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Rationale for governance and effective guidelines towards attainment of shared e-scooter micromobility benefits in Windsor, Ontario

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ABSTRACT

The paper evaluates e-scooter trips using six-month (May to October 2021) pilot study data in Windsor. It employs exploratory and kernel density analysis to gain insight into spatiotemporal e-scooter trip dimensions in the city. Also, it uses regression mediation analysis to determine the effect of population and household densities on the relationship between average household income and the trips generated from Wards in the city. In total, 114,071 e-scooter trips were used for disaggregated and aggregated analysis. At a disaggregated level, exploratory studies showed that e-scooter use generally starts around 10:00 am. Depending on the weekdays, e-scooters' trip peak between 7:00 pm and midnight and are primarily used for short distances, duration, and at lower speeds. Across the study months, trips gradually decreased, but compared to fall months, spring and summer months have higher numbers of rides. Increased trips around weekends, late-night peak riding, and identical kernel density hotspots of the trip starts and ends locations around a downtown park in the city suggest e-scooter might be replacing walking or cycling. The study highlights e-scooter use for recreational purposes and safety concerns with late night riding of e-scooters in the city. Further, aggregated origin and destination (O-D) of e-scooter trips revealed that most trips start and end within the same Wards and occasionally in neighboring Wards that shared similar boundaries. This served as the basis for mediation analysis for understanding the influence of population and/or household density on the relationship between income and trips originating from Wards. The results from the mediation analysis showed that the average household income plays a more significant role in e-scooter ridership in Windsor. Thus, the study recommends effective e-scooter integration and governance within the city for the sustainable benefits of e-scooters to be derived. It highlights the need to adopt lessons derived from other countries that fully implement e-scooter micromobility modes.

1. Introduction

Transportation systems are integral to livability of any city around the world (Şengül and Mostofi, 2021). The increased recognition of the importance of transportation to sustainable cities has led to other modes to be considered as environmentally friendly alternatives. Modes such as cycling, and walking are nowadays recognized as means to limit high automobile emission that plague our cities. Also, the recent pandemic has made these modes more popular due to the limited interaction that occur with other users: a situation usually lacking on crowded buses and other public transit. Before now, due to limited energy use and emission, focus has been more on the use of electric motor vehicles or traditional user propelled bikes as a more sustainable mode. Lately, it has shifted to electronic micromobility (e-micromobility) such as electric bikes (e-bikes) or scooters (e-scooter), the latter being the focus of this research article. The shift to e-micromobility alternatives that we currently see in our modern days has been predominantly due to advances in technology (Reck et al., 2021). Nowadays, batteries can now be built into bicycles or scooters and Global Positioning System (GPS) devices installed to monitor and evaluate their usage (Dias et al., 2021; Tabatabaie and He, 2022; Tuncer et al., 2020). This presents opportunities for data driven analysis for effective planning and policy formulation towards the use of these micromobility alternatives, hence the motivation for our study (Bai and Jiao, 2022; Hosseinzadeh et al., 2021a).

E-micromobility such as e-scooter are usually small and lightweight transportation modes specifically design for individuals and has a weight mostly less than 500 kg with a top speed of less than or equals 25 km per hour (km/h) (Boglietti et al., 2021; Bozzi and Aguilera, 2021; Glavić et al., 2021; Lo et al., 2020; O'hern and Estgfaeller, 2020; Şengül and Mostofi, 2021; Tuncer et al., 2020). They are usually faster than

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walking but slower than vehicles (Jiao et al., 2021; Merlin et al., 2021), and now widely accepted as good options that promotes a car free lifestyle with potentials to reduce car usage for short distance trips, thereby enhancing cities' sustainability (Almannaa et al., 2021b; Altintasi and Yalcinkaya, 2022; Echeverría-Su et al., 2023; Lo et al., 2020; Merlin et al., 2021; Şengül and Mostofi, 2021; Sikka et al., 2019; Zou et al., 2020). Also, e-scooters are now considered viable solutions to the problems of transport external cost, traffic congestion and accidents that characterize car use (Bieliński and Ważna, 2020; O'hern and Estgfaeller, 2020). More importantly, they are now causing a shift from car dependency, especially in most city centers around world such that projections now show that they can replace a sizeable proportion of car trips. For example, in Germany, e-scooter trips have been theoretically estimated to replace between 10 and 15% of all car trips made especially in low density areas (Almannaa et al., 2021b; Gebhardt et al., 2021). Unsurprisingly, e-scooter micromobility option are increasingly gaining attention and transport modes market share due to the convenience in their usage, accessibility, low cost, and the ability to cover intermediate ranges of about 0.5 to 4 km (Merlin et al., 2021; Sikka et al., 2019). As a result, municipal authorities now consider e-micromobility as a good strategy to meet mobility needs within various cities (Bai and Jiao, 2022; Hosseinzadeh et al., 2021).

Since its introduction in 2017, more than 300 million trips have been made with e-scooter and services are currently available to users in more than 630 cities worldwide (Glavić et al., 2021). Various implementations of e-scooter micromobility now exist across the countries of the world. These varies from the station based to dockless types also known as the free-floating versions (Boglietti et al., 2021; Huo et al., 2021; Moran et al., 2020). The dockless types which can be parked around in a service area has been widely accepted (Caspi et al., 2020; Huo et al., 2021; Merlin et al., 2021; Yang et al., 2021). It has seen various implementations across the cities in Canada. In general, the first pilot study in Canada on the use of e-scooter was conducted in the city of Kelowna, British Columbia to determine its suitability and acceptability as mode of transportation. Other cities such as Toronto, Ottawa, Waterloo, Brampton, and Mississauga have followed. Recently, Bird Canada – an e-scooter micromobility company estimated that about 1.3 million trips were made using their services alone in Canada ("Bird Canada," 2022). This number is expected to rise with greater acceptance and market penetration. The growing interest and wider acceptance of e-scooters in Canada has made the City of Windsor Ontario joined the ranks of municipalities that have implemented a pilot study for their suitability within her jurisdiction and the dockless version was adopted. However, the introduction of these e-scooters is not without impending challenges (regulation, safety, geographic availability, and visual pollution) to transportation planners if proper planning is not implemented (Caspi et al., 2020; Moran et al., 2020). It is therefore important to understand their usage, and contributions to transport efficiency (Merlin et al., 2021). Despite this recommendation, only a few studies have evaluated e-scooter micromobility patterns at a pilot stage and extensive research into their usage remains limited (Reck et al., 2021), especially in the city of Windsor. While e-scooter's contribution to our society could promote sustainability (Moran et al., 2020), the city of Windsor is not immune to challenges associated with e-scooter deployment as a mode of transportation. In fact, the recent introduction of e-scooter shared micromobility program to the city, calls for the need to uncover travel patterns at aggregated (Ward) and disaggregated levels (individual ride characteristics) using data obtained from one of the vendors for the Windsor pilot project. Thus, to successfully plan for infrastructural needs, the trip characteristics, travel pattern and the reason for e-scooter usage need to be determined (Bieliński and Ważna, 2020). This on the long run will help understand the role of e-scooter to mobility in our society and facilitate good governance as usage patterns are specific to cities (Bozzi and Aguilera, 2021).

This paper contributes to those research breaking grounds in the e-scooter study at aggregated (Ward) and disaggregated levels. Trip patterns were analyzed individually and aggregated into the Wards of the city of Windsor to gain insight about where e-scooter riders' trips originate and end. The study adopted the data obtained from the city's pilot e-scooter program that began in May of 2021. It is expected that analysis in this study will help understand trip characteristics, the likely demand and supply issues that might be associated with e-scooter ridership in the city of Windsor. Also, the possible planning challenges that might arise could be identified within the local jurisdiction. Our study contributes to knowledge by emphasizing that lessons learned from other countries with full implementation could serve as the basis for appropriate planning strategies to integrate e-scooter shared micromobility in small cities like Windsor. Essentially, our study complemented previous findings from other researchers and pointed out the need for appropriate planning before full adoption in Windsor Ontario.

2. Study objectives

The specific objectives of this paper are to:

1. Temporarily determine the hours and days for peak e-scooter demand and trips characteristics.
2. Identify the hotspots for trips' starts and end at disaggregated level to characterize demand and supply for e-scooter rides.
3. Spatially evaluates e-scooter trip origin, destination, and their relationship to the built environment characteristics at aggregated Ward level. Does the population density, household density and/or socio-economic classes determine the level of ridership?

The remaining parts of this paper are presented as follows; section 3 give a background into the previous research that have been done to understand the importance of e-scooter to our society, the likely challenges, and their impact on the built environment. In section 4, a detailed description of the study area and the source of data use was provided. Also, the method used to analyze the data obtained from the e-scooter vendor in Windsor is given in section 4. Section 5 shows analysis and discussion of results. Finally, a summary of findings, recommendations and future research direction can be seen in section 6.

3. Literature review

Ever since it first introduction, there have been an explosion in the dockless e-scooter micromobility service across many cities of the world (Heydari et al., 2022; Leurent, 2022). Enabled by private investments, the quick acceptance of these disruptive modes known as the shared e-scooters has been partly supported by technological advancements and the recent pandemic promoted their use as a social distancing mode (Altintasi and Yalcinkaya, 2022; Azimian and Jiao, 2023; Dean and Zuniga-Garcia, 2023; Dias et al., 2021; Echeverría-Su et al., 2023; Gibson et al., 2022; Glavić et al., 2021; Heydari et al., 2022; Jiao et al., 2021; Zhang et al., 2023). As a result, they have been well received in our urban communities and municipal authorities as a mode regardless of its functional use, be it transportation or fun recreational and ridership are on the increase (Field and Jon, 2021). However, the quick and rapid adoption of these e-scooters as means to achieve our societal transport sustainability has led to inadequate preparation or planning with most municipal authorities neglecting that e-scooters are disruptive transportation mode. Usually, pilots are conducted only for the program to be extended based on the perceived short-term benefits of reducing emission, congestions and shorter car trips within cities which later disappears because of improper planning to facilitate integration and full adoption of these e-scooters (Field and Jon, 2021; Glavić et al., 2021). Due to improper planning before the introduction of these e-scooters, citizens across cities and municipalities are nowadays concerned with their challenges in our urban space. Therefore, municipal authorities are now playing catch-up games with infrastructural planning and guidelines to address challenges associated with their usages

(Almannaa et al., 2021a; Echeverría-Su et al., 2023; Lo et al., 2020; Reck et al., 2021).

The challenges associated with the sudden appearance of e-scooters in our urban space relate to permit, insurance, pricing, ridership requirements, public education, safety: helmet wearing and speed limitation. Others include identifying or determining the locations for proper ridership within a city as it has been reported that most e-scooter rides occur on the sidewalk (Bai and Jiao, 2022; Boglietti et al., 2021; Merlin et al., 2021; O'hern and Estgfaeller, 2020; Sikka et al., 2019). In most cases, there is no designated law that states or enforces where they could be ridden. Generally, they are assumed to be able to share road infrastructures that are designated for other modes such as cars, and cyclists. However, most cities neglect that the addition of new transport modes requires comprehensive planning to facilitate integration with existing modes. Thus, lack of regulations that guide where e-scooters could be ridden has led to sharing of sidewalks with pedestrians thereby creating unnecessary interaction. When such unnecessary interaction occurs on sidewalks, they create immense danger for pedestrians and safety concern ensues (Ma et al., 2021; Zhang et al., 2023).

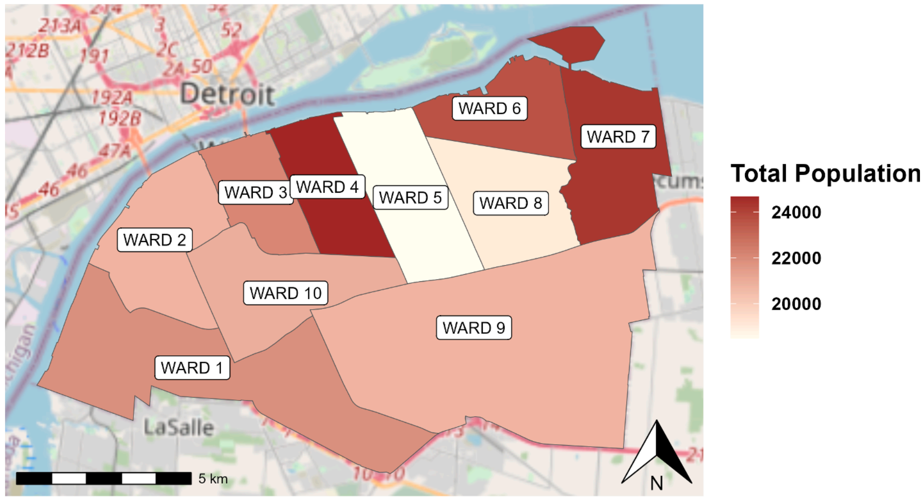
Other challenges of dockless e-scooters that cities face relates to parking (Bai and Jiao, 2022) and has been extensively highlighted in literatures. Previous studies on dockless e-scooters parking reported that 72% of e-scooters ended up being parked on sidewalks in San Jose California (Hawa et al., 2021). This implies that in some cases, infringement into pedestrian spaces could arise. Of the 606 parked e-scooters that were studied in Rosslyn Virginia, 16% were improperly parked while 6% encroached into the pedestrian right of way. This is a problem, especially for visually impaired pedestrians that rely on assistive devices for their mobility (James et al., 2019). Similarly, the study of parking violations of dockeless e-scooter in Austin, Texas found that intrusion on sidewalk ranks high among major violations (Bai and Jiao, 2022). Improperly parked e-scooter were predominantly found around Parks and are often in clusters. Thus, it was suggested that shared responsibility by reporting improperly parked dockless e-scooters can help prevent violation or intrusion into restricted public space. We presume that such suggestions will be applicable in cities with e-scooter regulation. While this suggestion may not be applicable to the city of Windsor which is currently at the pilot stage, the importance of regulation can be taken from the study. Furthermore, over-expansion by service providers under limited regulation could lead to reckless abandonment of e-scooters in public space thus resulting in visual pollution. Also, the geography of supply and demand (origin and destination of trips) of these dockless e-scooter ridership needed to be completely understood for rebalancing of these scooters. Comparatively, challenges relating to parking, where these scooters could be ridden and demand–supply problems these e-scooter poses are more difficult to address if proper planning is not initiated before full implementation (Merlin et al., 2021). Luckily the city of Windsor, Ontario is still at a pilot study stage and present opportunities for proper planning to be implement before full adoption.

Previous researchers have shown that bike lanes can adequately serve as infrastructure to promote e-scooter ridership and likely eliminate some of the challenges. It could help reduce riding on sidewalks as a recent study of e-scooter ridership in the city of Austin, Texas showed that adequate bicycle lanes within a city could supports e-scooter ridership (Caspi et al., 2020). Similar findings from other research from Belgrade showed that the willingness to use e-scooter increases when there is a dedicated infrastructure for their use or share lane with cyclist or pedestrian rather than cars. This increased willingness seen is influenced by the improved safety perception when using the roadways (Glavić et al., 2021) and suggests that adequate cycling facilities within the city of Windsor could facilitate e-scooter ridership as a legitimate mode of transportation. When these cycling lanes are protected or set apart from the main road, safety could be improved because of limited interaction with vehicles. Thus, there are numerous benefits that could be derived from e-scooter ridership when appropriate planning is done before full adoption.

However, the introduction of e-scooters in our society is not all about challenges and recent studies have showed that their benefits are likely the same as that of shared e-bike system due to their similarities (Lo et al., 2020; Yang et al., 2021). These benefits include improved physical activities which in the long run promote healthy living, better social interaction and social connection through improved quality of time spent outside of homes (Gebhardt et al., 2021). There are however contrary views about these perceived benefits of e-scooters as they are advertised as effort free modes thus weakening the claims that they promote physical activities (Bozzi and Aguilera, 2021). Also, e-scooter can promote environmental sustainability through CO2 and greenhouse gas emission reduction (Gebhardt et al., 2021) but other arguments exist that the production of batteries used in these e-scooters, transportation and maintenance could minimize the perceived benefit of emission reduction (Altintasi and Yalcinkaya, 2022). The validity of these claims requires additional research as the sustainability of e-scooter as transport mode will depend on the type of trips they replaced.

Sustainability through e-scooter use can only be achieved when they replace short trips made by cars and not walking or cycling and is achievable through proper integration with public transportation system to fulfil the first and last mile travel problem (Glavić et al., 2021). Furthermore, when e-scooters introduction to our cities are well-planned, they contribute to achieving equitable transportation for all through improved accessibility. Other lessons that could be learned from shared e-bike services include the need for understanding of the geographic variances and service layout which if not considered leads to uproar and resistance to acceptance of shared mobility forms. For instance, push back for the wider acceptance of e-bikes or likely e-scooter in the case the city of Windsor could relates to the geography of opportunity, transportation equity, and the influence of gentrification. While share mobility service providers have used sustainability to promote e-bike or e-scooter micromobility, they are often criticized. These criticisms usually relate to the reproduction of existing transport inequalities (Liu and Miller, 2022; Moran et al., 2020). For example, and as further highlighted by Moran et al., (2020) most e-mobility providers launch their services in transit rich neighborhoods (e.g., Mahattan, San Francisco and Oakland California) and in certain cases, low-income areas are ignored despite that they are the socio-economic class more likely to use any form of shared (e-bike or e-scooter) mobility. The pattern seen in services being launched in rich community highlights the focus of service providers (which are usually private organization) on profit maximization and not totally on strengthening community integration (Field and Jon, 2021). This contradicts the sustainable perspective for which these micromobility services are promoted. In fact, some empirical studies in some parts of the world such as Arizona, United States (US) showed that African and Hispanic descent who are over-represented in the low-income category are more likely to use e-scooter (Bozzi and Aguilera, 2021).Thus, e-scooter expansion could face resistance if spatial or user's geographic layout is not properly understood or autonomy is given to service providers to determine geographic coverage. Hence, shared e-scooter acceptance is dependent on accessibility to people of all social group (Bieliński and Ważna, 2020) and influenced by socio-demographic characteristics.

There have been suggestions that e-scooter ridership is dependent on population density, income levels, and the level of education (Caspi et al., 2020). Previous studies have shown that e-scooter ridership is significantly influenced by gender, and that men are more likely to ride them (Bozzi and Aguilera, 2021). Also, population density of any area has been reported to influence positively, the number of available e-scooter in an area at any given period of the day (Hawa et al., 2021). Compared to high income areas, low-income areas are likely to experience higher e-scooter usage and ride cost could be a significant influence. Thus, there are usually higher e-scooter accessibility around the downtown core of any city compared to the outskirts that represents high income areas which are located outside of the city center (Jiao et al., 2021). Further, men have been reported to travel faster on e-



Data source(s): City of Windsor

Fig. 1. The City of Windsor showing Ward Population.

scooter than women (Gebhardt et al., 2021). Also, the average e-scooter speeds are usually higher on the street compared to when driven on sidewalks (Hawa et al., 2021).

A recent study found that the proportion of commercial land use, industrial land use, employment and urbanism also influences e-scooter ridership (Hosseinzadeh et al., 2021; Kimpton et al., 2022). Interestingly, higher commercial activities; a phenomenon that characterizes downtown or the central business district of any city increases e-scooter ridership. This supports the findings that e-scooter trips are more prevalent around the city center (Jiao et al., 2021). On the contrary, the higher level of industrial activities correlates with low levels of e-scooter trips. This is logical because industrial areas are usually in low density locations and are usually set apart from residential or commercial land areas because of air and noise pollution. As earlier noted in previous research, the presence of parks and college campus significant affect e-scooter ridership (Caspi et al., 2020). However, the relationship between the presence of parks, college campus and e-scooter ridership has been shown to be unclear and will require further study. Other factors that increase e-scooter ridership are employment density, walk, and bike and transit scores (Hawa et al., 2021). These findings suggest that riders may be more comfortable around route with other sustainable modes of transportation especially when they are in high employment areas. Coupled with these factors that have been identified, intersection and bus stop densities have also been found to positively correlate with e-scooter ridership. However, it was found that the median age group and distance to the city center have negative correlation with e-scooter ridership (Huo et al., 2021).

This research identified factors such as population density, income levels etc., have mostly evaluated e-scooter ridership at aggregated level i.e., different geographic units such as Wards, census, or traffic analysis zones. While this research used different levels of analysis to understand e-scooter ridership, they serve as foundation for the current study. Rather our study suggests a combination of disaggregated and aggregated analysis to understand e-scooter trip patterns, characteristics, the origin and destinations of trips and the predominant factors that influences ridership in the city of Windsor, Ontario.

4. Materials and method

The study area is the city of Windsor. The city of Windsor is the southernmost city in the province of Ontario Canada. It is bordered in the south by the city of Detroit, Michigan United States and surrounded by other Canadian small towns in the North, West, and East by Amherstburg, LaSalle, Lakeshore and Tecumseh. It has a population of 217,188 in 2016. When the Windsor Census Metropolitan Area (which includes the town of Amherstburg, Tecumseh, Amherstburg, LaSalle, Lakeshore, Leamington, Kingsville, and Essex) is considered, the population of 398,718 was reported for year 2016. However, the focus of this study is solely on e-scooter trips within the city of Windsor and the thematic map showing the Wards boundary and the population of our study area is shown in Fig. 1.

The e-scooter data used in this study was obtained from the city of Windsor database. This data was supplied by Bird Inc., an e-scooter micromobility service provider saddled with the pilot program for the city and stored in Microsoft excel format for the six (6) months (May to October) pilot study period in year 2021. Rather than a comprehensive data showing all the trips for the six months period, trip information was collected for individual months of the study, but they all contained the geolocation information (longitude/latitude) of start and end for each e-scooter trip. Other information contained in the data are the unique code for each e-scooter, the trip distance, durations, start and end dates. While trip trajectory profile of e-scooter riders in Windsor is desirable, it was unavailable in the dataset provided. Also, the purpose of the trips, age, and gender were not available. However, some derivative information is obtainable from the sparse e-scooter data provided. This includes the travel speed for each e-scooter trip. The reporting format for the data was not also consistent. In some monthly data collected, the start and the destination Wards were included and in others, they were missing. Further, the longitude and latitude were interchanged in some months but the understanding that the longitude and latitude of the city of Windsor ranges between 42.317432 and −83.026772 helped in the processing of ridership data. The monthly e-scooter ridership data were then fused in R language environment and a comprehensive database created with unique identification number assigned to each of the trips for ease of analysis and for the purpose of differentiation.

Further analysis of the comprehensive e-scooter ridership data created showed that not all e-scooter trips have end coordinates and were excluded from subsequent analysis described in this study. Trips coordinates were plotted for the start and the end points separately and overlaid with the city of Windsor limit. The plotted coordinates of the end point showed that some trips ended outside the city of Windsor and were ignored from the study. These trips with end coordinates outside the city of Windsor were presumed either as information of stolen e-scooters or error arising when the data is collected by the service provider. Also, trips with origins outside the city of Windsor were ignored. These patterns were predominant with the first month of the pilot study i.e., the month of May 2021. Aside from that, the month did not provide information about the origin and destination Wards of each trip. Thankfully the coordinates of these trips

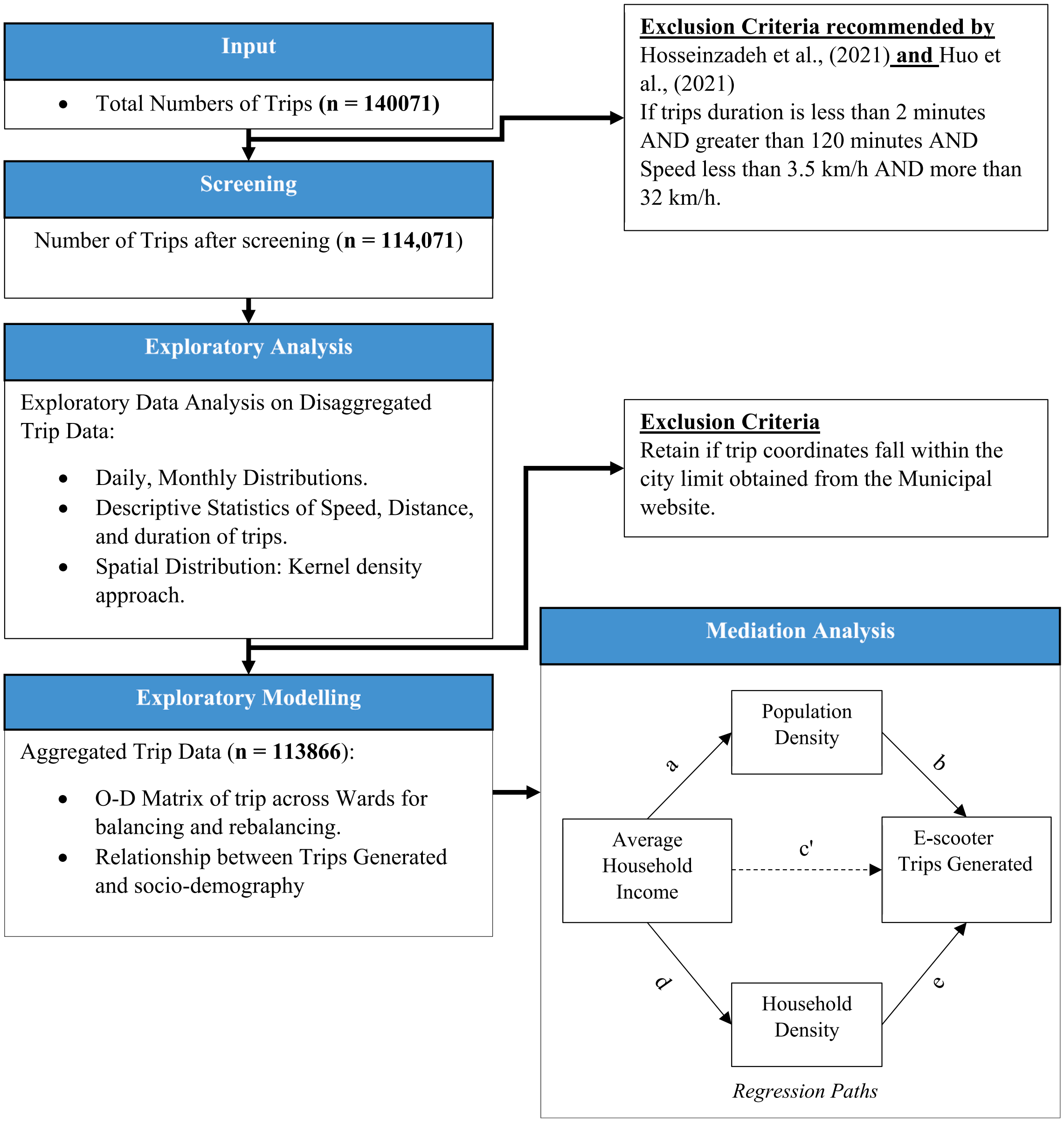


Fig. 2. Methodological Approach for the Study.

provided an opportunity to address any likely issues. Subsequent months have this information but for consistency, the coordinates i.e., longitude and latitude were used for spatial overlay analysis and identification of trips that start and end within each Ward. Also, trips that have total travel distance of zero meters and duration of less than two minutes and greater than 120 minutes were excluded from analysis. These trips were excluded due to some challenges that have been reported to be associated with e-scooter ridership. High trip distances and shorter duration on e-scooter has been attributed to scenarios where riders attempt to use these e-scooters but was not in working state or that the riders are unable to lock them after use thus, contributing to the reported shorter or longer e-scooter users' duration (Hosseinzadeh et al., 2021).

For accuracy, trips with these characteristics were not considered for further analysis. The speed for each trip made with e-scooter in the city of Windsor were estimated by dividing the distance travelled with time and found that some estimated speeds were higher than usual. Consistent with previous research by Huo et al., (2021), trips with speed less than 3.5 km/h and more than 32 km/h were also excluded from further analysis and a total of 114,071 complete trips were used in this study. The schematic description of the method used in our study is shown on Fig. 2.

While different unit of analysis exist and the transportation analysis zone: the units for reporting transportation related information being the preferred option for transportation study, the city of Windsor Wards was used as the unit of analysis for spatial aggregation due to availability at the time of the study. Now, the city of Windsor has 10 Wards and are currently serviced by one e-scooter provider i.e., bird Canada Incorporation. Although the city of Windsor e-scooter pilot study was two-phased with the initial implementation around the city center, all the 10 Wards were considered. This was based on the understanding that some e-scooter trips may not end around the vicinity where they start, even though the pilot program focused predominantly on certain areas within the city limit. Therefore, it is expected that the number of e-scooter trips within the city of Windsor will vary per Ward. All analysis both spatial and statistical described in this paper was done in R environment - an open-source language that could be used for various purposes and was chosen because of its flexibility and ability to be used to manipulate large and diverse datasets.

Firstly, and as initial step of analysis, the temporal clustering of e-scooter ridership was studied to determine the peak and the off-peak period that users prefers riding using clock plots. Clock plot basically

Table 1
Descriptive statistics of Demography and Socio-economic of Windsor.

Selected Variables	Minimum	1st Quantile	Median	Mean	3rd Quantile	Maximum
Total Population	18,487	20,735	21,386	21649.6	23205.25	24,670
Males	8953	10231.5	10589.5	10574.4	11204.75	12,074
Females	9454	10,203	10861.5	11074.3	12,088	12,596
Average Age of Population	36.9	39.2	41.25	41.07	42.65	45.7
Median age	32	39.05	41.45	41.15	43.175	47.7
Households	6785	8065.75	8876.5	9131.9	10818.25	11,418
Household Density	1332.19	1664.30	4530.73	4556.89	7455.84	8234.55
Persons per Household	1.9	2.125	2.25	2.41	2.675	3
Average Household Income	43,571	58433.25	71716.5	73301.8	91028.75	105,679
Area (km^2)	1.064394	1.174557	1.886363	3.577115	6.138314	8.516811
Population Density	2768.055	3696.754	12471.64	11086.12	17729.5	18583.13
Trip Generated from Wards	0	0.25	114.5	11386.6	13,892	68,598
Number of Wards (N)	10					

summarizes occurrences of events by hours of the day, month, or years. All the times recorded in the data obtained for our study were rounded up to the nearest hour. For example, 11:30 am/pm was rounded up to 12 while 10:15 am/pm to 10.00 am/pm. This was done to facilitate ease of understanding of temporal clustering of e-scooter ridership within the city of Windsor using the disaggregated trip data (i.e., 114,071 complete individual trips). Further, the density of e-scooter ridership within the city of Windsor was evaluated using planar spatial kernel density estimation described in equation (1) to understand the cluster of starts and end location/points (Xie and Yan, 2008). These clusters help understand where trips are likely to start or end.

$$\lambda(j) = \sum_{i=1}^{n} \frac{1}{\pi r^2} k\left(\frac{d_{ij}}{r}\right) \tag{1}$$

In equation (1), $\lambda(j)$ is the density of ridership that starts at a particular location, r search radius i.e., bandwidth of kernel density estimation, k is the weight at a point i relative to j at a distance d_{ij}. This is sometimes referred to as the kernel function described as the ratio of d_{ij} to r.

$k\left(\frac{d_{ij}}{r}\right)$ in equation (1) is estimated using the Gaussian function described in equation (2).

$$k\left(\frac{d_{ij}}{r}\right) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{d_{ij}^{\,2}}{2r^2}\right), \text{ when } 0 < d_{ij} < 0 \leq r \tag{2}$$

$$k\left(\frac{d_{ij}}{r}\right) = 0 \text{ when } d_{ij} > r$$

Using the start and end coordinates and the specific identification assigned to each trip, the origin and destination (O-D) matrix for each ride was determined at aggregated level considering the Wards in the city. In O-D matrix, the trip generated must be equal to those distributed. It aid in the understanding of the demand and supply that may guide e-scooter ridership. Where necessary, it may help in balancing the demand and supply of e-scooter ridership within the city and formulation of rebalancing policy as it has been reported that certain socioeconomics and demography uses e-scooter frequently (Lo et al., 2020).

As identified in the review of literature, certain socioeconomics, and demographic i.e., population density and incomes etc. affects e-scooter ridership. The effect of population on the relationship that exists between e-scooter trips generated and average household income was tested using linear regression methods to determine if there exist any direct or indirect effect. The theory that the average household income rather than population density will be a significant determinant of e-scooter trips generated was explored. Also examined was the impact of household density. Analysis described in this study used the demography and the socioeconomics information obtained from reports published on the city of Windsor's website (tinyurl.com/2016-Windsor-Demographics). However, at the point of conducting this study, only demographic and socio-economic breakdown for each of the Wards was available for the year 2016, thus it is assumed that the population was the same until 2021 when the e-scooter pilot study was implemented. Asides, the recent 2021 census only revealed that the total population of the city has only increased slightly (Statistic Canada, 2022), thus the use of the 2016 census information appears justifiable. Equation (3) through (7) describes the regression equations for the mediation analysis conducted in this study.

Path 1: Mediation effect of population density

$$Escooter\ Trip\ Generation = \beta_0 + \beta_1\ Average\ Household\ Income + \varepsilon \tag{3}$$

$$Population\ Density = \beta_0 + \beta_2\ Average\ Household\ Income + \varepsilon \tag{4}$$

$$\begin{aligned} Escooter\ Trip\ Generation = {} & \beta_0 + \beta_3\ Population\ Density \\ & + \beta_4\ Average\ Household\ Income + \varepsilon \end{aligned} \tag{5}$$

Path 2: Mediation effect of household density

$$Household\ Density = \beta_0 + \beta_5\ Average\ Household\ Income + \varepsilon \tag{6}$$

$$\begin{aligned} Escooter\ Trip\ Generation = {} & \beta_0 + \beta_6\ Household\ Density \\ & + \beta_7\ Average\ Household\ Income + \varepsilon \end{aligned} \tag{7}$$

$\beta_0, \beta_1 \cdots, \beta_7$ are the model parameters while ε represents error parameters.

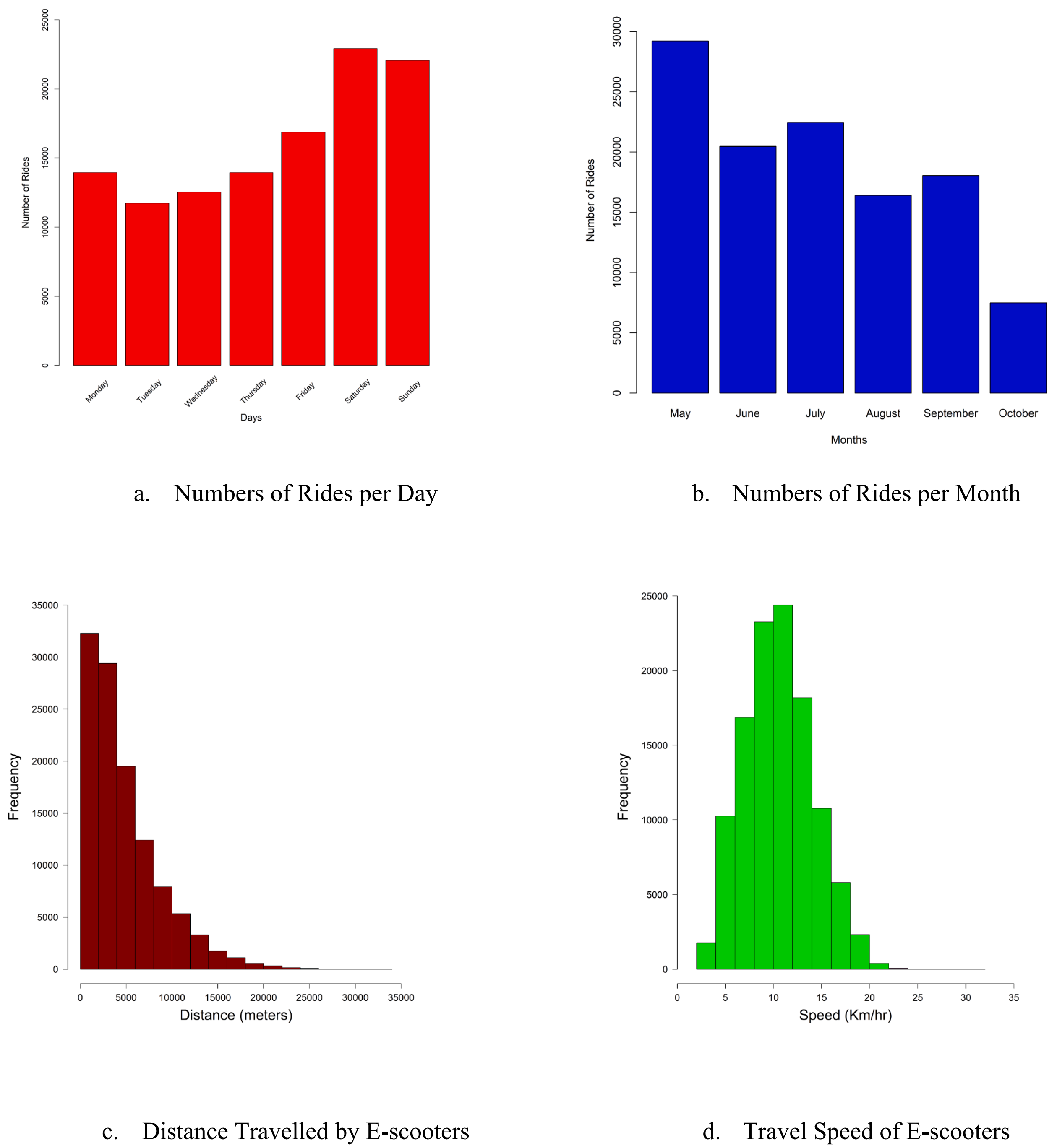
The descriptive summary of the demographic and socio-economic data used for the mediation analysis to understand the relationship that exist between population, household density, average household income and e-scooter trips generated by each Ward is given in Table 1.

5. Result and discussion

5.1. Attributes and temporal nature of e-scooter ridership in Windsor

Trips made by e-scooter riders in the city of Windsor were analyzed considering the daily, monthly, and hourly numbers of rides and it was found that the numbers of trips varied with days and months of the pilot study. There was a near linear increase in the numbers of trips made by users from Monday to Sunday. Ridership from Tuesday to Sunday showed a much more linear increase but Friday, Saturday and Sunday have more rides occurring than the other days of the week (see Fig. 3a). This finding was considered reasonable as weekends serve as off-times when individuals make recreational or fun trips. Hence, the high numbers of e-scooter trips seen on weekends is not surprising. It however raises the question whether e-scooter is used for work trips during the weekdays. On a monthly basis, the numbers of trips made were much higher in the months of May compared to the other months of the pilot study.

There was however an alternating increase and decrease in the numbers of trips made during the six months, but it could be inferred that there is a general decreasing trend in total trips made and October



a. Numbers of Rides per Day

b. Numbers of Rides per Month

c. Distance Travelled by E-scooters

d. Travel Speed of E-scooters

Fig. 3. Rides per Day, Months, Distance and Trip Speed Distributions of e-scooter Rides in Windsor, Ontario.

has the least number of trips (see Fig. 3b).

Different factors could have contributed to the decreasing trend seen across the months. The first plausible reason relates to seasonal effect on ridership as it has been reported that weather affects propensity to use e-scooters (Kimpton et al., 2022). As it may have been noticed, the pilot study of e-scooter program spanned between spring and fall months of 2021.

Due to the weather effect and as expected, more rides occurred in May - a spring month and the initial months of the pilot study. Another reason that could influence the decreasing pattern seen with the numbers of rides relates to utility function. The high number of rides seen during the initial months of the study could be because of novelty factor and more people could have wanted to try e-scooter as a transportation mode but as the months progress, novelty factor disappeared, and ridership fluctuates. This is consistent with utility function in transport economics that measures the level of satisfaction users derived from using any mode which is generally known to vary. It is suspected that the satisfaction derived from the use of e-scooter as a legitimate mode of transportation dropped across the month of the pilot study because of utility function. The minimum and maximum travel distance recorded for e-scooter rides was 117 and 33,824 m respectively. On average, the travel distance was 4759.84 m. From Fig. 3c, it could be seen that the distribution of distance travelled by e-scooters during the study period appeared not normally distributed and skewed to the right

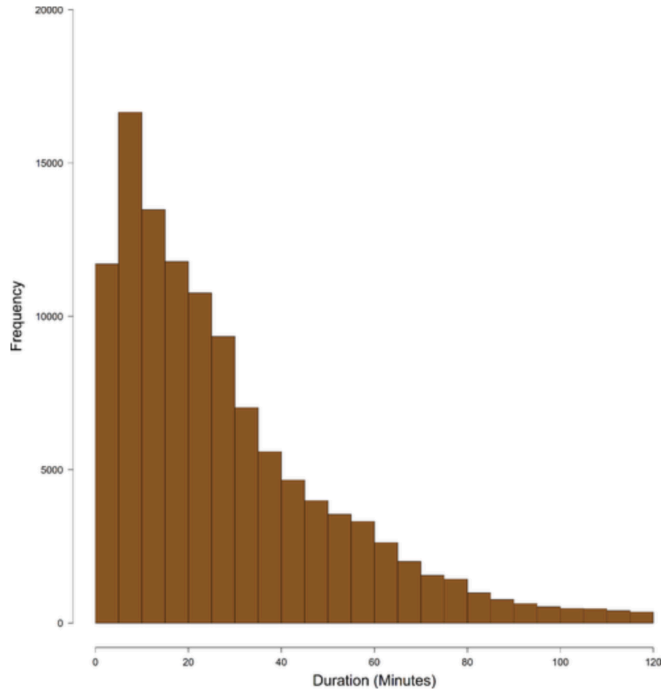


Fig. 4. Distribution of Trip time of E-scooter Rides in Windsor, Ontario.

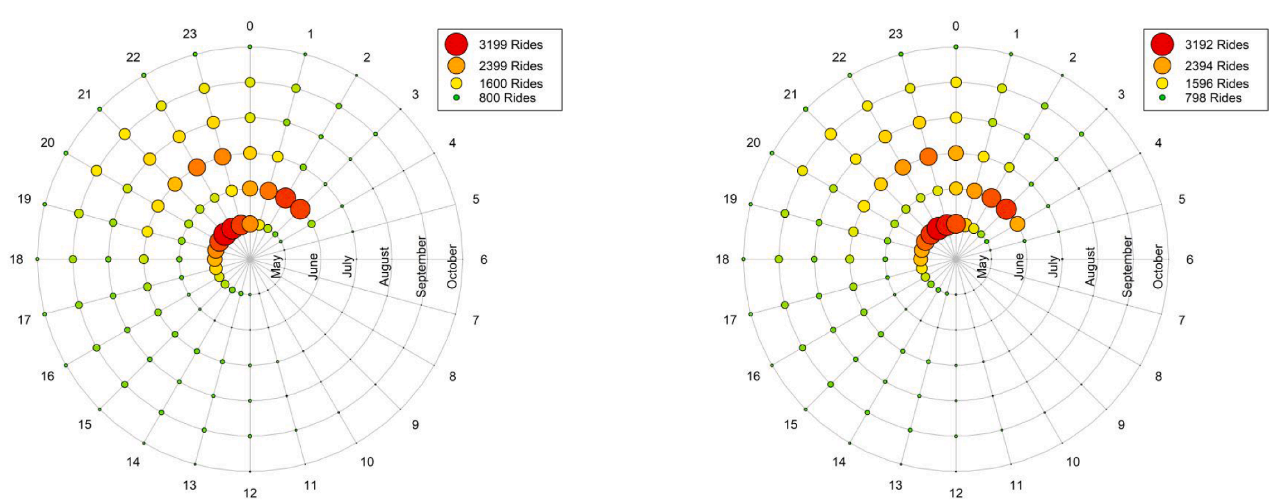
toward lower travel distances. It is inferred that riders in the city of Windsor appeared to use these scooters for short travel distances.

Also, the travel speed of e-scooters rides in the city of Windsor appears to be normally distributed around the average speed of 10.55 km per hour. During the pilot study, the minimum and maximum travel speed recorded for e-scooters were 3.5 and 31.65 km per hour (Fig. 3d). Although not frequent in the distribution, the maximum speed recorded is alarming and could lead to serious injury in case of accident because e-scooters are not designed to travel at high speeds. E-scooters are mostly designed for a top speed of 25 km per hour (Gössling, 2020; Nisson et al., 2020).

Similar to the distance travelled on e-scooter, the distribution of travel time is skewed towards lower travel durations. On average, riders spend 28.34 minutes on e-scooter, but some users' duration were much longer and extreme (Fig. 4). Take for instance, some users' duration on e-scooter was 120 min i.e., two hours. It is suspected that so many factors could have contributed to this. It is likely that some users' perception of the use e-scooters as fun or recreation mode of transportation might have contributed to keeping them for longer durations. Also, the cost of renting these e-scooters could have played a significant role in the duration of use as current service is time-based ($1.15 is required to unlock rides and $0.42 per minute of rides afterward). However, further analysis of the feedback from riders is expected to provide insight into this pattern.

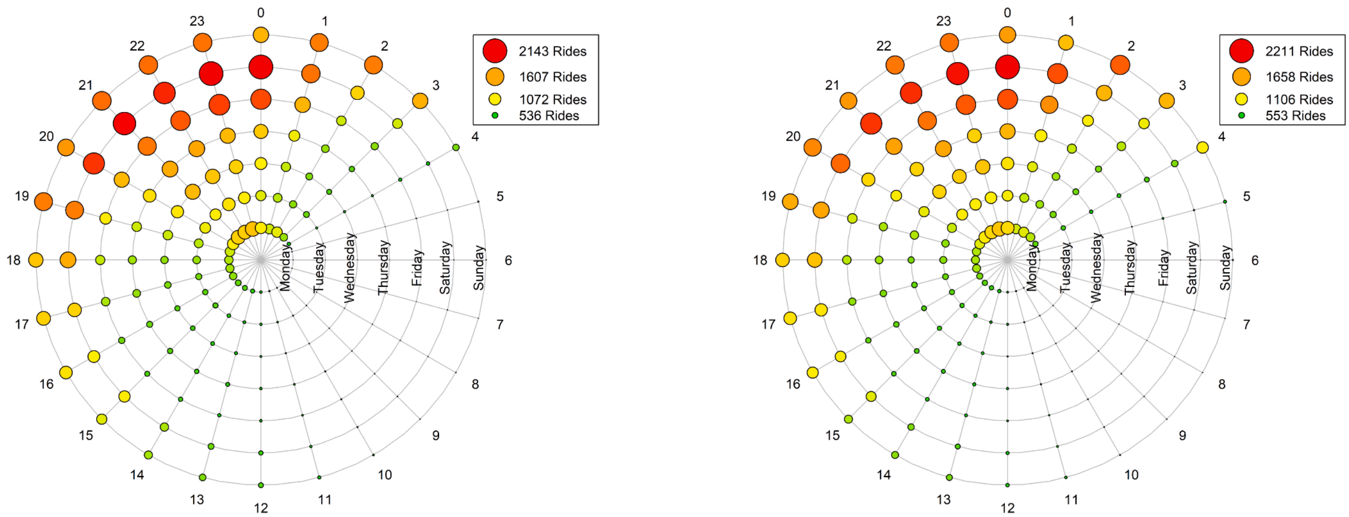
Temporal clustering of the numbers of rides per hour of the month was determined, and interesting patterns emerged. The start and end hour of e-scooter rides are similar (see Fig. 5). In 5 out of all months of the pilot study (excluding October), ridership increased gradually from 10:00 am in the morning, and it approaches peak monthly hourly ridership around 8.00 pm in the evening for the month of May, but later in the evening for the month of June. The late peak hour for ridership in the month of June could be attributed to summer effect on daylight – late Sunset. For the months of July, August and September, the peak hourly ridership could be seen between 7:00 pm and midnight. In October, ridership was more at the same level throughout the hours and there was no clear peak hourly ridership for the month. Compared to the other months, it was clear that ridership declined significantly in the month of October. This could be due to the weather effect; thus, it would be interesting to study seasonality effect on e-scooter ridership for effective planning. This would however require analysis of all year-round e-scooter ridership data in the city of Windsor but in the long run may facilitate effective e-scooter governance in the city. Further analysis was done to determine if there exist any temporal patterns in daily e-scooter usage in the city of Windsor. Relatively, there was no clear difference between the hourly times when rides start and end. Rides are likely to end around the same time when they start suggesting that e-scooters are not used for extensively long durations (see Fig. 6). These findings support earlier discussions that e-scooter travel durations in the city of Windsor is skewed towards shorter durations and correlates with the travel distance and speed.

It was found that the distribution of the hourly start and end times of ride per day of the week is consistent with what was seen with the monthly hourly numbers of rides. In the case of the daily hourly numbers of rides, more spread in the cluster of the numbers of trips made by



a. Start Times of Rides b. End Times of Rides

Fig. 5. Monthly Hourly Distribution of Times when E-scooter Ride starts and End in the City of Windsor.



a. Hourly Ride Start Time b. Hourly Ride End Time

Fig. 6. Daily Hourly Distribution of Times when E-scooter Ride starts and End in the City of Windsor.

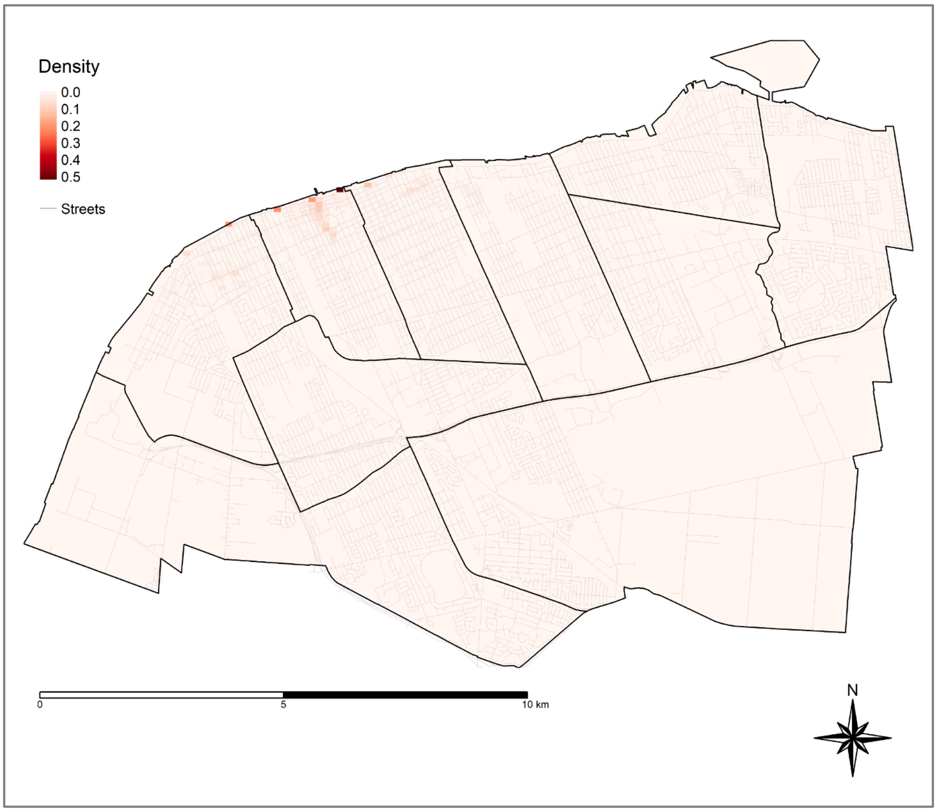
riders was seen. During the weekdays, ridership usually starts around 10.00 am in the morning and peaks between 7:00 pm and midnight. After midnight e-scooter ridership declined in the city of Windsor. Compared with the other days, the number of e-scooters trips on Friday, Saturday and Sunday was much higher. This was consistent with the initial findings that e-scooter trips are higher during or near weekend in the city of Windsor. Again, questions re-emerged on the reasons why trip numbers were higher during the weekend when people of the city are off from work rather than weekdays when residents are typically working. This study believes that the answer to this question is that e-scooters are considered recreational transport mode and brings the fear that they may be replacing other sustainable mode such as walking or cycling. Thus, emphasizing the importance of effective planning and proper integration with other travel modes. Another concern that could interest the decision or policy makers in the city of Windsor relates to the time during which e-scooters could be used. From the temporal analysis, patterns that emerged are late night riding of e-scooters. Most of the peak hours for ridership are around the nighttime in the daily and monthly analysis. Therefore, if adequate policies regarding late night riding of these scooters are not implemented, injury and in the worst-case fatalities could arise. A scenario that could get more severe when e-scooters are ridden impaired or under the influence of alcohol as it is has consistently been reported that poor cognitive function could result in improper decisions and accident may ensue. Asides, the high usage of e-scooters during the weekend, especially at night when most people are off-work in the city of Windsor suggests that they might be used to navigate the city after partying. Partying involving high drinking poses danger not only to e-scooter riders but other road users.

5.2. Spatial dimension of e-scooter ridership

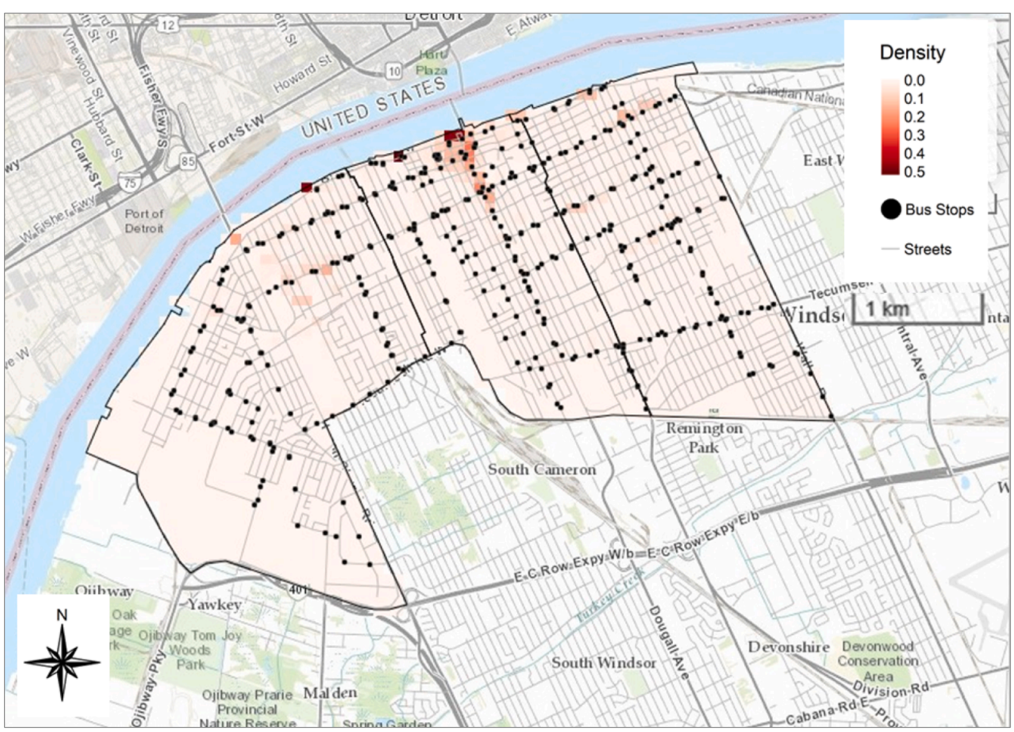
Kernel density estimation was used to determine the hotspots for ride start and end during the 6 months study period at optimal bandwidth of 2.515 km. It was found that the hotspots for most start and end of rides are located within the city's central business district i.e., the downtown core of the city (see Fig. 7 and Fig. 8). These patterns are quite strange because it does not give a very good indication of a well-integrated e-scooter service with the city's transit system. Another explanation for the high cluster of start and end points around the downtown core could be that e-scooters trips do not travel farther than the central business district of the city. Asides, e-scooter ride activities have been known to cluster around parks and recreational places within cities (Hosseinzadeh et al., 2021; Jiao et al., 2021). It is presumed that the presence of parks and recreational places around the downtown core bordered by River Detroit in Windsor could have influenced the high cluster of starts and end of trips at the same location. The patterns seen (high similarities) in hotspots for start and trip end are concerning as it is expected that a well implemented or planned out e-scooter service within any city will have multiple hotspots within the service area. This is not the case in the city of Windsor and the same hotspot locations for the start and end of trips seen could be because of the autonomy of the service providers in determining the ride zones and where scooters could be parked after use. This could be validated through analysis of the virtual georeferenced zones for e-scooter services in the city of Windsor and more interesting patterns could be revealed as it has been reported that service providers can arbitrarily change georeferenced zones where rides start and end without the approval of municipal authorities (Moran et al., 2020). Aside from this, the high clustering of rides starting and ending around the same location could be a business decision by the service provider.

Another implication of the high clustering of start and trips end in downtown area of the city of Windsor is that any unplanned increase without proper integration with other transport modes may lead to visual pollution. Other problems that could arise without adequate planning include improper parking such as dangerous encroachment onto the sidewalks which may be detrimental to the mobility of visually impaired persons. Thus, an increase in e-scooter's fleet number may not serve the interest of the city well but profit the service provider. Therefore, for e-scooter to achieve the sustainability benefit of reducing emission generated in the city of Windsor, appropriate regulations and policies are required. A proper integration policy with the transit system will promote the use of e-scooter to fulfill the first and last miles travel in the city of Windsor.

Further analysis to gain insight into e-scooter integration with the transit system within the city showed that currently, e-scooter services are mostly focused on Wards with greater transit accessibility determined by the number of stops in each of the Wards. These coincides with the three Wards where clusters of starts, and rides ends were seen (See Fig. 9). Thus, the finding is consistent with the claims that e-scooter

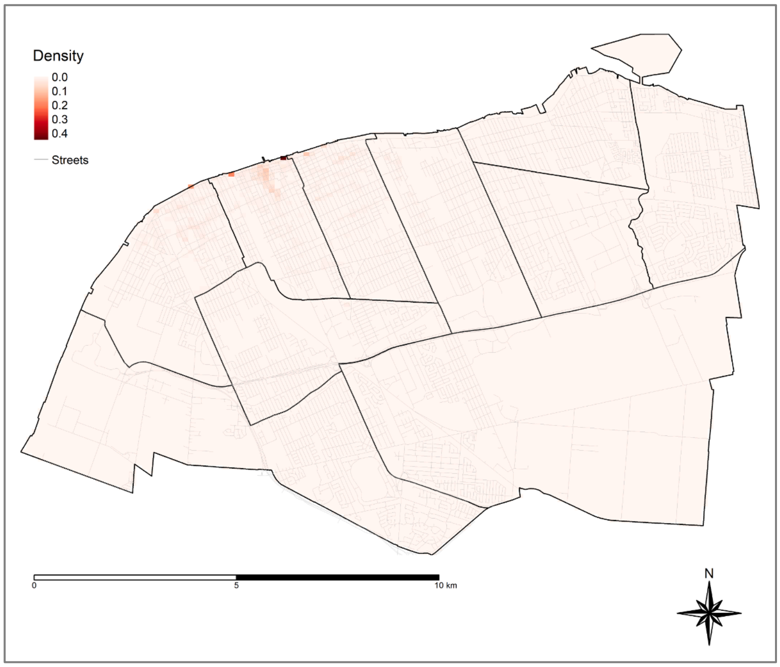


a. Ride Start Locations in Windsor

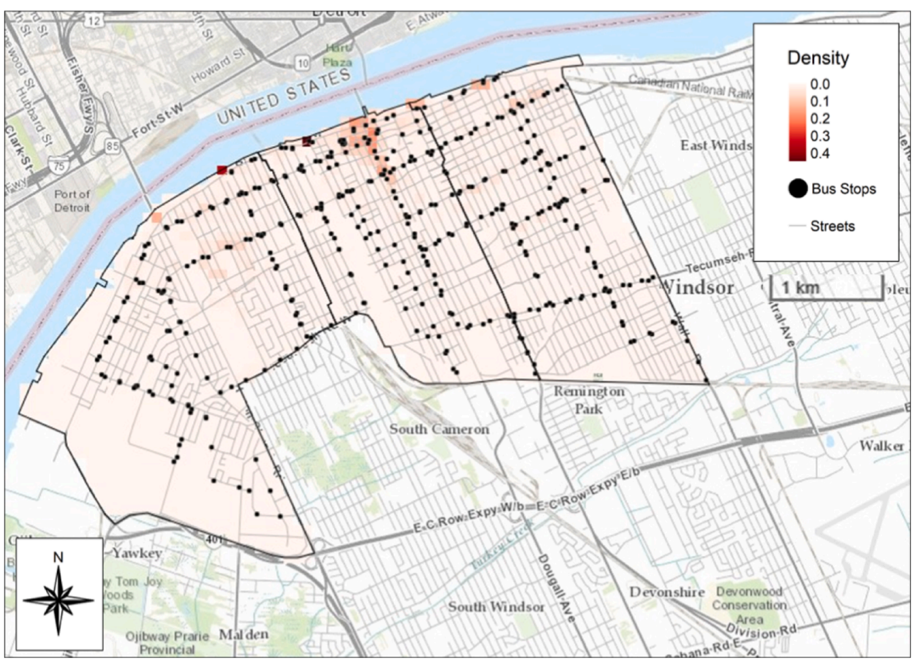


b. Three Wards where Most Rides Starts

Fig. 7. Kernel Density Estimates for Locations where E-scooter Rides Start.



a. Ride End Locations in Windsor



b. Wards Where Most Rides End

Fig. 8. Kernel Density Estimates for Locations where E-scooter Rides End.

services are mostly lunched in transit rich neighborhoods (Moran et al., 2020) and might not be serving the first and last mile trip purpose or replacing shorter car trips. An integration strategy for the city of Windsor could focus on Wards with less accessibility to transit stops to fulfill the first and last mile trip purpose from the bus stops to various homes or neighborhood shopping areas. This is achievable through strategic location of georeferenced zones where trips can start or end around the city and not the downtown core with greater transit accessibility.

Nonetheless the pilot stage at which the city's e-scooter program is at the city of Windsor provides opportunities to address these impending challenges. While the kernel density analysis revealed that the hotspots of start and end locations of e-scooter trips are similar, trips generated and attracted (Origin Destination: O-D) by each of the Wards in the city were examined to understand where most trips starting in a particular Ward end and vice versa. It highlights if any, e-scooter re-balancing needs and serves as foundation for subsequent mediation analysis to understand the influence of population density, household density and income on the number of trips starting from each Ward in the city.

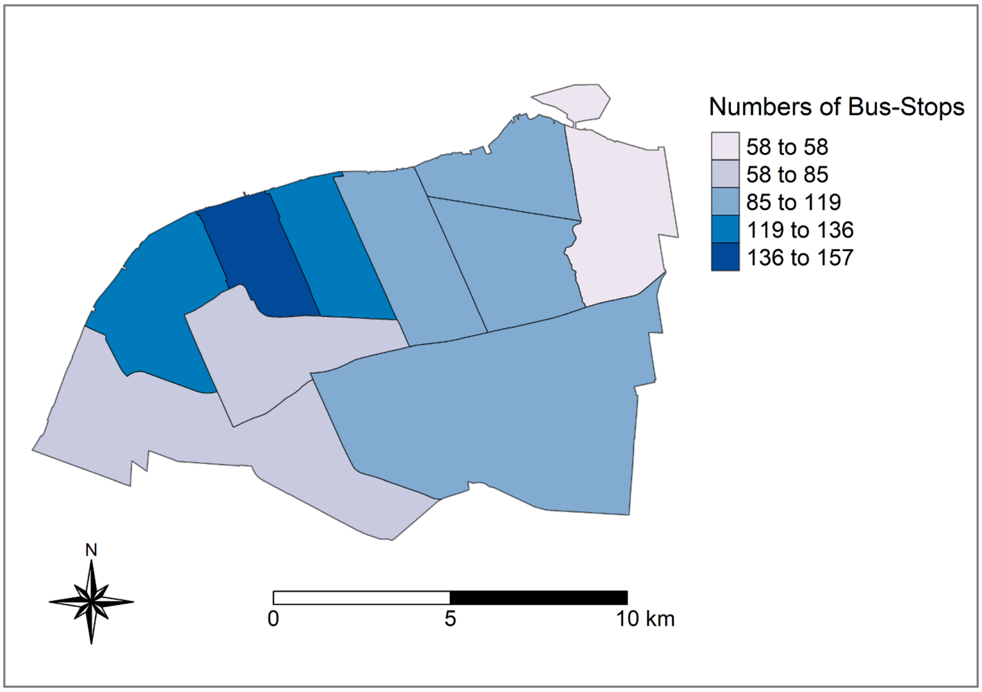


Fig. 9. Accessibility to Transit Determined by the numbers of Bus Stop within Wards.

5.3. Origin-Destination (O-D) of e-scooter trips in the city of Windsor

We balanced O-D matrix of e-scooter trips in the city of Windsor to determine Wards where most trips starts and end within the city of Windsor and for determining if income, population, and household density influences trips generated per Wards. However, O-D matrix analysis of trips within the city showed that not all the complete trips could be assigned to Windsor Wards after spatial overlay analysis. In total 205 complete trips could not be directly assigned to any of the Wards in the city of Windsor. This was attributed to trips ending outside of the city limit. Also, the digitization process of the shapefile of the city's boundary and Wards used for aggregated analysis might have given rise to some misalignments that led to non-classification of these 205 trips to any of the Wards during spatial aggregation. In total 113,866 e-scooter trips have known origin and destination Wards within the city limit. The O-D of e-scooter trips in the city of Windsor is shown in Fig. 10.

More trips activities seems to be occurring around Ward 2, 3, 4, and 5 with some spill to Ward 1, 8, and 10 but Ward 1 and 8 experienced the least e-scooter activities. In terms of trips attracted from other Wards, the pattern seen followed Tobler's first law of geography, "everything is related to everything, but closer things are more related" (Miller, 2004; Sui, 2004; Westlund, 2013; Zhu et al., 2019). For example, Ward 2 attracted most trips from Ward 3 and vice versa but these trips were fewer than the numbers of trips starting and ending within the same Wards. Such patterns were consistent across all Wards with high e-scooter activities and are attributed to proximity effect. From Fig. 9, it becomes obvious that most trips originating from any Ward within the city end in the same ward. Therefore, it is inferred that e-scooter trips in the city of Windsor do not travel far and are most likely to end in same area where trips begin. This is in alignment with the findings from the kernel density, temporal and trip distance distribution analysis that revealed that e-scooter trips in Windsor are likely to start and end around the same area or used for shorter duration and distance. Nonetheless, the distribution of e-scooter trips originating from the Wards of Windsor facilitated the understanding of the influences of population and household densities and income on e-scooter trips generated.

5.4. Socio-demographic influence of population density, household density, and income of e-scooter ridership in Windsor

Further analysis investigates the extent to which the claim that population or its derivatives, household density and income influence e-scooter ridership in the city of Windsor. Therefore, mediation analysis was used to explore direct or any indirect effect of population density, household density, and income on ridership. Based on the understanding of population and housing distributions in the city of Windsor, which is a sprawled city, it was hypothesized that income rather than population or household density might play a significant role in understanding e-scooter trip generation in the city of Windsor. Three paths 1) The influence of average household income on trips generated, 2) The mediating influence of population density on relationship between average household income on Trips generated and 3). The mediating influence of household density on relationship between average household income on trips generated were analyzed.

We examined these paths using regression analysis and estimated the parameters described on Table 2 and Table 3. The first step of our analysis examined the relationship between our main independent variable – average household income and e-scooter trips generated per Wards of the city of Windsor. In the city, there exist a linearly decreasing relationship between income and trips generated (-0.6430, $P < 0.05$). The second step which involved determining the association between income and population density (the first mediator considered in our study) showed that there is no statistically significant relationship (-0.0273, $P > 0.1$). The third part of our regression which examined the influence of both populations and household densities showed similar relationship as earlier highlighted (see Table 2). As claimed by many researchers that both income and population density play significant roles in understanding e-scooter ridership, we found that the effect could not be generalized.

Similar relationship seen with population density and average household income exists with household density and income but at a different effect levels. Income decreases with household density but not at a statistically significant level ($P > 0.1$). We found only average household income (-0.7717, $P < 0.05$) to be significant in explaining trips generated per Ward when the effect of both household density and

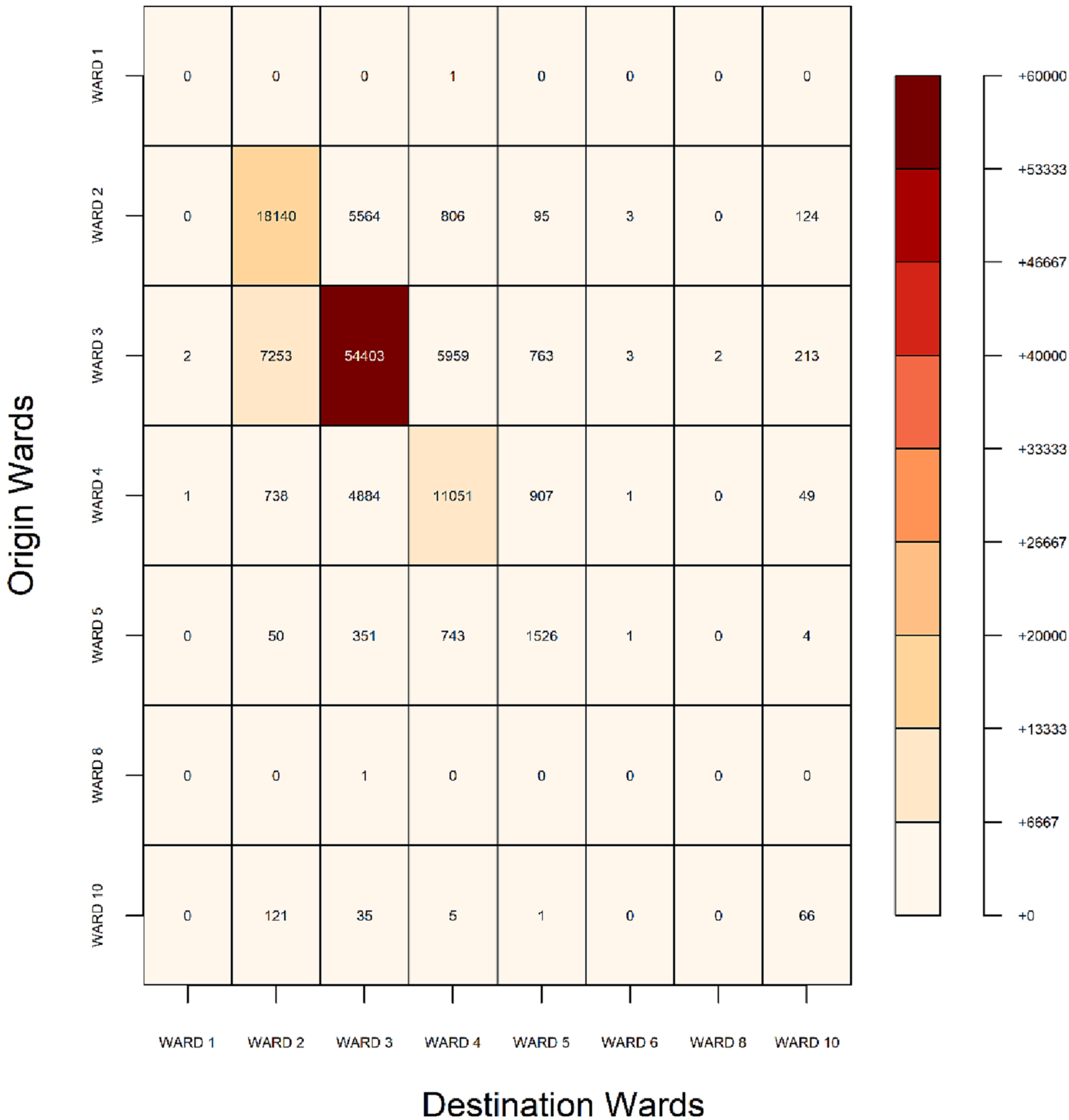


Fig. 10. E-scooter Trips Generated and Attracted from Wards.

income were considered (see Table 3).

We showed the summary of the parameters estimated from the regression models in Fig. 11 and incorporated it into our mediation analysis to determine if there are any direct or indirect relationship.

It is however important to note that different schools of thought exist on the mediator used in any analysis. The first thought believed that there must be a significant relationship between the mediator (population density, household density) and the independent variable (average household income). The other believed that there need not exist a significant relation because correlation does not mean causation. We agreed with the second school of thought as there was no significant relationship between population density, household density, and the average household income. This serves as the motivation to determine if there are any hidden relationships on e-scooter trips generated by Wards of the City of Windsor. Hence, to understand if there is any causal relationship between the effect of population and household densities, and average household income on trips originating from Wards, population density and household density was used as alternate mediator paths to understand the indirect effect of average household income on e-scooter trips.

Our mediation analysis of the effect of population and household densities on the relationship between average household income and trips generated showed that there is no significant causal effect of population density or household density on the relationship that exist between average household income and numbers of trips originating from Wards in Windsor. The Average Causal Mediation Effects (ACME) from Table 4 represents the indirect effect of population density on the influence of average household income on the numbers of trips generated per Wards. The ACME is estimated as 0.0354 (product of path a and b in Fig. 11) but was not statistically significant at 0.05. Therefore, no

Table 2
Relationship between, Population Density, Household Income and Numbers E-scooter Trips Generated per Wards.

Independent Variable Dependent Variable Mediator	Trips Generated Average Household Income Population Density			
	Independent Variables	Estimate	Std. Error	p-value
Step 1: Dependent Variable: Trips Generated	Average Household Income (c)	−0.6430	0.2588	0.0378
	R^2	0.3651		
Step 2: Dependent Variable: Population Density	Average Household Income (a)	−0.0273	0.1104	0.811
	R^2	−0.1165		
Step 3: Dependent Variable: Trips Generated	Average Household Income (c^1)	−0.6785	0.2313	0.0219
	Population Density (b)	−1.2970	0.7379	0.1222
	R^2	0.4966		

Table 3
Relationship between, Household Density, Average Household Income and Numbers of E-scooter Trips Generated per Wards.

Independent Variable Dependent Variable Mediator	Trips Generated Average Household Income Household Density			
	Independent Variables	Estimate	Std. Error	p-value
Step 1: Dependent Variable: Trips Generated	Average Household Income (c)	−0.6430	0.2588	0.0378
	R^2	0.3651		
Step 2: Dependent Variable: Household Density	Average Household Income (a)	−0.0360	0.0446	0.4427
	R^2	-0.0402		
Step 3: Dependent Variable: Trips Generated	Average Household Income (c^1)	−0.7717	0.2267	0.01139
	Household Density (b)	−3.5733	1.7293	0.07763
	R^2	0.5493		

indirect effect of population density was seen on the relationship that exist between average household income and trips generated per Wards. The proportion mediated −0.0551 was also not statistically significance ($P > 0.1$). The average direct effect of income on trips generated however remained the same. This value was the same as estimated on Table 3. Similar mediation effect of household density exists on the relationship between average household income and trips generated per Ward. The ACME showed no indirect effect of household density on the existing relationships (see Table 5). However, the direct effect was significant as reported on Table 5.

Therefore, our study inferred that the effect of average household income on trip originating from a Ward is not mediated via either population density or household density. Analysis confirmed that as the average household income decreases the likelihood of e-scooter trips originating from a Ward increases. This finding is logical as it has been reported that there is a negative association between income and the willingness to use these scooters (Torabi et al., 2022) and affluent i.e., high income neighborhoods within any city are car centric (Lansley, 2016; Li and Zhao, 2017; Power, 2012). Similarly, we inferred that household density has no mediating effect on the relationship between average household income and trips originating from any Wards in Windsor.

6. Conclusion, recommendation, and future research direction

The study evaluates the spatial and temporal patterns of e-scooter

Table 4
Mediation Result of the Effect of Population Density on the Relationship between Average Household Income and the Numbers of Rides Starting per Wards.

Effect	Estimate	95 % CI Lower	95 % CI Upper	p-value
Average Causal Mediation Effects (ACME)	0.0354	−0.2553	0.33	0.818
Average Direct Effects (ADE)	**−0.6785**	**−1.2114**	**−0.06**	**0.01**
Total Effect	**−0.6430**	**−1.2276**	**−0.06**	**0.006**
Prop. Mediated	−0.0551	−0.6455	0.31	0.816

Table 5
Mediation Result of the Effect of Household Density on the Relationship between Average Household Income and the Numbers of Rides Starting per Wards.

Effect	Estimate	95 % CI Lower	95 % CI Upper	p-value
Average Causal Mediation Effects (ACME)	0.129	−0.183	0.380	0.518
Average Direct Effects (ADE)	**−0.772**	**−1.298**	**−0.170**	**0.008**
Total Effect	**−0.643**	**−1.260**	**−0.100**	**0.002**
Prop. Mediated	−0.200	−0.968	0.230	0.516

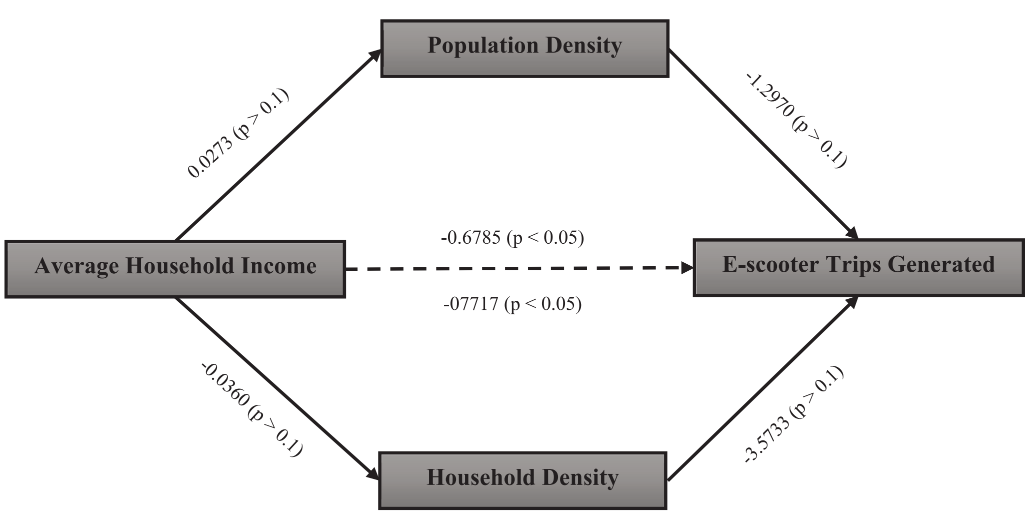


Fig. 11. Effect of Population and Household Density on the Relationship between Income and E-scooter Trips Generated.

trips in the city of Windsor, Ontario using six (6) months data (May to October 2021) collected over a pilot study period. The pilot stage before full implementation that the city is currently at provides the possibility to identify the likely opportunities and challenges that could arise if proper planning is not initiated. Thus, both aggregated and disaggregated analysis was employed to gain insights into e-scooter trip patterns. Findings from the study were consistent with other studies on e-scooter micromobility modes but contributes to knowledge by highlighting the need for appropriate planning before full implementation especially in small cities like Windsor. It recommends that lessons derived from other cities of the world such as proper integration and guidelines could be used as input for formulation of appropriate planning strategies in the city of Windsor.

At disaggregated level, the study found that e-scooter use during the initial 6 months pilot study decreased linearly but the numbers of trips made in the spring and summer months were greater than those of the fall months and was attributed to weather/seasonal or novelty effect on ridership. Further analysis at disaggregated level revealed that compared to other days of the week, more e-scooter trips are made on Weekend (Friday, Saturday) and slightly decreased on Sunday. This pattern is concerning because Friday and Saturday are relative non-workdays and e-scooters in the city of Windsor might be considered as a recreational fun mode and not a legitimate means of transportation. The latter being the main purpose for which e-scooters are introduced – to replace shorter car trips and not utilized for fun. Although it is acceptable that the use of these modes could be fun to certain people, the objective for which it was introduced must be prioritized. However, this will require that the purpose for which these scooters are used be collected by service providers at the start of trips.

Also, it was found that e-scooters are used for short duration and distance and mostly travel at a relatively low speed, but this is not without some exceptions. There are few cases where e-scooter trips speed was higher. Temporal analysis showed that the peak period for e-scooter usage in the city of Windsor is between 6:00 pm and midnight but it is dependent on the days of the week. The issue with these peak periods and high speed of trips is the late-night riding which may be hazardous to users especially when used under influence, or on improper section of the road. The absence of policies or regulations in the city of Windsor to prohibit e-scooter riding beyond certain times of the day could lead to fatalities especially when ridden under the influence of alcohol.

Kernel density analysis used to determine the hotspots for ride start and end showed that most trips are likely to end where they begin around the central business district of the city of Windsor. It was expected that there would be differences in hotspots if these modes were legitimately used to fulfil first and last mile travel in the city. As it stands and evident from the kernel density analysis, trips start, and end locations appeared the same along a park or riverside in the city - an indication that these modes are not used for transportation. It appears to be that the city is promoting e-scooters sustainability without incorporating or applying the lessons learned from other cities that are ahead with implementation of these modes. Thus, proper integration with the transit system is required for the sustainability benefit for which e-scooters were promoted to be realized. Poor integration with the transit system could imply that service providers are prioritizing profit and simply using the city's assets for profit maximization.

At aggregated Ward level, it was revealed that most trips start and end within the same Ward or at most travel to the neighboring Wards. This further validates the findings that e-scooter trips in Windsor remain near the vicinity where they start especially around the downtown core of the city and might be replacing walk or other sustainable modes of transportation. Using Mediation analysis, the general notion that population density, household density and income can significantly explain e-scooter trips originating from an area and in our case, Wards was tested. Mediation analysis revealed that the average household income can significantly explain e-scooter trips originating from a Ward. At Windsor Ward level, population density and household density does not have mediating effect on the relationship between average household incomes and trips originating from any Ward.

While the current research has uncovered patterns that existed during the six-month e-scooter's pilot study in the city, there are opportunities for improvement. In terms of policies, there exist no detailed guidelines within the City of Windsor to guide e-scooter usage: concerning the speed of travel, when and where it could be ridden as well as safety enforcement. In most cases across the province of Ontario where the city of Windsor is located, most municipalities refer to provincial regulations which transfer some responsibility to municipal authorities. In some cases, e-scooters are treated as bicycles with the presumption that they are similar modes neglecting that e-scooters are disruptive technology.

As it stands it appears that the service provider has autonomy in data collected. This was evident in the quality of data that was supplied to the city as inconsistencies were found in the format of the data reported. In some cases, longitudes and latitude were interchanged, in other Origin Wards, where trips start, and end are included. These inconsistencies are challenges that could limit the ability of some non-technical professionals to quickly gain insight into trip patterns. Also, the trip purpose for which e-scooters were used was missing in all the data supplied. It is recommended that the municipal authorities minimize the autonomy of the service provider in the type of data collected if effective planning is to be achieved. For example, it would be interesting to know the purpose of the trips made by e-scooters.

Also, collection of the travel trajectory information of e-scooters might help understand the routes that most e-scooters use. The benefit of using trajectory information could lead to provision of adequate bike infrastructures which in-turn promote scooter as a legitimate mode of transportation. It will also minimize pedestrian-scooter conflicts that occur when riding on sidewalks. Future research could use the purpose of e-scooter trips to gain knowledge if they are replacing short car trips.

Author contributions

Seun Daniel Oluwajana Ph.D., conceived the idea for the manuscript. He was involved with the project administration, data curation, development of study method, formal analysis, results interpretation, writing and preparation of manuscript. Crystal Mingyue Wang, MASc., assisted with project administration, the review of results/manuscripts. She also helped with results interpretations where applicable.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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