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Dockless micromobility sharing in Calgary: A spatial equity comparison of e-bikes and e-scooters

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Abstract
This paper reports on a comparison of the spatial equity dimensions of dockless bike and e-scooter sharing in Calgary, Alberta. Using trip data from the City of Calgary's Shared Mobility Pilot (between July-September 2019), this study investigates differences in micromobility utilization by dockless mode between areas characterized by different levels of deprivation. ANOVA and linear regression results show that utilization of both dockless modes was spatially inequitable, with e-scooter and dockless bike trips concentrated in the least deprived areas. Dockless bike and e-scooter sharing utilization declined with each increase in deprivation level by 0.138 trips per 1,000 persons per vehicle for dockless e-scooters, and 0.015 trips per 1,000 persons per vehicle for dockless bikes, suggesting that more equity considerations are required to ensure that the benefits of dockless micromobility sharing are available to all areas regardless of the relative advantage or disadvantage.

Keywords: bikesharing, dockless, e-scooters, micromobility, spatial equity

Résumé
Cet article rend compte d'une comparaison des dimensions d'équité spatiale du partage de vélos et de scooters électriques sans quai à Calgary, en Alberta. À l'aide des données sur les déplacements du projet pilote de 'mobilité partagée' de la ville de Calgary (entre juillet et septembre 2019), cette étude examine les différences d'utilisation de la micromobilité en mode sans quai entre les zones caractérisées par différents niveaux de privation.
Les résultats de l'ANOVA et de la régression linéaire montrent que l'utilisation des deux modes sans quai était spatialement inéquitable, et de même que spatialement inéquitable, tant les déplacements en scooter électrique et en vélo sans quai étant concentrés dans les zones les moins défavorisées. L'utilisation du partage de vélos et de scooters électriques sans quai diminue à chaque augmentation du niveau de privation de 0,138 trajets pour 1 000 personnes par véhicule pour les scooters électriques sans quai et de 0,015 trajets pour 1 000 personnes par véhicule pour les vélos sans quai. Ce qui suggère que davantage de considérations d'équité sont nécessaires pour garantir que les avantages du partage de la micromobilité sans quai sont disponibles dans toutes les régions, quel que soit l'avantage ou le désavantage relatif.

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Mots-clés : partage de vélos et de scooters électriques sans quai, Calgary, micromobilité, équité

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Introduction

Micromobility sharing systems, including shared bikes and e-scooters, have been adopted by many cities as an alternative mode of short-range urban transportation (Fishman 2016). Dockless micromobilities, which do not rely on physical stations for accessing vehicles, grant greater flexibility in travel compared to their docked counterparts, whose fixed station locations restrict the distances over which vehicles may be utilized across a service area. Because they forgo the need to originate and terminate trips at fixed station locations, dockless micromobilities are seen as having the potential to close some of the spatial equity gaps in transportation that are characteristic of docked bikesharing systems.

Spatial equity is a measure of how well a transportation system equally serves all potential users in a service area, irrespective of differences in the socioeconomic characteristics of the neighbourhoods in which those users live, work, and play (Chen et al. 2020). As more cities start piloting micromobility sharing programs as approaches to facilitating more sustainable, healthy, traffic congestion reducing modes of transportation, spatial equity is an important axis to consider in the planning and evaluation of these systems to ensure that their actual and potential benefits are evenly distributed across a city's spatial fabric. Yet to date, there has been scant evaluation of which mode of shared dockless micromobility—bikes or e-scooters—expresses superior potentials for spatially equitable short-hop transportation in cities. Previous studies have explored the spatial equity dimensions and uptake of dockless bikes and e-scooters, respectively, and have also compared the spatial equity dimensions of dockless versus docked bikesharing systems. However, within-dockless mode direct spatial equity comparisons of e-bikes and e-scooter sharing systems within the same city remain outstanding.

This paper reports on an analysis comparing the spatial equity profiles of dockless bike and e-scooter sharing systems in Calgary, Alberta, using publicly available data about shared scooter and dockless bike trips taken between July 1st – September 30th, 2019, that were collected as part of the City of Calgary's Shared Mobility Pilot. Building from Hosford and Winters' (2018) foundational Canadian analysis of the urban spatial equity of docked bikesharing systems, we mobilize area-level deprivation—a measure of the relative aggregate 'well-being' characteristic of different geographical areas—as a proxy for spatial equity. We consider dockless bike and e-scooter sharing to be equally spatially in/equitable if both systems exhibit the same pattern of utilization across Calgary's differential geography of deprivation. We compare the volume of shared e-scooter and dockless bike trip terminus locations (end points) by deprivation quintile scores calculated using the Pampalon Deprivation Index (Pampalon et al. 2012) for the sub-neighborhood scale Dissemination Area geographies in which those trips ended. We then use ANOVA (Analysis of Variance) and linear regression to test whether any differences in the spatial equity profiles of the two dockless modes were statistically significant.

The results of our analysis indicate that the utilization of dockless bikes and e-scooters in Calgary was comparatively spatially inequitable over the three-month period for which data was available (July – September 2019 inclusive). The utilization of both shared dockless bikes and e-scooters was concentrated in the least deprived (most advantaged) areas. This study contributes to the emerging research on micromobility sharing systems, including recently popularized e-scooters, and can help to inform the planning of existing and future micromobility sharing services by identifying utilization of these services as a factor that may require more spatial equity considerations in dockless system planning, testing (pilot programs), and expansion.

Transportation equity, micromobilities, and the urban context

Transportation equity

Transportation is closely linked with quality of life; access to life opportunities, including education and employment; and social inclusion (the ability to participate in society) and thereby social cohesion (Delbosc and Currie 2011; Lee et al. 2017; Lo et al. 2020; Shaheen et al. 2017). *Transportation equity* describes the fairness with which the urban transportation resources—a concept which includes modes (walking, cycling, driving, etc.), infrastructures (e.g., roads, cycle lanes), and systems (e.g., public transit networks)—necessary for enjoying a high quality of life, gaining access to opportunities, and fostering social inclusion are distributed amongst a city's residents and across an urban spatial fabric (Shaheen et al. 2017, 14). An analytic focus on transportation equity is essential to understanding the impacts of transportation policy and planning in cities, which inevitably have equity impacts, as well as to contending with the complexity of urban travel behaviours, which are affected by equity differentials (Di Commo and Shiftan 2017; Litman 2002). Within urban studies, equity considerations have gained both prominence and urgency as intensifying waves of gentrification, including those induced by urban transportation development itself, displace city residents–disproportionately those from racialized, ethnic-minoritized, and low-income backgrounds–from long-term neighbourhoods into increasingly peripheral urban enclaves and suburbs that are 'transportation poor', lacking access to transportation options, infrastructures, and services (Allen and Farber 2019; City of Portland Bureau of Transportation, 2019; Delmelle 2021; Grube-Cavers and Patterson 2015). Allen and Farber (2019) have estimated that one million Canadians experience transportation poverty.

Analyses of transportation equity usually focus on one of two dimensions of differentials in transportation access: *social* equity, and *spatial* equity. Social equity concerns differences in social groups who are under/served by transportation opportunities, services, and infrastructures. It is "generally analysed along socio-demographic lines, such as income, race, gender, or age" (Lee et al. 2017, 212), as well as the "[s]ocial, cultural, safety, and language" factors that play into travellers' "comfort with using" different transportation modes, systems, and infrastructures (Shaheen et al. 2017, 23). Social equity interventions focus on expanding transportation opportunities and easing barriers to access for individuals from populations "who have historically been marginalized by [transportation] policy decisions" (Lee et al. 2017, 212), by for instance discounting public transit fares for low-income riders. Spatial equity, in turn, concerns whether the benefits and costs (negative externalities) of transportation system development, policy, planning, and operations are shared equally across areas differently positioned in spatial hierarchies on a spectrum of relative advantage versus disadvantage (Chen et al. 2020). Spatial equity interventions are aimed at achieving the fairer distribution of transportation opportunities and resources across urban spatial fabrics by, for example, increasing the density of bus stops in underserved areas.

The objectives and outcomes of social as compared to spatial equity analyses are divergent. Whereas social equity approaches analytically identify *who* is using, likely to use, and/or may benefit from transportation developments (be these new systems or policy interventions), spatial equity analyses conversely identify *where* particular mobilities and infrastructures are being (under-)utilized (Lee et al. 2017). Because of prohibitions against implicating the ecological fallacy–which preclude making determinations about the characteristics of individuals on the basis of the aggregate characteristics of areas in which they may live, work, etc.—spatial analytic approaches such as GIS methodologies are suitable for evaluating the spatial equity of urban transportation systems, but are not always appropriate for making determinations about the social equity dimensions of these systems (i.e., they cannot answer questions about who is actually using particular mobility modes). For this reason, the social and spatial equity profiles of urban transportation systems tend to be analyzed separately, although some studies do combine assessments of both aspects of equity (see Lee et al. 2017 and Dill and McNeil 2021 for comprehensive reviews of studies' methodologies). Yet even in the latter instance, the methods used to assess the spatial and social equity dimensions remain distinct and are operationalized separately (Lee et al. 2017).

Micromobility sharing

Over the last decade, micromobility sharing has been added to the transportation modal mix in many cities around the world, including in the Canadian urban context. Micromobilities are comprised of lightweight vehicles–including docked shared bikes, dockless e-bikes, and e-scooters–intended for point-to-point travel over relatively short distances in cities. The 'sharing' of these systems describes the way that utilization of the system is organized, whereby vehicles may be rented for set intervals of time, and then released back into the system for use by other riders. Micromobilities have been espoused and adopted as supplements to existing transportation systems in cities, namely public transit networks, for their ability to provide a transportation solution to close 'first-last' mile gaps in urban travel, such as trips to and from transit hubs like light rail stations (Frisbee et al. 2022). Docked bikesharing systems–in which bicycles must be retrieved from and returned to stations at fixed locations–have been operating in Canadian municipalities for some time (see Hosford and Winters 2018). Dockless electrified or 'e'-scooters and 'e'-bikes represent more recent additions to the Canadian urban transportation landscape (Frisbee et al. 2022). Calgary and Edmonton, Alberta, were the first two Canadian cities in which e-bikes and e-scooters were allowed to operate (Frisbee et al. 2022).

As asserted by Chicago-based urban planner Benjie de la Peña (interviewed in Lazo 2021), cities both need to adopt and are actively adopting micromobilities for three key reasons: 1) to reduce traffic congestion through facilitating a modal shift away from single-occupancy vehicle trips to lightweight electrified vehicles that are not restricted to road surfaces (dependent on regulatory framework in any one city); 2) to abate the effects of climate change through reductions in tailpipe exhaust emissions, achieved by providing viable alternatives to fossil-fuel powered car trips; and 3) to enhance transportation equity (see also Lo et al. 2020). Indeed, spatial equity is one of the stated objectives of micromobility adoption in some cities, such as in Portland, Oregon (City of Portland Bureau of Transportation 2019). Dockless micromobilities in particular have been touted as representing a spatially equitable mobility solution for cities due to two factors that differentiate them from legacy transportation networks such as public transit and road infrastructures, as well as docked bikesharing systems, all of which are spatially 'fixed' (i.e., confined to surface road networks, rail lines, bike stations, etc.). First, the lightweight nature of e-bikes and e-scooters combined with their 'freedom from the station' mean that shared dockless vehicles may easily be redistributed across an urban spatial fabric to increase use opportunities, and systems can be expanded into underserved area at minimal cost simply by putting more vehicles into circulation in those places (Chen et al. 2020; McCarty Carino 2018; Mooney et al. 2019; Shaheen et al. 2017). Second, because of this possibility for expansion into transportation poor areas, dockless micromobilities can either increase or reduce "the viability of [other] existing [transportation] options"–for both "entire trip[s] or first-and-last mile connections"–in areas "with limited alternatives to private vehicle ownership," and even more so in low-income enclaves where vehicle ownership rates may be low and people are more likely to require and depend on transportation alternatives (Shaheen et al. 2017, p. 15, 24).

The spatial equity of micromobility sharing

Given the spatial equity potentials of dockless micromobilities, whether or not actual dockless vehicle sharing systems implemented in cities are spatially equitable merits evaluation. Because they represent an earlier transportation intervention, a substantive corpus of studies has examined the spatial equity profiles of docked bikesharing systems around the world. This includes Hosford and Winters' (2018) landmark study of the spatial equity of docked bikesharing in five Canadian cities (Montreal, Toronto, Hamilton, Ottawa, and Vancouver). They compared the deprivation geography of the service areas for bikesharing systems in all five cities using the Pampalon Deprivation Index (PDI), a Canadian-based measure of spatial welfare calculated using census data at the sub-neighbourhood scale of dissemination areas (DAs) that reports deprivation using a quintile classification from 1 (least deprived) to 5 (most deprived). In Hosford and Winters' (2018) study, the bike share service area for each city was identified as the area within a perimeter comprised of DAs that were fully or partially enveloped by a 500-metre buffer around each bicycle docking station. The researchers then evaluated the spatial equity of these docked bikesharing systems by assessing whether the PDI quintile scores for DAs contained within each city's service area reflected an even spatial distribution of deprivation. Their results showed that the bikesharing systems in most of the study cities disproportionately served the least deprived (i.e., most advantaged) areas, with the exception of Hamilton, Ontario, where the service area was concentrated in the most deprived area of the city (see also Bradshaw and Kitchin 2022). A review of spatial analyses of the equity of shared mobilities conducted by Dill and McNeil (2021) identifies that the state of the field of research overwhelming confirms that, on the whole, bikesharing systems are spatially inequitable, with lower-income and more racially/ethnically diverse neighbourhoods disproportionately characterized by lower access to bikesharing as compared to more affluent, majority-white enclaves.

Scholarly assessments of the spatial equity dimensions of dockless micromobility systems are more recent, and to date, have analyzed both dockless modes separately from each other. Caspi et al.'s (2020) study of e-scooter sharing in Austin, Texas, found that e-scooters were used throughout the city regardless of the socioeconomic characteristics of Austin's neighbourhoods, suggesting that dockless e-scooters can potentially minimize gaps in urban transportation inequities. In Portland, Oregon, however, analysis by the Portland Bureau of Transportation (PBOT) found that e-scooters were underutilized in East Portland neighbourhoods that include a large proportion of Equity Matrix Areas comprised of Census Tracts characterized by the lowest income and the most racialized/ethnic minoritized demographics.

Studies of dockless bikesharing spatial equity include Mooney et al.'s (2019) analysis of access to dockless bikesharing in Seattle, Washington, which found that there was a higher availability of vehicles in wealthier and more privileged neighbourhoods (areas with more community resources overall). Gehrke et al. (2021) found that in Boston, Massachusetts, dockless shared bikes were less accessible in neighbourhoods with higher concentrations of renters and historically disadvantaged (racialized and lower income) populations as compared to whiter, more affluent areas characterized by higher rates of owner-occupied housing. A second important group of dockless micromobility sharing studies are those that offer comparative analyses of the spatial equity profiles of docked versus dockless bikesharing systems. Such comparative analyses importantly understand docked and dockless bikesharing as representing two distinct approaches to organizing the spatiality of system utilization. With docked systems, shared bike trips need to originate and terminate at fixed bike station ('dock') locations distributed over a service area. In contrast, dockless bikesharing trips originate at the location of an idle (not currently in use) e-bike; this location either represents where a bike has been placed by a system operator, or where a previous rider terminated their trip. Indeed, rather than needing to terminate at a fixed location, dockless e-bike trips may terminate anywhere within an urban spatial fabric. Because dockless bikesharing systems' 'freedom from the station' expresses the potential for being more spatially equitable as compared to docked systems, researchers have strived to evaluate whether this promise is realized in actually-existing cities.

A study by Clewlow et al. (2018) identified that dockless bike and e-scooter sharing in Washington, D.C. did not improve upon the spatial inequities of the docked Capital Bikeshare system, with vehicles across both docked and dockless modes being unevenly distributed across their service areas. A separate study by Qian et al. (2020) comparing the equity of service between docked and dockless bikesharing systems in San Francisco conversely identified that dockless bikesharing did represent spatial equity gains over its docked counterparts, with dockless e-bikes found to be more available than docked bikes in areas defined as Communities of Concern (CoC), where the proportion of the population exceeds a set threshold level for disadvantage factors. Similarly, the results of Caspi's (2022) study of the spatial equity impacts of the integration of dockless e-bikes with Philadelphia's extant docked bikesharing system show that the addition of e-bikes increased the utilization of bikesharing in disadvantaged areas (low-income/impoverished and majority Black/Hispanic neighbourhoods).

Beyond these spatial equity comparisons of docked and dockless modes within the same urban context, to date limited research has examined differences between the spatial equity potential *within* the dockless mode (i.e., between dockless bikes and dockless scooters). An understanding of whether or not one dockless mode delivers superior spatial equity gains in urban transportation over the other is vital towards informing urban planners and policymakers about which modes of dockless micromobilities, if any, should be prioritized in considerations of permitting, governing, and supporting dockless systems in their cities. Spatial equity differences may exist between dockless micromobility modes because dockless bikes and e-scooters are designed and intended for trips of different durations and distances (shorter for e-scooters and longer for e-bikes; McKenzie 2019), and also because of the required skills differential between the two vehicles (use of an e-bike requires knowledge of how to ride a bicycle, whereas no prior skillset is required to ride an e-scooter). This study moves to close this gap by analyzing the comparative spatial equity profiles of dockless bikesharing and e-scooter utilization within the same city—Calgary, Alberta.

Methodology

Study area

This study analyzes the spatial equity of dockless micromobility utilization in Calgary, Alberta, the fourth largest metropolitan area in Canada. In 2016, the city had a population of approximately 1.2 million people within its 825 km^2 area (Statistics Canada 2018a). The city prides itself on having the largest urban pathway and bikeway network in North America (The City of Calgary n.d.), which is well suited for the use of micromobility sharing services. Calgary and Edmonton, Alberta, were the first two Canadian cities in Canada to allow the operation of dockless electrified micromobility systems (e-scooters and e-bikes; Frisbee et al. 2022). A two-year Shared Mobility Pilot project (hereafter referred to as 'Pilot') was implemented in the City of Calgary in the summer of 2018. The Pilot commenced with the introduction of a fleet of 500 shared dockless bicycles operated by the transportation company Lime (Krause 2019). A year later in 2019, the Pilot added 1,500 shared dockless e-scooters, with 1,000 scooters provided by Lime and 500 operated by the micromobility company Bird, alongside the 500 dockless bikes already in operation (The City of Calgary 2019) for an initial trial period during that summer. Other Canadian cities have also tested and implemented dockless micromobility sharing systems (see Frisbee et al. 2022 for a review of the dockless micromobility operation, permitting, and regulatory landscape in Canadian cities). This study focusses on Calgary's micromobility sharing system as at the time of analysis, it was the only Canadian city for which trip data for both scooter and bikes had been made available under an open data license. The inclusion of e-scooter and dockless bike share trips over the same geographic area (City of Calgary) within the same time period provides a standardized spatio-temporal frame of reference for making a direct comparison of the spatial equity dimensions of dockless bikes and e-scooters.

Since the conclusion of the Pilot, The City of Calgary implemented dockless micromobility sharing as a permanent fixture of its transportation modal mix in 2021 (Smith 2021). Unlike during the Pilot, which only ran during summer months, dockless micromobilities are now permitted to operate year-round with the caveat that vehicles need to be taken out of circulation during periods of inclement winter weather (Smith 2021b). Additionally, Lime is no longer operating in Calgary; instead, a second operator, Neuron, now operates a fleet of dockless e-bikes and e-scooters alongside Bird (Smith 2021a; The City of Calgary 2022).

Micromobility data and data processing

Data for a temporal period of the Pilot covering 92 operating days inclusive of July 1st to September 30th, 2019 was published under an open data license through the City of Calgary's Open Data Portal. This dataset represents dockless bike and scooter trips made using vehicles operated by Lime and Bird, and includes the origin and terminus locations of each trip generalized to 30,000 m^2 hexagonal bins (hexbins), with the location points corresponding to the centroid of the hexbin. Additional information contained in the dataset includes the trip start date and day of the week, start hour, trip duration in seconds, and trip distance in metres. Prior to publication, the curators of the dataset removed trips lasting less than 30 seconds or 100 m, and trips with poor geospatial data quality. The resulting downloaded dataset contains a total of 482,021 trips, comprised of 464,743 (96.42%) e-scooter trips and 17,278 (3.58%) dockless bike trips.

Data cleaning was performed in advance of analysis. Scooter trips that were recorded to be over two hours (7,200 seconds) in duration were excluded from analysis due to scooter battery life limitations, which allow for a maximum trip duration of approximately two hours on a single charge (McKenzie 2019). These were not likely to constitute genuine trips or may have included a stop, for which locational data was not available. Trips that originated or were terminated outside of the City of Calgary boundary were also excluded in order to circumscribe the analysis to the Calgary city limits. Similarly, trips that originated or were terminated in dissemination areas with no calculated deprivation index score (detailed below) were likewise removed. Finally, trips were also filtered based on the average speed of the trip. The City of Calgary limits e-scooter speeds to up to 20 km/h via limitations on the physical assets themselves (Potkins 2019). Scooter trips with an average speed >20km/h (calculated using the recoded distance and duration of each trip) are either inaccurately recorded or are not indicative of a genuine trip. For bikesharing trips, Lime bikes (which were the only bikes available for the bikesharing service in Calgary) similarly have an upper speed limit of 15 mph, or approximately 24 km/h. Bike trips with an average speed of >24 km/h were also excluded from analysis. After exclusions, a total of 406,895 trips remained, comprised of 391,843 (96.30% of all micromobility trips) e-scooter and 15,052 (3.70% of all micromobility trip) e-bike trips.

Measuring spatial equity

This study mobilizes Hosford and Winters' (2018) approach to measuring spatial equity for micromobility analysis. As detailed above in the discussion of previous studies of micromobility spatial equity, their approach uses the Pampalon Deprivation Index (PDI) as an indicator of the differential geographies of relative well-being experienced across a city's enclaves. Building on the analytical precedent set by their methodology, this study uses the PDI as a proxy for the contours of Calgary's urban geography of socio-economic inequality, an essential data point for making within-city comparisons of differences in the spatial equity dimensions of micromobility sharing between dockless bikes and e-scooters. The PDI is an area-based measure of material deprivation for Canada calculated at the sub-neighbourhood scale of Dissemination Areas (DAs) (Pampalon et al. 2012). DAs are compact units of Canadian census geography delineated to include a population size of 400-700 persons, and are the finest (smallest) unit for which aggregate socioeconomic data is publicly disseminated (Statistics Canada 2018b). The material component of the PDI provides an indication of relative socioeconomic advantage and disadvantage for each DA in Canada (Pampalon et al. 2012). In this study, following Hosford and Winters' (2018) approach, the material component of the

PDI is used as opposed to the social component. Three socioeconomic variables from Canadian census data are used to calculate the material deprivation PDI scores for DAs (which have already been determined for all of Canada) are:

- The proportion of people without a high school diploma;
- Average personal income; and
- The employment-population ratio.

The PDI uses a quintile scoring system for the deprivation level of each DA ranging from least deprived (PDI score = 1) to most deprived (PDI score = 5) (Institut National de Santé Publique du Québec, 2016). A dataset of the PDI scores was downloaded from the Institut National de Santé Publique du Québec website. The dataset includes a table of PDI scores for each DA in Canada. A separate spatial dataset of the DA boundaries for Canada was downloaded from the Statistics Canada open data portal (Statistics Canada 2016). The attributes of the PDI scores were joined to the DA dataset in GIS using the unique DA number identifier. This allowed for the PDI quintile score of each DA to subsequently be associated with micromobility trips in subsequent analysis steps.

Analytic rationale

Some previous analyses of micromobility spatial equity, such as Mooney et al.'s (2019) study of dockless bikesharing in Seattle, use rebalancing[1] locations as indicators of micromobility utilization. In this study, we instead use trip terminus locations (where trips ended) as the spatial datum of analysis. This is for two reasons. First, the open dataset did not have rebalancing data. Second, analyzing trip terminus location positions riders' utilization practices and own spatial preferences at the centre of analyses of micromobility spatial equity. Conversely, rebalancing locations, or locations to which dockless vehicles are redistributed, reflect the spatial preferences of micromobility system operators and their profit motives (Bai and Jiao 2021). In other words, these are locations where operators intend for riders to initiate travel from, which may reflect operators' spatial biases against placing vehicles in certain areas, particularly those that are stigmatized (e.g., as being high crime, or 'bad', neighbourhoods). Rebalancing effectively circumscribes the potential locations from which riders may choose to originate trips, and as such may not reflect the spatial needs and preferences of system users. Indeed, rebalancing locations may not correspond to the locations from which riders would themselves choose or like to originate travel.

Furthermore, while vehicles may be rebalanced to specific locations, this does not mean that they are necessarily used by the urban denizens who live, learn, work, and/or leisure in these vicinities; indeed, assets may sit idle (unused) for extended periods of time before being rebalanced to subsequent locations where they may have a greater likelihood of being ridden. Furthermore, while some studies use dockless vehicle idle time as an inverse proxy of utilization (see e.g., Mooney et al. 2019), it is unclear whether the end of an idle period for any one vehicle marks a trip initiated by a rider or the vehicle being collected for purposes of further redistribution (rebalancing) to alternate locations where demand and/or utilization rates may be higher. By contrast, dockless micromobility trip destinations (where trips end) provide spatial information about trips actually taken. As such, trip terminus locations provide a more direct proxy of the utilization equity profile of a shared micromobility system for the reason that destination locations impart information about the spatial intentions, preferences, and needs of riders (terminus locations are where micromobility users have chosen to travel to), which are independent of use opportunity circumscriptions imposed by operators' rebalancing location decisions and practices.

Data analysis

Our analysis combines the two datasets used for this study: 1) the trip data, including trip origin and terminus locations; and 2) the DAs spatial boundaries with associated PDI quintile scores. The point locations of all e-scooter and bike trip terminuses were mapped (with points representing the hexbin centroid that contains the start or end of the trip) and spatially joined to the DA in which any one trip ended. Next, the number of trip terminuses were then summarized in each DA that had an associated PDI score. The total number of e-bike and e-scooter trip terminus locations were summed to the level of the DA, and the trip counts for each mode were then normalized by the 2016[2] population of the DA. Normalizing the values by population was important because while Canadian dissemination areas are defined as small, relatively stable geographic unit with a targeted population count of between 400 to 700 each (Statistics Canada 2018b), the range of Calgary dissemination areas were much wider, with some DAs comprising of populations over 10,000. As a result of the varying DA populations, it was appropriate to adjust the total trip values by population to accurately reduce the impacts of differences in population when comparing utilization patterns between different deprivation quintiles. Because the normalization returned small decimal values, the normalized values were then multiplied by a factor 1,000 for the purposes of visual clarity and reporting.

Throughout the Pilot's 3-month period, there were 1,500 e-scooters and 500 bikes deployed for use. To account for the disproportionate number of in-service vehicles between the two different transportation modes, total numbers of trips taken in either mode were also normalized by the number of available vehicles (i.e., the total number of e-scooter trips were divided by 1,500, and the total number of bike trips were divided by 500 for each DA). The resulting values to be analyzed were the number of micromobility trip ends per vehicle, per 1,000 persons in each DA that had an associated PDI score. Our use of trip ends—or terminus locations—as proxies for dockless micromobility utilization moves beyond previous analytical studies privileging asset rebalancing locations that prefigure vehicle availability as a basis for evaluating the spatial equity profile of a dockless system.

To determine whether there was a significant difference in the normalized volume of bike and e-scooter trips taken during the period of the Pilot between different deprivation areas, a one-way analysis of variance (ANOVA) at $\alpha = 0.05$ was run in SPSS to compare the mean number of trip ends per vehicle per 1,000 persons for the two micromobility sharing modes. The ANOVA test is used to determine if there are statistically significant differences between the means of two or more groups (Fisher 1919). In this study, we wanted to determine whether there is a significant difference in the number of normalized trip ends between different PDI categories for both bikes and e-scooters. Tukey's honestly significant difference (HSD) test was subsequently run post hoc to identify if any PDI quintiles significantly different from each other in the volume of trip ends for bikes and e-scooters, as well as to identify any utilization patterns differences between the two micromobility modes.

This study also ran a linear regression in SPSS to further analyze the effects of PDI score on micromobility sharing utilization. Linear regression models are used to determine whether the strength of the relationship between the independent (in this instance, PDI score) and dependent variables (normalized bike and e-scooter trip ends) are statistically significant, and also to determine how much the dependent variables changes with a change in the independent variable (i.e. how many more or less bike and e-scooter trips occurs with each incremental increase or decrease in PDI quintile) through the unstandardized beta coefficient (Freedman 2009). The linear regression analysis further determines the strength of the model through the R^2 value, which explains how much of the variance in the dependent variable is explained by the independent variable.

Results

The ANOVA results show that there is a significant difference between the number of both normalized bike ($F(4,1540) = 13.679$, $p < .001$, Table 1) and e-scooter ($F(4,1540) = 6.351$, $p < .001$; Table 1) trips ending in DAs classified as being within different quintiles of deprivation, indicating that area-level deprivation had a statistically significant impact on the utilization of dockless bikes and e-scooters in Calgary during the three-month period of the Pilot.

Table 1
T-test of normalized dockless micromobility trip volume by vehicle type during Calgary's Shared Mobility Pilot (July 1st – September 30th, 2019)

	One-Way ANOVA		
	F-value	Degrees of freedom	p-value
E-scooter	6.351	1540	.000
Bike	13.679	1540	.000

The results of the Tukey's HSD post hoc test reveal that the least deprived DAs in Calgary (categorized as PDI score of 1) had a significantly higher volume of normalized e-scooter trips ending in them compared to DAs with PDI quintile scores of 2 (.453 ± .116, p = .001), 3 (.513 ± .134, p = .001), 4 (.462 ± .150, p = .018) and 5 (.518 ± .134, p = .001) (Table 2). Similar results were found for dockless bikes (Table 2), where higher volume of bike trip ends were

Table 2
Tukey's HSD for E-scooters and bikes

(I) PDI	(J) PDI	E-scooter Mean Difference I-J (*Std. Error*)	Sig.	Bike Mean Difference I-J (*Std. Error*)	Sig.
1	2	0.453* *(0.116)*	.001	0.048* *(0.008)*	.000
	3	0.513* *(0.134)*	.001	0.055* *(0.009)*	.000
	4	0.462* *(0.150)*	.018	0.051* *(0.011)*	.000
	5	0.518* *(0.134)*	.001	0.056* *(0.009)*	.000
2	1	-0.453* *(0.116)*	.001	-0.048* *(0.008)*	.000
	3	0.059 *(0.152)*	.995	0.007 *(0.011)*	.964
	4	0.008 *(0.166)*	1.000	0.003 *(0.012)*	.999
	5	0.065 *(0.152)*	.993	0.009 *(0.011)*	.923
3	1	-0.513* *(0.134)*	.001	-0.055* *(0.009)*	.000
	2	-0.059 *(0.152)*	.995	-0.007 *(0.011)*	.964
	4	-0.051 *(0.179)*	.999	-0.004 *(0.013)*	.998
	5	0.006 *(0.166)*	1.000	0.002 *(0.012)*	1.000
4	1	-0.462* *(0.150)*	.018	-0.051* *(0.011)*	.000
	2	-0.008 *(0.166)*	1.000	-0.003 *(0.012)*	.999
	3	0.051 *(0.179)*	.999	0.004 *(0.013)*	.998
	5	0.057 *(0.179)*	.998	0.005 *(0.013)*	.992
5	1	-0.518* *(0.134)*	.001	-0.056* *(0.009)*	.000
	2	-0.065 *(0.152)*	.993	-0.009 *(0.011)*	.923
	3	-0.006 *(0.166)*	1.000	-0.002 *(0.012)*	1.000
	4	-0.056 *(0.179)*	.998	-0.005 *(0.013)*	.992

* The mean difference is significant at the .05 level

found concentrated in DAs with a PDI quintile score of 1 as compared to 2 (.048 ± .008, $p < .001$), 3 (.055 ± .009, $p < .001$), 4 (.051 ± .011, $p < .001$), and 5 (.056 ± .009, $p < .001$). While the least deprived (i.e., most advantaged; DAs with PDI = 1) areas of Calgary were significantly different from the more deprived areas, the categories that were more deprived (i.e., DAs with PDI = 2, 3, 4, and 5) were not significantly different from each other for both e-scooters and bikes. Tukey's HSD test results show that for both micromobility modes, a disproportionate majority of trips ended in the least deprived areas of Calgary during the three-month period of data availability, while DAs further down the deprivation spectrum (from the second least deprived through to the most deprived quintiles; PDI = 2-5) were underrepresented as dockless micromobility trip destinations.

The results of this ANOVA with Tukey's HSD support rejection of our null hypothesis, and inform two significant findings. First, micromobility sharing utilization in Calgary during the Pilot was spatially inequitable, with utilization (proxied by trip end locations) of both modes shifted more towards the least deprived, more privileged areas of the city. Second, there were no significant differences between the spatial equity profiles of dockless bikes and e-scooters. In other words, not only was the utilization of both bikes and e-scooters spatially inequitable in the favouring of the most advantaged areas of the city as destinations for micromobility travel, but both modes were inequitable and inequitable in the same way (with utilization dropping off from the second-least deprived quintile).

The findings of our linear regression model of the effects of PDI score on the mean number of trip ends show that there is a significant difference between the mean number of both normalized e-scooter and bike trips ending in DAs classified as being within different quintiles of deprivation. This indicates that area-level deprivation did have an impact on the utilization of dockless bikes and e-scooters in Calgary during the three-month period of the Pilot for which data was available. In particular, based on the unstandardized coefficient of the linear regression model (Table 3), each increase in deprivation quintile score (i.e., going from least to most deprived quintiles) is associated with a decrease of 0.138 trips per 1,000 persons per vehicle for dockless e-scooters ($t = -4.146$, $p < .001$), and a decrease of 0.015 trips per 1,000 persons per vehicle for dockless bikes ($t = -6.171$, $p < .001$). These results indicate that both dockless micromobility modes are inequitable in utilization since higher deprivation areas is associated with a decrease in micromobility usage. This difference can be observed when looking at the distribution of total micromobility trip ends across DAs by quintile score for both e-scooters and dockless bikes (Table 3). In the least deprived areas (PDI score of 1), the average number of normalized scooter trip ends was 0.530 (± 2.803), with the volume dropping across subsequently more deprived quintiles. The same difference in means were observed in dockless bike trip ends, with the least deprived areas (PDI score of 1) averaging 0.058 (± 0.204) normalized bike trip ends, with this value likewise dropping off across more deprived DAs.

The results of our analysis support rejection of our null hypothesis and inform two significant findings. First, micromobility sharing utilization in Calgary between July and September 2019 was spatially inequitable, with utilization (proxied by trip end locations) concentrated in the least deprived, more privileged areas of the city, and declining across increasingly more deprived areas of the city. Second, there were no differences between the spatial equity profiles of dockless bikes and e-scooters, in that both modes were similarly inequitable by virtue of favouring the most advantaged areas as destinations for micromobility travel, and with utilization declining in more deprived areas. Overall, this study found that the utilization of dockless micromobility sharing in Calgary favoured more privileged areas of the city, as opposed to being equally utilized across differently advantaged areas normalized by

Table 3
Micromobility sharing ends per 1,000 persons per vehicle in operation: Linear regression analysis results

	Linear Regression					
	E-scooter			Bike		
	Unstandardized coefficient	t-value	Sig	Unstandardized coefficient	t-value	Sig
PDI	-0.138	-4.146	.000	-0.015	-6.171	.000
	R Squared = .011 Adjusted R Squared = .010			R Squared = .024 Adjusted R Squared = .023		

population (and vehicles in circulation). Despite having the potential to alleviate the disparities in micromobility sharing, the utilization of both dockless bikes and e-scooters appear to maintain the historically ingrained inequities of these systems as with antecedent docked bikesharing modes. We discuss both the limitations and urban policy and planning implications of our study in the next section.

Discussion and Conclusion

Significance of study findings and study limitations

The findings of our study show an overall spatial inequity in the geographical distribution of dockless micromobility utilization in Calgary, irrespective of dockless mode. We attribute no intentionality nor responsibility for these analytically observed spatial inequities in utilization to either the City of Calgary nor to the micromobility system operators. Our findings nevertheless echo Médard de Chardon's (2019, 401) conclusion that short-hop vehicle sharing systems often fall short of their touted benefits–such as their potentials to close spatial gaps in urban transportation–instead "mostly facilitate[ing] transport for already privileged demographics" and advantaged urban areas. While our results show that dockless e-bike and e-scooter sharing was spatially inequitable in Calgary, our analysis does not explain nor account for factors that explain these spatial inequities in dockless micromobility sharing. We speculate that amongst the possible explanations is the tendency of micromobility trips to be concentrated in urban centres dense with points of interest (shopping, eating, cultural venues, etc.), workplaces, and transit hubs, a finding that is well established in the key literatures (eg., Arnell 2019; Médard de Chardon 2019; Matthew et al. 2019; Qian et al. 2020). In the City of Calgary, the downtown core is considered to be a more advantaged enclave in that the majority of the DAs comprising the area of the downtown core have a PDI quintile score of 1 (least deprived). The majority of e-bike and e-scooter trips ending in the most advantaged areas may potentially be explained by this tendency of micromobility journeys to concentrate in city centres, which in Calgary's case is a non-deprived area.

A second factor that may account for the pattern of e-bike and e-scooter trips having ended in the most advantaged areas of Calgary relates to how Calgary's deprivation and infrastructural geographies may be intersecting. Studies have consistently shown that one of the most significant predictors of micromobility utilization is the density and accessibility of dedicated infrastructures to support ridership, including recreational paths, dedicated cycleways (on which e-scooters are frequently also allowed, depending on regulatory context), and protected bike lanes (see e.g. Castiglione et al. 2022; Smith et al. 2015; Xu et al. 2019; Zhang et al. 2021); in Calgary, dockless micromobilities are allowed on the city's existing cycling infrastructure (Frisbee et al. 2022). Research has also shown that there is a strong spatial equity differential associated with the urban geography of infrastructures, which tend to be disproportionately concentrated in wealthier, and in the North American context, whiter neighbourhoods (Hoffman 2016; Stehlin and Payne 2022). This calls for further research that analytically combines micromobility utilization patterns, differences in area-level deprivation, and the urban geography of cycling (micromobility) infrastructure in Calgary, and also has implications for how micromobility systems are integrated into urban transportation frameworks from the policy and planning perspectives.

Urban policy and planning implications

The findings of this analysis evidence that simply adding dockless systems to the mobility mix in cities does not in and of itself solve urban transportation spatial equity challenges, nor does it deterministically lead to spatial equity gains in short-hop urban transportation. For micromobility systems to contribute to urban transportation equity, their introduction by cities must take equity into consideration both during the planning and permitting phase, as well as prior the pilot program stage. Indeed, geographical equity needs to be a leading consideration in the planning and roll-out of micromobilities, even in their pilot program phases. This is because for private micromobility operators who dominate the dockless micromobility scene in cities, equity considerations "are the least deciding factor", trumped by profit and other concerns (Bai and Jiao 2021, 4). Unfortunately, spatial equity is usually an afterthought of the full-scale adoption of micromobility systems by urban planners and policymakers (Clewlow et al. 2018). A notable exception of a micromobility sharing system that included equity considerations is the planning of the service for Chicago's dockless bikesharing program (Claffey and Chacon 2018), which expressly piloted the use of dockless bikes in the far South Side of the city, an area characterized by higher deprivation that was underserved the city's docked bikesharing program.

Such innovative approaches—in Chicago, incentivizing micromobility sharing operators to service historically underserved areas (Claffey and Chacon 2018)—are needed to address the existing inequalities of new mobility solutions in order to ensure that more communities, including those residing in less advantaged areas, have equal opportunities to accessing the benefits of these alternative transportation modes (Clewlow et al. 2018). Not prioritizing spatial equity in the planning and pilot stages of micromobility roll-outs requires governance efforts to redress inequities, which may not always be successful. For instance, despite the Portland Bureau of Transportation (PBOT) found that requirements that e-scooter operators to "deploy 15% of their fleet in East Portland"–which accounts for approximately 50% of the city's area and includes a high proportion of racialized/ethnic minoritized and low-income Census Tracts, a 2019 analysis revealed that "only 5.5% of [e-scooter] trips were taken in East Portland neighborhoods" (City of Portland Bureau of Transportation 2019, 33). Such discrepancies, however, may not only be specific to the ineffectiveness of urban policy efforts to achieve spatial equity in dockless micromobility sharing through urban governance interventions, but may also be related to how urban geographies of inequality (in our study, deprivation) intersect with differential distributions of and investments in micromobility infrastructures.

As we argue above by drawing on consensus in the key literatures, the geography of micromobility utilization is contingent not only on the distribution of micromobility vehicles across areas of a city, but also on the availability of key infrastructures to support ridership throughout an urban spatial fabric. Thus, in order to ensure spatially equitable utilization, urban policymakers and planners need to invest in micromobility transportation infrastructures (protected cycle lanes, recreational paths, bikeways, etc.)–especially in transportation poor areas–priori to pursuing and/or considering welcoming micromobility operators into their cities to ensure that once dockless vehicles are added to the transportation modal mix in a city, they are not only equally accessible across all parts of a city, but also equally rideable throughout its urban spatial fabric.

Notes

[1]Rebalancing is the process where micromobility sharing operators redistribute idle vehicles from one location to another, usually from areas with low demand to areas with high demand.

[2]2016 was the last Canadian census period for which data was available at the time of analysis.

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