-scooters can be a solitary mode itself or the connector to increase accessibility to public transit. Questions discussing accessing transit are also observed in Austin and San Francisco (Austin, City of, 2018; San Francisco Municipal Transportation Agency, 2019), which can allude to e-scooters being viewed as a potential first/last-mile solution (Krier et al., 2021). This travel behavior shift might illustrate how e-scooters are becoming more legitimized for Portlanders since regular e-scooter ridership could indicate a greater reliance on e-scooters as an integral part of Portland's transportation networks and less of a fad or novelty. However, the shift from novelty to acceptance is influenced by a rider's pre-established modal preference, since cyclists and motorcyclists are often less likely to show any interest in e-scooters (Nikiforiadis et al., 2021). The results of the descriptive statistics for trip purpose shows that over the years, older riders, male, white, middle and high income, weekly and daily users are more likely to choose e-scooter for work/school or utilitarian or transit stop trips rather than fun/recreation (Table 3). Affluent, white male users continually dominate e-scooter ridership and there is a need to promote accessibility to more marginalized groups to increase different forms of shared micromobility. Rectifying this imbalance requires local leadership to prioritize equity policies and programs to raise awareness, ensure service in underserved communities and provide affordable options.

According to the generalized linear regression model for the travel distance (Table 4), socio-economic, travel behavior, and the most recent trip variables are all significantly associated with the travel distance. By analyzing these data in 2019 and 2020, this research found differences, which can be seasonal differences or trends with the provision of e-scooters. It is important to recognize that the 2020 survey was performed during the late winter months and the 2019 survey was executed during the early fall. The seasonal difference showed shorter distances traveled during colder and rainier winter weather in Portland, which are in line with showing significant decrease in use during winter months "Weekday/Weekend Heatmap" in the "PBOT E-Scooter Trips Dashboard" (Portland Bureau of Transportation, 2020B). E-scooter users in Portland have a tendency to travel shorter distances during the winter (Portland Bureau of Transportation, 2020A). However, it is hard to conclude this is only from seasonal differences since the average trip distance for east Portland in 2019 decreased from 2018 with increased deployment of the e-scooter fleet in east Portland, although 2018 and 2019 surveys were conducted in the same season (Portland Bureau of Transportation, 2020A). After e-scooters were introduced in Portland, many respondents used e-scooters over short walking trips. Additionally, people who used a car for their trips are more likely to travel longer distances by e-scooter from some of their trips. But in general, an e-scooter is being used for short distance trips. People are more likely to use e-scooters to get to their destinations quickly if destinations are within short distance, indicating e-scooter can serve as an efficient transportation mode for trips under a mile away. Based on the trip distance model (Table 4), e-scooters can replace 2.08 average miles of travel distance of vehicle trips. This result supports the findings that e-scooter could replace other transportation modes and help reduce traffic congestion and lower VMT (Gou and Zhang, 2021; Lee et al., 2021).

6 Conclusion

This paper provides an examination of a multi-period cross-sectional shared e-scooter mode substitution, trip purpose, and trip distance data. This analysis examines if e-scooters are a viable option for municipalities to achieve climate change, congestion, and equity policy goals based on the observed travel behavior changes witnessed in Portland, Oregon. The results of the study confirm findings from the literature that suggest (1) e-scooter riders are more likely to substitute walking, transit, and short car trips with e-scooter trips, (2) as shared scooter operations mature and some people use them more often, with some shift from fun/recreation trips to commuting and utilitarian trips, and (3) e-scooter riders are more likely to use e-scooters for short-distance travel, especially for utilitarian trips.

The mode substitution model and trip purpose descriptive statistics showed that e-scooter can be a potential alternative transportation mode to private vehicles for essential trips. A significant number of vehicle trips were replaced with e-scooters, particularly for younger, BIPOC, and frequent riders. Over time, the primary trip purpose of e-scooters shifted to essential trips. The percentage of utilitarian trips increased the greatest share of trip types, as fun/recreation trips decreased. While our trip purpose model produced a weak association, it is countered by the cross-city comparison which illustrates similar trip purposes. Moreover, the calculated reduced VMT by trip distance model supported that e-scooter possibly reduces traffic congestion, impacting environmental benefits. Additionally, there is some evidence that shared e-scooters are used to address first/last-mile problems in Portland's transportation network, especially by connecting to transit. Studies like ours and similar findings support the growing view that e-scooters are here to stay and enrich local transportation networks.

While there are unique and nuanced observed travel behaviors specific to certain demographics, the majority of riders in Portland are white, middle and higher income, and men. This regularly observed demographic across cities imply there is a significant research gap pertaining to shared e-scooter accessibility and barriers for all BIPOC and low-income communities. Baltimore, a Black majority city, found Black riders constituted the lowest share of e-scooter ridership in an e-scooter program study, further highlighting the need to investigate the relationship between BIPOC riders and e-scooters (Young et al., 2019). This illustrates the need for regulation and equity programs to ensure all urban residents have equitable access to e-scooters to ensure all residents can access the benefits of e-scooters. Based on the analysis, e-scooters fill a unique mobility gap in urban transportation networks and possess the potential to local municipality policy goals of climate change mitigation, congestion reduction, and enhancing equity.

Limitations were identified and mitigated as best as possible. The questions used for analysis were not congruent across the three survey periods and required several manual adjustments to provide a reasonable degree of multi-year continuity, but the authors feel these are minor concerns. Questions offering multiple answers one year, with single answers the following survey years or questions offering different options during different years required some coding. The most notable change was the 2020 survey which was performed during the late winter months while the 2018 and 2019 surveys were executed during the early fall months, which might have potential impacts on the demographics of respondents and survey responses. For example, some people may be less willing to use scooters during the winter months due to colder temperatures and rain. The survey was sent out to people who used a scooter in the last 6 months but the people responding to the survey during the winter months might be of different demographics or use the scooter for different purposes, such as work or other utilitarian trips.

This study was bounded by only the three ridership surveys and did not include external data sources. Investigating spatial temporal factors are outside of the bounds for this study, but should be included in future research to examine the specific impacts of e-scooter ridership on vehicle miles traveled and congestion. Another fruitful avenue is to examine how e-scooter ridership is influenced by Portland's built environment and transportation network. Furthermore, seeking a potential answer to Portland's e-scooter frequency-mode substitution relationship requires future exploration.

Additionally, the number of companies fluctuated from year to year and some companies left the Portland market before the end of the pilot periods. Also, the decision to group BIPOC respondents into one category is, due to the comparatively low number of BIPOC respondents who responded to the survey. Parsing out respondents into even basic groupings was attempted but produced poor results. The same was true for gender, as a traditional nonbinary approach to gender analysis produced marginal results. These limitations produce significant research gaps which should be expanded and explored. Despite these limitations, this study is expected to be an important cornerstone in supporting e-scooters as a potential transportation mode in the future in terms of congestion, climate, and equity by understanding the shared e-scooter user's travel behavior.

With the data limitation, it is challenging to distinguish whether the reason for increased e-scooter ridership over time is actual travel behavior changes or the effects of e-scooter plans from companies. While PBOT required e-scooter companies to provide a low-income plan and deploy a certain percentage of the fleet in east Portland, with higher percentage of communities of color and low-income areas (Portland Bureau of Transportation, 2018; 2020A), this research cannot determine that low-income plans are the reason for the difference in e-scooter usage and travel behavior between years. Additionally, it is possible that the differences in e-scooter ridership between years were influenced either by familiarity and adoption of e-scooters or improved transportation infrastructure for e-scooters. Another limitation of the study is that income was only collected on the individual and not at the household level.

Though there are some limitations to the data and methodology, this study previous a unique dataset multi-period cross-sectional exploration on e-scooter usage in Portland. Based on our findings, the introduction of e-scooter provides more mobility options for low-income people with subsidized fare program, and it can potentially improve quality of life by increasing mobility of people (Makarewicz and Németh, 2018). Despite these limitations, by analyzing the yearly multi-year data of shared e-scooter in Portland, this study is able to identify how strong mode substitution, trip purpose, and trip distance associations of e-scooter ridership are to the e-scooter usage since the introduction of the e-scooter to Portland.

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7 Appendix

Appendix 1. Descriptive Statistics of Demographics

Variables	**2018 (n=2213)**		**2019 (n=970)**		**2020 (n=331)**	
	N	**%**	**N**	**%**	**N**	**%**
Demographics						
Age						
Millennials (18-35)	1180	53.3	526	54.2	172	52.0
Gen X (35-55)	916	41.4	405	41.8	137	41.4
Boomer (55+)	117	5.3	39	4.0	22	6.6
Gender						
Male	1416	64.0	632	65.2	246	74.3
Female	797	36.0	338	34.8	85	25.7
Race						
White	1773	80.1	776	80.0	276	83.4
BIPOC	440	19.9	194	20.0	55	16.6
Income						
Low income (less than $30K)	482	21.8	181	18.6	45	13.6
Middle income (between $30K and $75K)	910	41.1	407	42.0	123	37.2
High income (more than $75K)	821	37.1	382	39.4	163	49.2
Frequency						
Less than Weekly	1349	61.0	578	59.6	189	57.1
Weekly	792	35.8	358	36.9	125	37.8
Daily	72	3.2	34	3.5	17	5.1

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