Four-Year Trends of Personal Mobility Devices in Metropolitan Vancouver:

The Evolution of Mode Shares, Speeds, and Comfort in Off-Street Paths

Alexander Bigazzi, Amir Hassanpour

research on active transportation

react

Research Report
December 2024

About REACT Lab

React Lab is a group of researchers dedicated to finding ways to make our transportation systems more effective, sustainable, equitable, and healthy. We do this work on the unceded lands of the Coast Salish nations, with the guiding values of integrity, rigor, creativity, and empathy. To learn more about our projects, visit: reactlab.civil.ubc.ca

Acknowledgements

This research was funded by Natural Sciences and Engineering Research Council of Canada (NSERC) Alliance Grant #ALLRP 585929-2023, and TransLink, the authority responsible for the regional transportation network of Metro Vancouver in British Columbia, Canada. The views expressed in this study are those of the authors and do not necessarily represent the views of the project funders.

The authors would like to thank the following people for offering valuable direction and advice on this project: Elmira Berjisian, Graham Cavanagh, Rick Du, Mirtha Gamiz, and Gurdiljot Gill.

Cover photo by Jimmy Jeong/The Globe and Mail

Report Authors

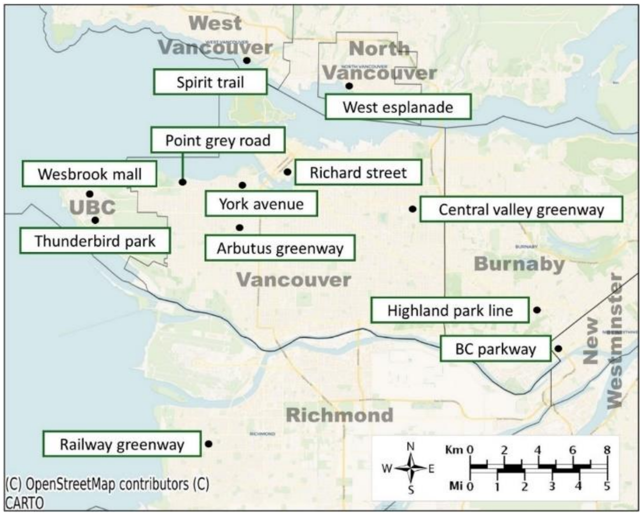
Alexander Bigazzi
Associate Professor, Transportation Engineering
Department of Civil Engineering
University of British Columbia, Vancouver, Canada, V6T 1Z4
Email: abigazzi@civil.ubc.ca

Amir Hassanpour
PhD Candidate, Transportation Engineering
Department of Civil Engineering
University of British Columbia, Vancouver, Canada, V6T 1Z4
Email: amirhhm@student.ubc.ca

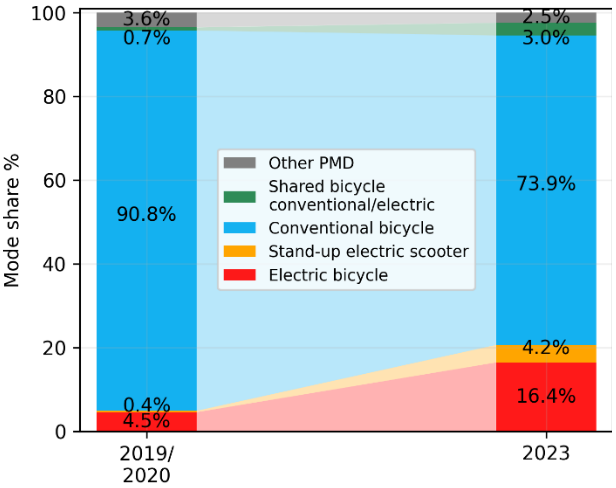
EXECUTIVE SUMMARY

Micromobility or personal mobility devices (PMD) such as bicycles, scooters, and skateboards, with or without electric-assist, are increasingly popular for urban travel, which poses challenges in the constrained spaces of cycling facilities and multi-use paths. Consequently, understanding the evolving usage of PMD and their impacts on other path users is essential to ensure safety and comfort for all users of off-street cycling facilities and multi-use paths.

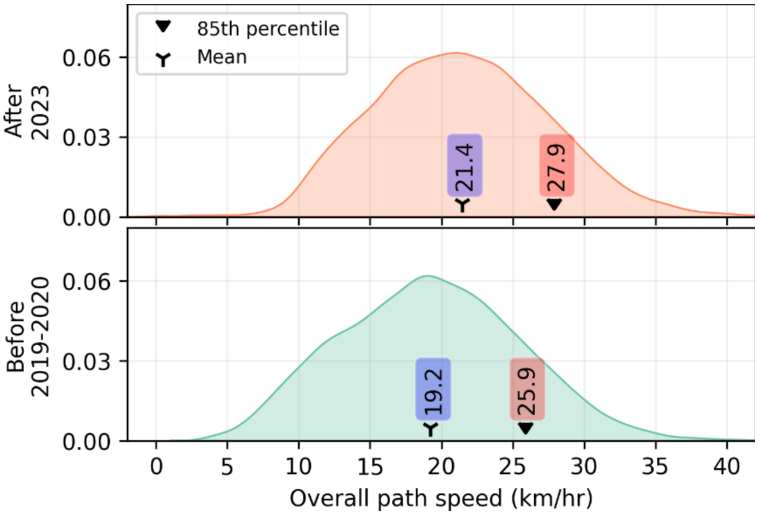
The objectives of this study are 1) to investigate longitudinal changes in the mode shares and speeds of personal mobility devices over 4 years (2019-2023) in metropolitan Vancouver, Canada and 2) to determine the implications of those changes for the comfort of travellers in off-street facilities. Classified count and speed data of PMD were collected at 12 sampling locations in off-street cycling facilities and multi-use paths in metropolitan Vancouver in summer of 2023.

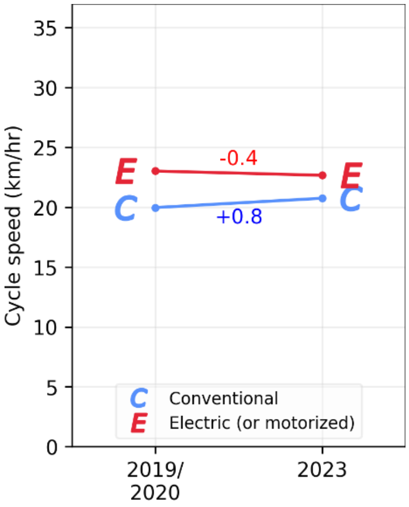


Those data were combined with similar count and speed data as well as survey data collected at the same locations in 2019 and 2020. Our previous study provided a PMD taxonomy with baseline mode share and speed data from 12 locations in 2019 and 2020. We also previously assessed perceptions of comfort sharing paths with each type of PMD for travellers at the same locations. Those results provide a comfort model which can be applied to estimate the effects of changes in PMD use on path user comfort.



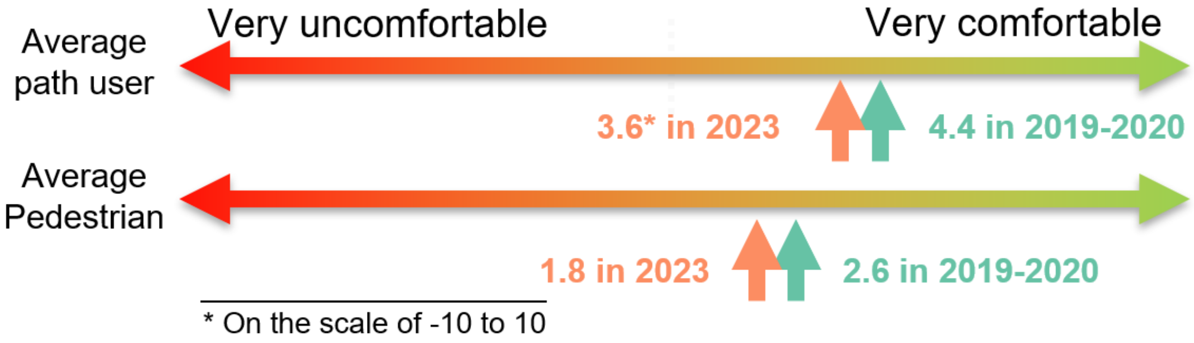
Results show that between 2019 and 2023 the mode share of conventional bicycles decreased from 91% to 74%, while electric bicycles increased from 4.5% to 16.4% and stand-up electric scooters increased from 0.4% to 4.2%. There has been a 17.2%pt shift from non-motorized to motorized PMD, dominated by a shift from non-motorized to motorized cycles (Figure 3). Mode share for motorized cycles has increase by a factor of 4, while mode share for other motorized PMD has increased by a factor of 5.





Overall mean speed in cycling facilities and multi use paths has increased by 11% (2 km/hr). Controlling for contextual factors, electric and conventional bicycle speeds became more similar, while electric skateboard speeds increased by 4 km/hr and self-balancing unicycle speeds increased by an alarming 10 km/hr. Self-balancing unicycles are the fastest PMD in 2023, with an 85th percentile speed of 41 km/hr and nearly half of them exceeding 32 km/hr. The overall 85th percentile speed in off-street cycling facilities and multi-use paths has increased from 25.9 km/hr in 2019-2020 to 27.9 km/hr in 2023. Overall, 33% of traffic on off-street cycling facilities and multi-use paths travel at speeds above 24 km/hr, and 5% above 32 km/hr—up from 23% and 2%, respectively, in 2019–2020.

In 2019-2020, average path user comfort weighted by mode shares of PMD was 4.4 on the scale of -10 (very uncomfortable) to 10 (very comfortable). This study shows that in 2023, average path user comfort is reduced to 3.6. Isolating the comfort ratings of pedestrians, the volume-weighted average pedestrian comfort level decreased from 2.6 in 2019-2020 to 1.8 in 2023. Model results indicate that these mode share and speed changes will reduce comfort, but the average path user (including pedestrians) remains moderately comfortable with most PMD.



Key findings

- The mode share of motorized PMD has quadrupled in 4 years.
- Bikeshare represents a small but an increasing portion of PMD use – especially motorized PMD.
- The average speed in off-street facilities increased by 11% or 2 km/hr.
- Conventional and electric bicycle speeds are more similar now.
- Speeds increased dramatically for some less common motorized PMD.
- These mode share and speed changes will degrade path user comfort, although the average path user is expected to still be moderately comfortable with most other path users.

Conclusions

Our previous study concluded that the Vancouver region was ready to accommodate new PMD in off-street paths without major effects on speeds and with only slight reductions in path user comfort. That has proven to be largely true following a 4-fold increase in motorized PMD use over the intervening 4 years.

Significant increases in the mode shares of electric bicycles and stand-up electric scooters over 4 years reflect the impact of changing policy on micromobility use in the region, in addition to broader trends in motorized PMD growth. Along with a more than 10-fold increase in usage, average stand-up electric scooter speeds have risen to 25 km/hr, exceeding the electric scooter pilot program's motor-assist limit. This finding suggests a need for mitigation measures in the market for private stand-up electric scooters. In contrast, we previously concluded that the 32 km/hr motor-assist limit for electric bicycles was effective, and that seems to still be the case.

We previously found that a 30 km/hr design speed was appropriate. Our new results suggest that a 30 km/hr design speed is still marginally conservative, but may require upward adjustment to 32 or 35 km/hr in the future if current trends continue, or in locations with particularly high shares of motorized PMD. In addition, to accommodate increased overtaking maneuvers safely and comfortably, wider paths may need to be provided, particularly on steep grades.

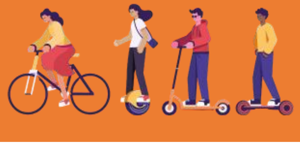
Continued monitoring is needed to see if shares or speeds for self-balancing unicycles, electric tricycles, electric skateboards, and sit-down electric scooters increase further. Results suggest that we should consider ways to mitigate the impacts of self-balancing unicycles and electric skateboards, either through speed management or removal from off-street facilities – particularly those shared with pedestrians.

In addition, the deterioration in comfort for pedestrians in multi-use paths further supports our previous recommendation to lower the volume thresholds for separating pedestrians from PMD when motorized PMD are allowed.

Table of Contents

List of Figures

List of Tables



1 INTRODUCTION

The popularity of personal mobility devices (PMD) with and without electric-assist has grown in recent years, due to their relative convenience, affordability, and health and environmental benefits (1–7). PMD, sometimes referred to as micromobility, have evolved beyond conventional and electric bicycles to include a wide array of device configurations and attributes (8). These new types of PMD, especially those with electric-assist, present new challenges for urban transportation systems where there is already competition for space and access among travellers. A wider variety of PMD sizes and speeds sharing limited space can lead to more interactions and conflicts, making active forms of travel less attractive (9). Consequently, understanding the evolving usage of PMD and their impacts on other path users is essential to ensure safety and comfort for all users of off-street cycling facilities and multi-use paths.

1.1 Literature review

Data on cycling has improved over the past few decades with new technologies and increased focus on cycling in transportation analyses, but data on other types of PMD (particularly those privately owned) are still limited (10,11). Household travel surveys are a primary source of information on cycling, including ownership and usage, although most surveys fail to distinguish bicycle types and exclude data on non-bicycle PMD. Household survey data from 3 municipalities of metropolitan Vancouver, Canada (District of West Vancouver, City of North Vancouver, and District of North Vancouver) reveal that total bicycle (conventional and electric) access declined from 58% to 49% between 2021 and 2023, although access to electric bicycles increased from 9% to 17%, and access to stand-up electric scooters, electric skateboards, electric unicycles and “hoverboards” increased from 3% to 4% (12,13). The City of Vancouver reported that from 2021 to 2022 electric bicycle access increased from 5% to 8% and access to electric scooters, electric skateboards, and “hoverboards” increased from 3% to 5% (14). They also estimated that 1 in 5 bicycle trips was made on an electric bicycle based on the same household survey data (14). Outside of Canada, a study using travel survey data from the Netherlands reported that the share of adult cyclists using electric bicycles grew from 4% to 10% between 2007 and 2013 (15).

Another common source of information on PMD use is permanent counters on cycling facilities. These counters provide fairly reliable data on total volume at select locations, but typically do not distinguish among PMD types (11,16). With increasing focus on new and electric-assist PMD, some data collection efforts have manually classified observed PMD to examine mode shares. For example, the City of Vancouver manually classified 16,573 observed PMD at 5 locations in 2023 and reported a mode share of 15% for electric bicycles (see Appendix A: Count and mode share data collected by City of Vancouver). During 10 hours of data collection in 2017 and 2020, a total of 1,879 PMDs were observed and categorized into conventional bicycles, electric bicycles, and electric scooters in Christchurch and Wellington, New Zealand (17). The results showed that the mode share of electric bicycles increased from 3% to 11% in Christchurch and from 10% to 24% in Wellington. No electric scooters were observed in 2017, but by 2020 electric scooters accounted for 3% of PMD in Christchurch and 1% in Wellington. In a previous study, we developed a detailed and comprehensive taxonomy of 27 types of PMD used in off-street paths in metropolitan Vancouver, Canada, and reported modes shares for each based on 25,282 observations at 12 locations over 4 seasons in 2019 and 2020 (8). The vast majority of PMD (91%) were conventional bicycles, while 4% were electric bicycles and all other types comprised only 5%.

More data are available for shared PMD usage, which are systematically collected and reported by most sharing system operators (11,18). Membership in Vancouver’s bikeshare system increased from 5% of the population in 2021 to 9% in 2022 (14). Bikeshare ridership increased by 20% during the same period (see Appendix B: Shared personal mobility devices). Nationally, Canada saw a 41% increase in shared PMD trips from 2022 to 2023, with 17% of trips made on shared electric scooters and the remainder on shared bicycles in 2023 (19). Across North America, 23% of shared PMD trips were made on electric bicycles in 2023, while 36% were on conventional bicycles and 41% on electric scooters (19).

In addition to volumes and mode shares, speed is another important aspect of PMD use for transportation planning, design, and analysis. A growing literature investigates the speeds of conventional bicycles, electric bicycles, and electric scooters using Lagrangian or Eulerian approaches (20–25). Speed data for other types of PMD are scarce, with only a few existing studies on skateboard, skate, or self-balancing scooter speeds including small sample sizes of 4 to 160 (26–28). Our previous study of PMD in Vancouver reported speed distributions for each of the 27 PMD types, although sample sizes for some types were small (29). We found that most PMD types with electric-assist had average speeds of 20 to 24 km/hr, compared to 19 km/hr for conventional bicycles. Sit-down electric scooters were a clear outlier with an average speed of 28 km/hr and 32% of observations over the motor-assist limit of 32 km/hr for motor-assisted cycles.

To our knowledge, there is almost no literature on how PMD speeds may be changing over time. The report from New Zealand cited above (17) also reported that average speed of conventional bicycles across five locations in Christchurch and Wellington increased slightly from 24.4 km/hr to 24.8 km/hr between 2017 and 2020, while the average speed of electric bicycles slightly decreased from 30.4 km/hr to 30.0 km/hr.

1.2 Study objectives and context

Existing literature provides limited information about PMD use other than bicycles or sharing systems. It also lacks information on how usage of various PMD (private and shared, motorized and not) is changing over time. This knowledge gap limits our ability to understand and manage the evolving impacts of PMD on urban transportation systems. Modal volumes and speeds are two of the most fundamental parameters in transportation network design, and critical factors for operations, safety, and comfort (30–33). Understanding of PMD volume and speed trends is necessary for strategic planning to accommodate new mobility options while ensuring safe and comfortable facilities for non-motorized travellers.

This study addresses the knowledge gap with an empirical investigation of longitudinal changes in PMD use in cycling facilities and multi-use paths of metropolitan Vancouver, Canada. The objectives of this study are 1) to investigate changes in the mode shares and speeds of personal mobility devices over 4 years (2019-2023) and 2) to determine the implications of those changes for the comfort of travellers in off-street facilities. Our previous study provides a PMD taxonomy with baseline mode share and speed data from 12 locations in 2019 and 2020 (8,29). In this study, we revisit the same locations after four years to investigate how PMD use has evolved. We also previously assessed perceptions of comfort sharing paths with each type of PMD for travellers at the same locations (34). Those results provide a comfort model which can be applied to estimate the effects of changes in PMD use on path user comfort. Key factors influencing comfort sharing with a PMD were its speed, presence of electric-assist, and similarity to the perceiver's travel mode.

Several policy and service changes could have influenced PMD use in metropolitan Vancouver during the intervening four years, in addition to broader trends in PMD market growth.

1. The bikeshare operator in the City of Vancouver, Mobi, introduced electric bicycles to the system and expanded the service area in 2023 (35), contributing to increasing bikeshare usage (36).
2. A dockless electric bikeshare system was introduced by Lime (Neutron Holdings, Inc.) in three municipalities (North Vancouver, West Vancouver, and Richmond) in 2021 (37).
3. The Province of British Columbia introduced an electric kick scooter pilot program in 2021, allowing select municipalities to pass bylaws enabling electric scooters to be used on public streets and pathways (38). Each municipality could develop custom regulations (private or shared, operating restrictions, etc.) within the provincial regulations (which set a maximum motor-assisted speed of 24 km/hr[1], among other rules). At the time of data collection in 2023, 13 municipalities had legalized some form of electric kick scooter use, 3 of them within metropolitan Vancouver: City of Vancouver, City of Richmond and City of Coquitlam.

---

[1] The limit has since been increased to 25 km/hr (after data collection in 2023).

2 METHODS

A schematic of the analysis methods is provided in Figure 1. We collected data on PMD use in the summer of 2023 to complement previously published data collected between August 2019 and April 2020 (8,29). The data consist of classified counts and speeds of PMD at 12 sampling locations in off-street cycling facilities and multi-use paths in metropolitan Vancouver, Canada. The same procedure (described below) was used to collect data in 2023 as previously used in 2019 and 2020. The PMD observations are enhanced with self-reported comfort data collected from 1,054 path users at the same locations in September and October 2020 (34).

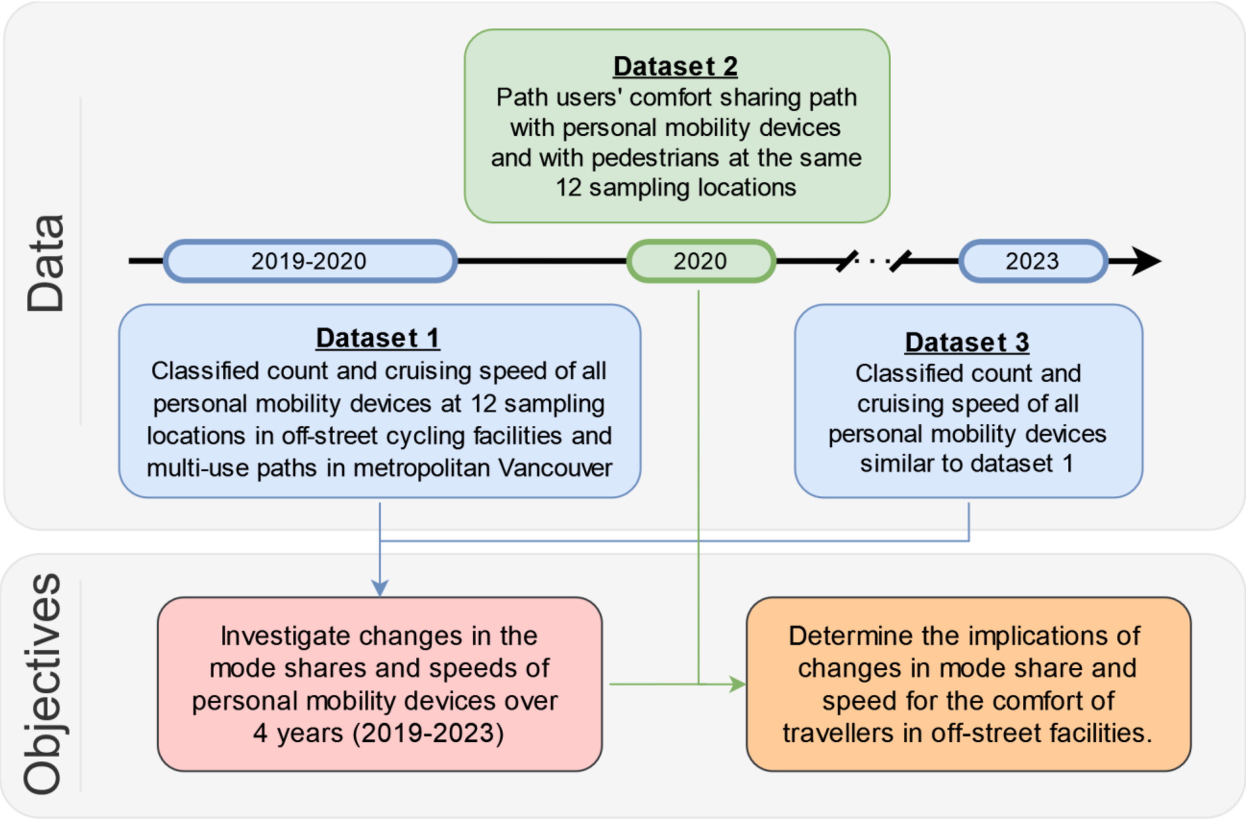


Figure 1. Illustration of study methods

2.1 Data collection

Classified count and speed data were collected using pneumatic tube counters (MetroCount RidePod BT5926) co-located with video cameras (GoPro Hero5 Black) followed by manual coding. Pneumatic tubes recorded crossing PMD time, direction, and speed. Synchronized video data were retrieved for each passing PMD and manually coded based on ten reliably observable attributes such as existence of electric assist and pedals (listed below). Our previous validation of this method indicated “almost perfect” to “perfect” agreement between researchers coding the ten attributes, and less than 2% error margin in speed measurements (8). The coding method was re-validated for this data collection (see Section 2.2)

Data were collected at 12 sampling locations across metropolitan Vancouver in off-street cycling facilities and multi-use paths. These locations were previously selected based on a series of criteria to reflect cruising speed conditions including being on a straight path more than 30 m from an intersection or access point and having less than 3% absolute grade (8). Figure 2 presents the sampling locations which span 7 municipalities: Vancouver, North Vancouver, West Vancouver, Burnaby, New Westminster, Richmond, and University Endowment Lands (UBC).

Data were collected from July 9 to July 30, 2023, between approximately 8 am and 6 pm to capture peak summer usage. Our previous study collected data over 4 seasons, but found no significant effect of season on PMD mode shares (although season did effect volumes) (8). This study was restricted to summer to maximize the number of observations per day, due to both higher hourly volumes and more daylight hours (the manual coding was previously found to only be reliable in daylight conditions). Each location was visited twice, once on a weekday and once on weekend, similar to data collection in 2019 and 2020.

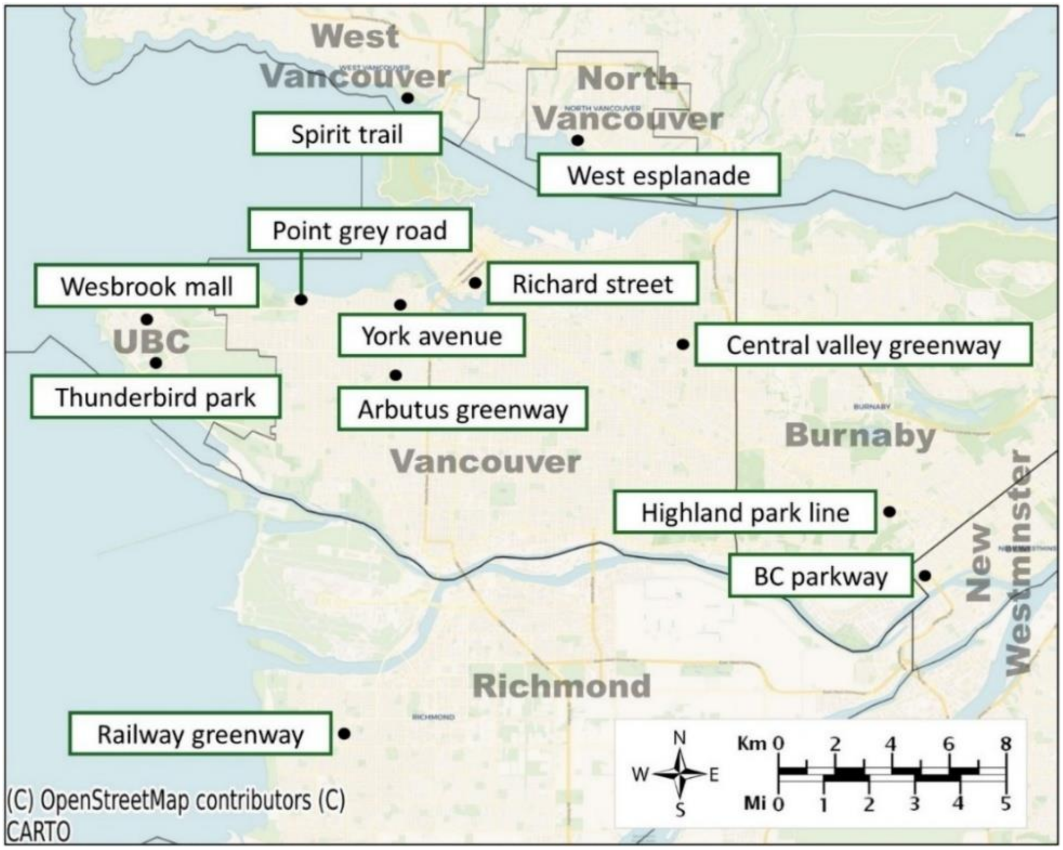


Figure 2. Map of sampling locations and municipalities

2.2 Data processing

Data processing followed the same procedure as the previous study (8,29). Raw data from pneumatic tubes were processed using the classification scheme "shared path +" in MetroCount Traffic Executive Software v5 to separate PMD observations from non-PMD observations such as pedestrians or noise. PMD observations were also manually verified from video data during the coding process. Before coding, researchers familiarized themselves with an album of various PMD types, previously created through internet search of the following keywords: "personal," "low-power," "electric," "motorized," "lightweight," "hybrid," "active," "mobility," "micromobility," "transportation," "transporter," "rideable," "cycle," and "vehicle" (8).

For each observed PMD, the following 10 attributes were extracted from the video data:

1. Does the PMD have a visible battery or motor (electric-assist)?
2. Does the PMD have pedals?
3. How many seats does the PMD have?
4. Does the PMD have handles?

5. Does the PMD have a seatback?
6. Is the PMD attached to the feet?
7. How many axles does the PMD have?
8. How many wheels does the PMD have?
9. Does the PMD have built-in cargo space?
10. Is the PMD a shared device?

In addition to the above questions for PMD classification, the number of human riders (any age) on the PMD was recorded. To ensure consistency in extracting the above attributes from video data, an interrater reliability test was conducted on two researchers' responses to the above 10 questions for 500 randomly selected PMD observations. The level of agreement in responses was measured using Cohen's Kappa (39).

The observed PMDs were classified using the ten attributes given above with the previously established PMD taxonomy (8). Any new PMD type (i.e., combination of attributes not previously observed) were added to the original taxonomy as a new taxon. Mode shares for each taxon (PMD type) were computed and hourly traffic patterns at each location and the global average were created for weekdays and weekends, and compared with publicly available usage data from MobiBikes (Vancouver's docked bikeshare operator) for July, 2023 (40).

Speed data was cleaned by identifying and flagging instances where travellers walked or jumped their PMD over the pneumatic tubes, multiple travellers crossed the tubes simultaneously, or travellers were visibly distracted by the data collection equipment (e.g., slowing down or stopping to inspect it). These flagged observations were then excluded from the speed analysis. A Welch's t-test was used to compare the mean speeds of each PMD type in the *before* (2019-2020) versus *after* (2023) datasets. The null hypothesis, which states that "there is no difference in mean speed over time," is rejected at 95% confidence. Average speed changes were also investigated at two higher-level PMD aggregations:

1) **Taxonomic categories:** 4 mid-level taxonomic categories presented by Hassanpour & Bigazzi (2023), which include non-motorized cycles, other non-motorized PMD, motorized cycles, and other motorized PMD.
2) **Comfort-speed clusters:** 4 data-derived PMD clusters based on speed and comfort presented by Hassanpour & Bigazzi (2024a), which include low speed and high comfort (cluster 1 – most non-motorized, non-cycle PMD such as skates and mobility devices), medium speed and comfort (cluster 2 – most non-motorized cycles), high speed and low comfort (cluster 3 – most motorized PMD), and extremely high speed and low comfort (cluster 4 – only sit-down electric scooters).

2.3 Speed modeling

A mixed-effects linear regression model was used to investigate the changing speeds of PMD while controlling for contextual factors, with random effects by location. The following fixed effect variables were included in the model. These variables were informed by previous speed modelling in Hassanpour and Bigazzi (29).

- **Study effect:** A binary *after* variable indicates that the observations are from the 2023 dataset (versus the 2019-2020 dataset).
- **PMD categories:** A 7-level categorical variable aggregating PMD types from the full taxonomy (informed by common classifications in policy and regulation) as: *cycles* (conventional bicycles, electric bicycles, cargocycles, tricycles, tandem bicycles, recumbent tricycles, recumbent bicycles, and elliptical bicycles), *shared bicycles* (conventional shared bicycles and electric shared bicycles), *scooters* (conventional push/kick scooters and stand-up electric scooters), *skateboards* (conventional skateboards and electric skateboards), *self-balancing unicycle* (one PMD type), *sit-down electric scooter or motorcycle* (one PMD type), and *other PMD* (roller/inline skates, mobility scooters, conventional wheelchairs, electric wheelchairs, balance bicycles, and self-balancing scooters). Motor vehicles and golf carts were not included in the speed model.

- **PMD attributes:** A binary variable indicating PMD with *electric-assist*, and a continuous (integer) variable for the *number of riders* (any age).
- **Facility:** A binary variable indicating a *multi-use path* shared with pedestrians (versus cycling-exclusive facilities with a parallel facility for pedestrians), and a continuous variable for *path grade* (in %) in the direction of travel.
- **Operational controls:** Integer variables for *hourly PMD volume* on the path (excluding pedestrians) and *immediate ongoing* and *oncoming PMD volumes* measured in the 5 seconds before a PMD was observed, and a binary variable for *salmoning* that indicates when a PMD was traveling against the designated direction of traffic on a one-way facility.
- **Context controls:** Two continuous variables representing average hourly *temperature* (degrees Celsius, C) and daily *rain* (millimeters, mm and centimeters, cm) (42).
- **Temporal controls:** Three binary variables for *peak hour* (7-9 am or 4-6 pm on weekdays or 12-2 pm on weekends), *weekend* day (versus weekday), and *COVID lockdown* period (beginning March 18, 2020, when the government of British Columbia declared a provincial state of emergency until June 30th, 2021, when the state of emergency was lifted).

The *after* variable was interacted with *PMD type* and *electric-assist* to investigate longitudinal speed changes by PMD category. Random effects for the location variable, representing the 12 sampling locations, were also included in the model to account for error correlation by location. Analyses were conducted on a desktop computer using R Statistical software (version 4.1.1; R Core Team, 2021) on Windows 10 x64 (build 19042), with the packages 'glmmTMB' version 1.1.7 (43) and 'corrplot' version 0.90 (44), and using Python version 3.7 with the packages 'Pandas', 'Numpy', 'Matplotlib', 'statsmodels' (45–48).

2.4 Comfort estimation

Our previous study on path user comfort with PMD at these locations found significant comfort differences by PMD category and that for every 1 km/hr increase in mean PMD speed, path user comfort decreases by 0.17 units on the scale of -10 (very uncomfortable) to +10 (very comfortable) (34). We employ this model to estimate changes in path user comfort due to the observed changes in PMD mode shares and speeds. As shown in Eq. 1, the projected comfort effect of each PMD type i in the *after* period $\left(C_{i,a}\right)$ is the baseline comfort level from the *before* study $\left(C_{i,b}\right)$ minus the modelled effect of observed speed changes for that PMD type in km/hr (ΔS_i).

$$C_{i,a} = C_{i,b} - 0.17 \times \Delta S_i \qquad \text{(Eq. 1)}$$

An illustrative measure of overall path user comfort in time period t is calculated as the weighted average of comfort by mode share for PMD type i, $MS_{i,t}$, as described in Eq. 2. Comfort ratings were unavailable for shared bicycles, cargocycles, and elliptical bicycles; therefore, their impact on comfort was not included.

$$\overline{C_t} = \sum_i \left(C_{i,t} MS_{i,t}\right) / \sum_i \left(MS_{i,t}\right) \qquad \text{(Eq. 2)}$$

3 RESULTS

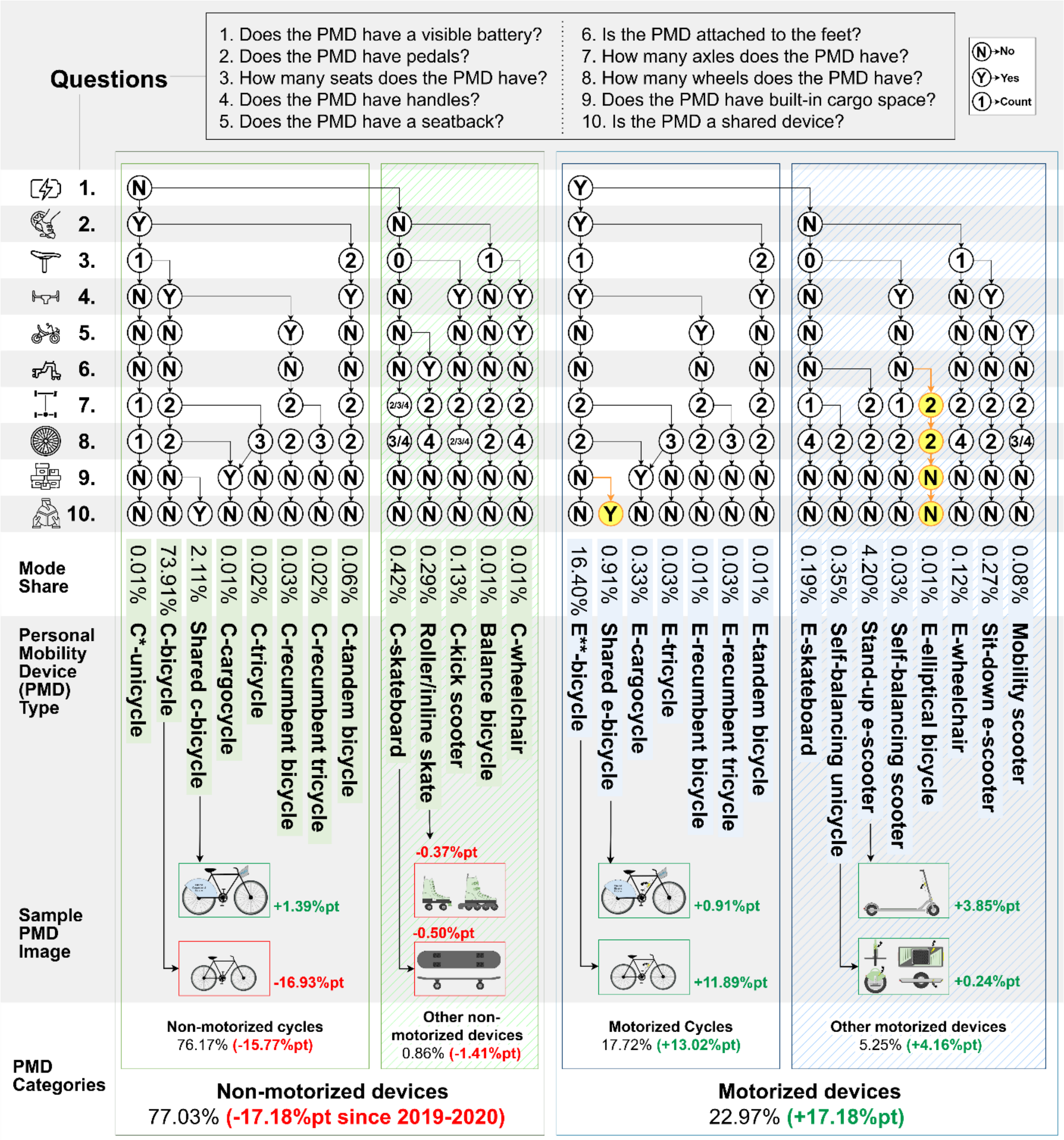
3.1 Observed PMD mode shares

The dataset collected in 2023 consists of 233 hours of video data and 19,903 hits registered on the pneumatic tubes. After data cleaning, 17,939 PMD observations were coded and categorized into the taxonomy of 29 PMD types, including 2 new taxons (PMD types) that were not observed in the 2019-2020 dataset. The interrater reliability test resulted in excellent agreement for the questions *"does the PMD have a visible battery or motor (electric-assist)?"* and *"how many human riders are on the PMD?"* with Cohen's Kappa of 0.92 and 0.91, respectively. All other questions were coded with perfect agreement among the evaluators (Cohen's Kappa = 1.00). These results are consistent with the high coding reliability of the *before* data (8).

The taxonomy and mode shares of PMD are presented in Figure 3, as well as mode share changes since 2019-2020 for select PMD categories. All previously observed PMD types (in 2019-2020) were observed again in 2023 except for motor vehicles and golf carts (not included in the taxonomy). Two new taxons of electric shared bicycle and electric elliptical bicycle were observed (highlighted in yellow in the figure). Electric shared bicycles were from Mobi bikeshare in the City of Vancouver and Lime bikeshare in North Vancouver, West Vancouver, and Richmond. A single electric elliptical bicycle was observed: a two-wheeled device that combines the stand-up pedalling motion of an elliptical trainer with electric-assist cycling.

Table 1 presents detailed count and mode share data of PMD observed in each dataset. Table 1 shows that the 4 most prevalent PMD in 2023 (with mode share >1%) experienced the greatest mode share changes since 2019-2020. The mode share of conventional bicycles dropped dramatically from 90.8% to 73.9% (-16.9 percentage points or %pt). The next three most prevalent PMD were electric bicycles, stand-up electric scooters (electric push/kick scooters), and shared conventional bicycles with mode shares of 16.4%, 4.2%, and 2.1%, respectively. These devices experienced mode share increases of 11.9%pt, 3.9%pt, and 1.4%pt, respectively, since 2019-2020. While the rest of the PMD have shown less than a 1%pt change in mode share, there is a general shift toward the motorized PMD. Overall, there has been a 17.2%pt shift from non-motorized to motorized PMD, dominated by a shift from non-motorized to motorized cycles (Figure 3). Mode share for motorized cycles has increase by a factor of 4, while mode share for other motorized PMD has increased by a factor of 5.

Table 1 also reports the Inter-Quartile Range (IQR) of mode shares, a measure of variability in mode shares across the 12 sampling locations. For the four PMDs with the highest mode share (conventional bicycles, electric bicycles, stand-up electric scooters, and shared conventional bicycles) the IQR increased from 2019-2020 to 2023. This increase in IQR indicates greater heterogeneity in mode share across study locations, and a non-uniform shift from conventional cycling to new PMD. Information about the observed PMD by location is given in Appendix C: Spatial pattern of PMD use, and information about the temporal distribution of observed PMD is given in Appendix D: Temporal pattern of PMD use and hourly volume model.



1. Does the PMD have a visible battery?
2. Does the PMD have pedals?
3. How many seats does the PMD have?
4. Does the PMD have handles?
5. Does the PMD have a seatback?
6. Is the PMD attached to the feet?
7. How many axles does the PMD have?
8. How many wheels does the PMD have?
9. Does the PMD have built-in cargo space?
10. Is the PMD a shared device?

* Conventional ** Electric

Figure 3. Taxonomy and mode shares of PMD in 2023. Attributes for new taxons (PMD types) are highlighted in yellow. Percentage point (%pt) changes in mode share since 2019–2020 are indicated in red (decrease) or green (increase) for aggregate PMD categories and the two taxons with the highest mode share in each PMD category.

Table 1. Classified count and mode share of each PMD type

	2019-2020		2023		
Personal mobility device name	Count	Mode share % (IQR by location)	Count	Mode share % (IQR[1] by location)	Mode share change %pt[2]
Conventional bicycle	16306	90.84 (6.10)	13259	73.91 (11.46)	-16.93
Electric bicycle	810	4.51 (4.22)	2942	16.40 (5.64)	+11.89
Stand-up electric scooter	63	0.35 (0.30)	753	4.20 (4.75)	+3.85
Shared conventional bicycle	130	0.72 (1.44)	378	2.11 (2.54)	+1.39
Shared electric bicycle	0	0.00 (0.00)	163	0.91 (0.84)	+0.91
Conventional skateboard	166	0.92 (0.78)	76	0.42 (0.31)	–0.50
Self-balancing unicycle	19	0.11 (0.30)	63	0.35 (0.38)	+0.24
Electric cargocycle	22	0.12 (0.15)	59	0.33 (0.36)	+0.21
Roller/inline skate	119	0.66 (0.42)	52	0.29 (0.42)	–0.37
Sit-down electric scooter (or motorcycle)	53	0.30 (0.56)	49	0.27 (0.36)	–0.03
Electric skateboard	11	0.06 (0.17)	34	0.19 (0.24)	+0.13
Conventional kick scooter	95	0.53 (1.20)	24	0.13 (0.26)	–0.40
Electric wheelchair	2	0.01 (0.00)	22	0.12 (0.10)	+0.11
Mobility scooter	35	0.19 (0.38)	14	0.08 (0.10)	–0.11
Conventional tandem bicycle	14	0.08 (0.09)	11	0.06 (0.07)	–0.02
Conventional recumbent bicycle	21	0.12 (0.16)	6	0.03 (0.04)	–0.09
Electric tricycle	7	0.04 (0.04)	6	0.03 (0.01)	–0.01
Self-balancing scooter	2	0.01 (0.00)	6	0.03 (0.00)	+0.02
Electric recumbent tricycle	1	0.01 (0.00)	6	0.03 (0.05)	+0.02
Conventional tricycle	19	0.11 (0.29)	4	0.02 (0.00)	–0.09
Conventional recumbent tricycle	3	0.02 (0.01)	4	0.02 (0.01)	0.00
Balance bicycle	14	0.08 (0.29)	2	0.01 (0.00)	–0.07
Conventional wheelchair	15	0.08 (0.17)	1	0.01 (0.00)	–0.07
Conventional cargocycle	5	0.03 (0.01)	1	0.01 (0.00)	–0.02
Conventional unicycle	4	0.02 (0.00)	1	0.01 (0.00)	–0.01
Electric recumbent bicycle	2	0.01 (0.00)	1	0.01 (0.00)	0.00
Electric tandem bicycle	1	0.01 (0.00)	1	0.01 (0.00)	0.00
Electric elliptical bicycle	0	0.00 (0.00)	1	0.01 (0.00)	+0.01
Motor vehicle or golf cart	11	0.06 (0.19)	0	0.00 (0.00)	–0.06
Total	17950		17939		

[1] Inter-quartile range

[2] Percentage point

3.2 Observed PMD speeds

Table 2 presents the speed characteristics of PMDs observed three or more times in both the 2019-2020 and 2023 datasets. After data cleaning, 519 observations (2.9%) in the after dataset were removed. PMDs are listed in descending order of their combined mean speed, and those with significant ($p < 0.05$) speed changes over time are formatted in bold. Results show that the overall speed of multi-use paths and off-street cycling facilities has experienced a significant speed increase of 2.2 km/hr over 4 years (an increase of 11.5%). Among conventional devices, roller/inline skates, skateboards, and bicycles experienced significant speed increases of 2.4 km/hr, 1.9 km/hr, and 1.8 km/hr, respectively. Electric PMDs exhibited the greatest speed increases, with self-balancing unicycle and electric tricycle mean speeds increasing by 11.6 km/hr and 8.7 km/hr, respectively. Stand-up electric scooters (electric push/kick scooters) and electric

bicycles also showed statistically significant speed increases of 2.8 km/hr and 0.5 km/hr, respectively. Shared conventional bicycles did not show a significant change in speed, with mean speeds of 17.4 km/hr and 17.2 km/hr in the *before* and *after* dataset, respectively. The mean (standard deviation) speeds for shared electric bicycles and electric wheelchairs (not included in Table 2 due to insufficient observations in the *before* period) were 19.96 (4.21) km/hr and 11.96 (7.50) km/hr, respectively.

Figure 4 illustrates the change from 2019-2020 to 2023 in speed distributions of conventional and electric cycles (bicycles, cargocycles, tricycles, tandem bicycles, recumbent tricycles, recumbent bicycles, and elliptical bicycles combined), conventional and electric shared bicycles, conventional and electric stand-up scooters, conventional and electric skateboards, self-balancing unicycle, and sit-down electric scooter. The percentages at the top of each column report the share of PMD that exceed the motor-assist limit of 32 km/hr for motorized cycles (electric cycles) in the British Columbia Motor Vehicle Act (MVA) (49). An upward trend in speeds can be seen in the figure, most notably for self-balancing unicycles. Self-balancing unicycles are the fastest PMD in 2023, with an 85th percentile speed of 41 km/hr and nearly half of them exceeding 32 km/hr.

Table 3 provides more detailed information regarding 85th percentile speeds and percent of PMD exceeding the MVA motor-assist thresholds of 32 km/hr for motorized cycles and 24 km/hr for stand-up electric scooters. The overall 85th percentile speed in off-street cycling facilities and multi-use paths has increased from 25.9 km/hr in 2019-2020 to 27.9 km/hr in 2023. Overall, 33% of traffic on off-street cycling facilities and multi-use paths travel at speeds above 24 km/hr, and 5% above 32 km/hr—up from 23% and 2%, respectively, in 2019–2020. Percent of PMD exceeding the Province's updated motor-assist limit of 25 km/hr for stand-up electric scooters is given in Appendix E: PMD speed statistics.

Table 2. Speed by PMD type (with at least 3 observations in both 2019-2020 and 2023 datasets)

	Mean (standard deviation) speed (km/hr)					
Personal mobility device name	All data combined	Before (2019-2020)	After (2023)	Number of observations (Before/After)	Speed change (km/hr)	p-value
Self-balancing unicycle	**29.12 (10.83)**	**20.28 (7.48)**	**31.88 (10.26)**	**19/61**	**11.6**	**<0.01**
Sit-down electric scooter	27.75 (7.85)	27.72 (8.90)	27.78 (6.59)	53/48	0.06	0.97
Electric skateboard	25.82 (8.13)	22.37 (10.04)	26.97 (7.20)	11/33	4.60	0.18
Stand-up electric scooter	**24.93 (6.66)**	**22.36 (7.25)**	**25.14 (6.57)**	**62/753**	**2.78**	**<0.01**
Electric bicycle	**22.77 (6.29)**	**22.35 (6.94)**	**22.89 (6.09)**	**800/2,881**	**0.54**	**0.05**
Electric cargocycle	20.53 (5.84)	21.68 (6.96)	20.09 (5.35)	22/58	-1.59	0.34
Conventional bicycle	**20.06 (6.19)**	**19.26 (6.12)**	**21.07 (6.13)**	**16,170/12,864**	**1.81**	**<0.01**
Electric tricycle	**19.71 (6.27)**	**15.71 (5.91)**	**24.37 (2.01)**	**7/6**	**8.66**	**<0.01**
Conventional recumbent bicycle	18.62 (5.37)	18.54 (5.41)	18.92 (5.75)	21/6	0.38	0.89
Conventional tandem bicycle	18.43 (6.57)	16.86 (7.29)	20.44 (5.16)	14/11	3.58	0.16
Shared conventional bicycle	17.24 (4.94)	17.44 (4.62)	17.17 (5.05)	128/361	-0.27	0.58
Conventional recumbent tricycle	16.28 (6.37)	13.14 (6.53)	18.63 (5.97)	3/4	5.49	0.31
Roller/inline skate	**13.96 (5.77)**	**13.32 (5.36)**	**15.67 (6.49)**	**112/42**	**2.35**	**0.04**
Conventional skateboard	**13.03 (4.75)**	**12.45 (4.67)**	**14.32 (4.71)**	**157/71**	**1.87**	**<0.01**
Conventional tricycle	12.32 (3.90)	11.86 (4.18)	14.28 (1.33)	17/4	2.42	0.06
Mobility scooter	10.46 (4.49)	10.29 (4.66)	10.90 (4.15)	35/14	0.61	0.66
Conventional kick scooter	9.87 (4.05)	9.75 (3.88)	10.34 (4.73)	86/22	0.59	0.59
All PMD	**20.32 (6.42)**	**19.23 (6.32)**	**21.44 (6.33)**	**17,773/17,420**	**2.21**	**<0.01**

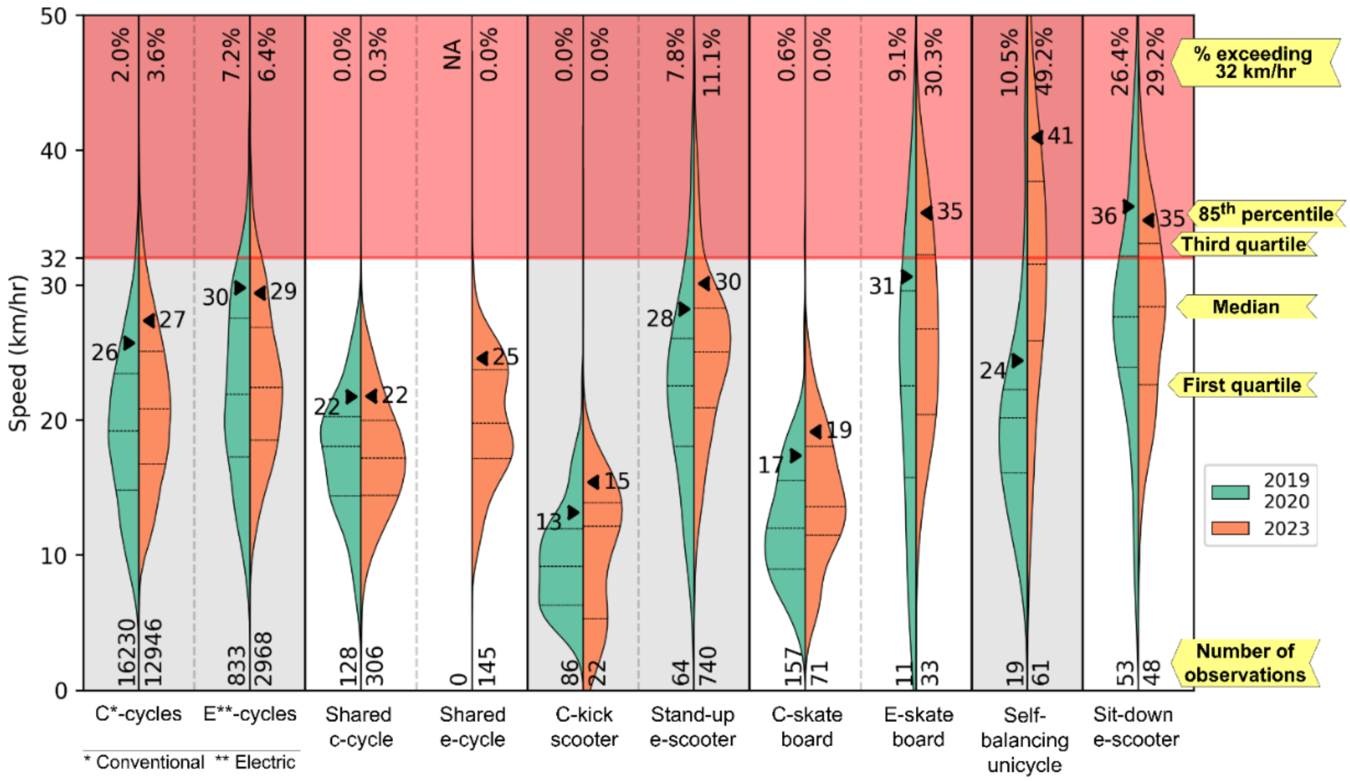


Figure 4. PMD speed distributions for 2019-2020 and 2023; 32 km/hr is the motor-assist limit for motorized cycles (e-cycles) in the British Columbia Motor Vehicle Act.

Table 3. 85th percentile speed and percent exceeding MVA motor-assist thresholds by PMD type (for types with at least 3 observations in both 2019-2020 and 2023 datasets).

	2019-2020 (before)			2023 (after)		
	85th percentile	Percent exceeding		85th percentile	Percent exceeding	
Personal mobility device name	speed (km/hr)	24 km/hr	32 km/hr	speed (km/hr)	24 km/hr	32 km/hr
Self-balancing unicycle	24.4	15.8	10.5	41.0	83.6	49.2
Sit-down electric scooter	35.8	73.6	26.4	34.8	68.8	29.2
Electric skateboard	30.6	45.5	9.1	35.4	63.6	30.3
Stand-up electric scooter	28.3	38.7	8.1	30.2	58.2	11.2
Electric bicycle	29.9	40.0	7.5	29.5	40.6	6.6
Electric cargocycle	28.8	45.5	0.0	26.2	25.9	0.0
Conventional bicycle	25.7	22.3	2.0	27.4	31.0	3.7
Electric tricycle	21.5	14.3	0.0	26.1	83.3	0.0
Conventional recumbent bicycle	24.8	23.8	0.0	23.9	16.7	0.0
Conventional tandem bicycle	25.5	21.4	0.0	26.2	27.3	0.0
Shared conventional bicycle	21.7	8.6	0.0	21.5	6.1	0.3
Conventional recumbent tricycle	17.3	0.0	0.0	22.7	25.0	0.0
Roller/inline skate	18.9	2.7	0.9	21.1	4.8	0.0
Conventional skateboard	17.4	1.9	0.6	19.2	1.4	0.0
Conventional tricycle	16.6	0.0	0.0	15.2	0.0	0.0
Mobility scooter	13.5	2.9	0.0	14.8	0.0	0.0
Conventional kick scooter	13.2	0.0	0.0	15.4	0.0	0.0
All PMD	25.9	22.7	2.3	27.9	33.1	4.6

The 24 and 32 km/hr speed thresholds are used as illustrative reference levels. These regulatory limits only apply to stand-up e-scooters and e-cycles, respectively. The thresholds are motor-assist (not operating) speed limits, meaning travellers are allowed to go faster from human and gravitational energy inputs. However, given the low grades at the study locations, it is unlikely riders would exceed these thresholds without motorized assistance. The highest-speed PMD (self-balancing unicycle, sit-down electric scooter, electric skateboard) are illegal to operate on public facilities in BC according to the MVA, and so the motor-assist limits are irrelevant.

As described in Section 1.2, stand-up electric scooters became legal to operate on cycling facilities in the City of Vancouver and City of Richmond between the *before* and *after* data collection periods under the Province's electric kick scooter pilot program. Half of the 12 study locations are in these two municipalities (Figure 2). Figure 5 shows the mode shares and speeds of stand-up electric scooters in 2019–2020 and 2023 separately for municipalities participating vs. not participating in the pilot program (i.e., where they were legal vs. illegal to operate). Mode share increased by +3.9%pt in participating municipalities and +3.6%pt in non-participating municipalities, indicating consistent growth across metropolitan Vancouver regardless of municipal legal status. Average scooter speeds increased by +2.4 km/hr and +5.7 km/hr in participating and non-participating municipalities, respectively, with speeds converging at or above the pilot program's 24 km/hr motor-assist limit.

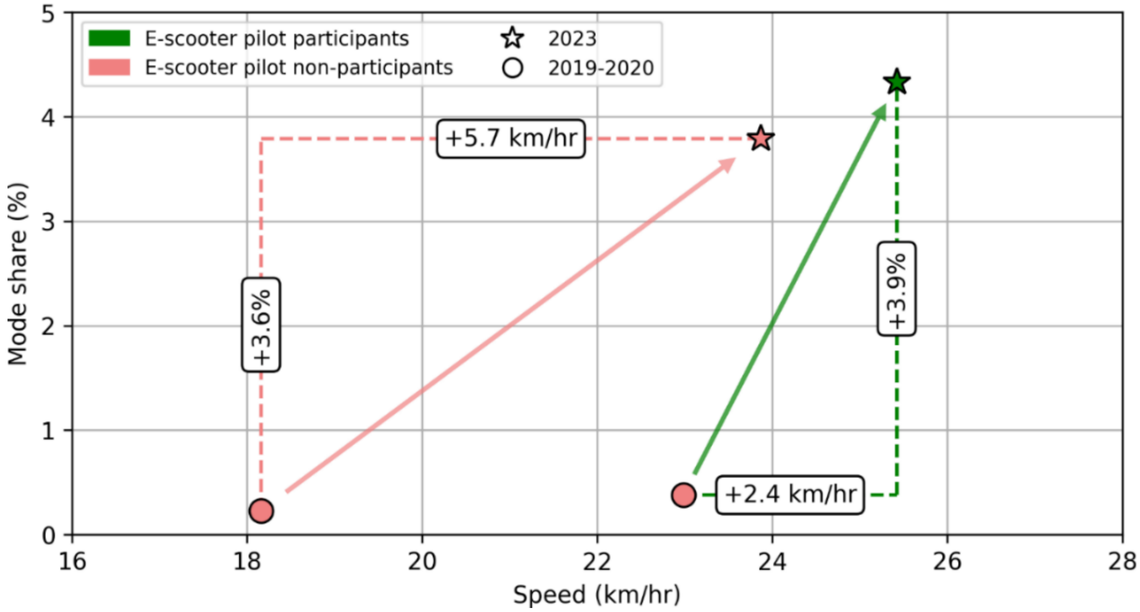


Figure 5. Mode share and speed of stand-up electric scooters in municipalities participating versus not participating in BC's electric kick scooter pilot program, which legalized their use between data collection periods.

Table 4 presents speed results at two higher levels of PMD aggregation of taxonomic categories and comfort-speed clusters. The results in Table 4 demonstrate an upward trend in speeds across all PMD groups, including motorized and non-motorized. The six significant speed increases range from 1.3 km/hr to 4.3 km/hr and are accompanied by increases in the 85th percentile speeds as well.

Table 4. *Speed results for aggregate PMD categories*

		Speed[1] (km/hr)		Speed change (km/hr)	p-value	Number of observations (Before/After)	85th percentile speed (km/hr)	
Categorization types	Categories	Before (2019-2020)	After (2023)				Before	After
Taxonomic categories in Figure 3	**Non-motorized cycles**	**19.23 (6.12)**	**20.96 (6.14)**	**1.73**	**<0.1**	**16,362/13,252**	**25.68**	**27.24**
	Other non-motorized PMD	**11.63 (5.02)**	**14.03 (5.54)**	**2.40**	**<0.1**	**383/138**	**16.83**	**19.54**
	Motorized cycles	22.28 (6.95)	22.70 (6.04)	0.42	0.11	833/3,113	29.82	29.24
	Other motorized PMD	**20.98 (9.62)**	**25.24 (7.60)**	**4.26**	**<0.1**	**195/917**	**30.32**	**31.70**
Comfort-speed clusters in Hassanpour & Bigazzi (2024a)	**Low speed and high comfort**	**11.59 (5.00)**	**13.70 (5.83)**	**2.11**	**<0.1**	**411/171**	**16.76**	**19.54**
	Medium speed and comfort	**19.25 (6.12)**	**21.07 (6.13)**	**1.82**	**<0.1**	**16,222/12,885**	**25.71**	**27.37**
	High speed and low comfort	**22.21 (7.04)**	**23.51 (6.45)**	**1.30**	**<0.1**	**908/3,733**	**29.82**	**29.92**
	Extremely high speed and low comfort	27.72 (8.90)	27.78 (6.59)	0.06	0.97	53/48	35.83	34.79

[1] Mean (standard deviation)

The results in this section are based on observed speeds, without accounting for confounding factors that may influence speed, such as environmental, temporal, and path-related variables. The speed regression model presented in the next section examines speed changes controlling for these other factors.

Table 5 presents the estimated mixed effects linear regression model of PMD speed (excluding motor vehicles and golf carts). Results show that each 1% increase in *grade* was associated with 1.2 km/hr and 0.7 km/hr speed reductions for conventional and electric devices, respectively. Each additional *rider* on a PMD reduced speed by 2.2 km/hr. PMD speeds in *multi-use paths* (shared with pedestrians) were 2.4 km/hr slower than in cycling facilities separated from pedestrians (not significant, with $p = 0.11$). Riding on the *weekend* and during the *COVID 19 Lockdown* were associated with 0.5 km/hr and 1.6 km/hr slower speeds respectively. Weather factors, including *temperature* and *rain*, did not show a significant relationship with PMD speed. Higher *hourly traffic volume* was associated with a slight speed increase (an increase of 0.8 km/hr when *hourly traffic volume* rose from the 1st to the 3rd quartile – from 12 to 90 PMD/hr). Regarding *immediate (5 seconds preceding) traffic volume*, every additional PMD in the same direction reduced speed by 0.7 km/hr, while those in the opposite direction caused a reduction of 0.2 km/hr (not significant, with p=0.09). *Salmoning* (riding against the flow of traffic in one-way cycling facilities) was associated with a 4.4 km/hr speed decrease.

Significant effects are highlighted with bold formatting and asterisks in the figure. Changes in speed for conventional cycles (+0.8 km/hr, $p < 0.01$) was significant and for electric cycles (-0.4 km/hr, $p = 0.07$) not significant after controlling for other factors in the model, despite the raw speed differences reported in Table 4. In contrast, the speeds of electric skateboards and self-balancing unicycles increased dramatically by +4.2 km/hr ($p = 0.02$) and +9.5 km/hr ($p < 0.01$), respectively, after controlling for other factors. Other PMD categories show small to moderate but not statistically significant speed differences over time of no more than ±1.3 km/hr.

Table 5. Mixed effects regression model of PMD speed with location random effects

Variable	Descriptive statistic[2]	Coefficient	Standard error	P-value
Speed	23.32 (6.42)	NA	NA	NA
Intercept	NA[3]	23.337	1.237	<0.01
Electric-assist (binary)	14.34%	3.049	0.185	<0.01
After (binary)	49.51%	0.777	0.105	<0.01
Grade %	-0.02 (0.35)	-1.189	0.024	<0.01
Electric-assist X After	11.45%	-1.132	0.213	<0.01
Electric-assist X Grade	-1.85 (1.30)	0.478	0.066	<0.01
Number of riders	1.02 (0.14)	-2.201	0.206	<0.01
Multi-use path (binary)	69.15%	-2.348	1.483	0.11
Weekend (binary)	51.27%	-0.521	0.061	<0.01
COVID 19 lockdown (binary)	25.75%	-1.566	0.092	<0.01
Temperature (Celsius)	17.72 (5.58)	0.011	0.009	0.21
Rain (cm)	0.04 (0.14)	-0.088	0.023	0.70
Hourly traffic volume X10	13.69 (8.88)	0.067	0.000	<0.01
Immediate ongoing traffic volume (5 sec)	0.41 (0.74)	-0.700	0.039	<0.01
Immediate oncoming traffic volume (5 sec)	0.08 (0.32)	-0.181	0.089	0.04
Salmoning (binary)	0.19%	-4.394	0.664	<0.01
Shared bicycle[1]	1.65%	-2.804	0.471	<0.01
Shared bicycle X After	1.28%	-0.754	0.534	0.16
Scooter[1]	2.59%	-9.311	0.573	<0.01
Scooter X Electric-assist	2.29%	9.719	0.893	<0.01
Scooter X After	2.17%	-0.306	1.265	0.81
Scooter X Electric-assist X After	2.10%	2.004	1.454	0.17
Skateboard[1]	0.77%	-6.769	0.424	<0.01
Skateboard X Electric-assist	0.13%	5.170	1.658	<0.01
Skateboard X After	0.30%	0.376	0.758	0.62
Skateboard X Electric-assist X After	0.09%	4.226	1.999	0.03
Self-balancing unicycle[1]	0.23%	-1.547	1.225	0.21
Self-balancing unicycle X After	0.17%	9.853	1.402	<0.01
Sit-down scooter[1]	0.29%	5.445	0.748	<0.01
Sit-down scooter X After	0.14%	-0.611	1.072	0.57
Other PMD[1]	0.76%	-7.541	0.396	<0.01
Other PMD X After	0.24%	-0.934	0.697	0.18

Number of observations = 35,182
Number of location groups (random effects) = 12
Standard deviation of location effects: 5.85
Conditional R2: 0.40; Marginal R2: 0.27

[1] Categorical variable with *cycles* as reference level

[2] Mean (standard deviation) for continuous variables, and % for binary variables

[3] NA: Not Applicable

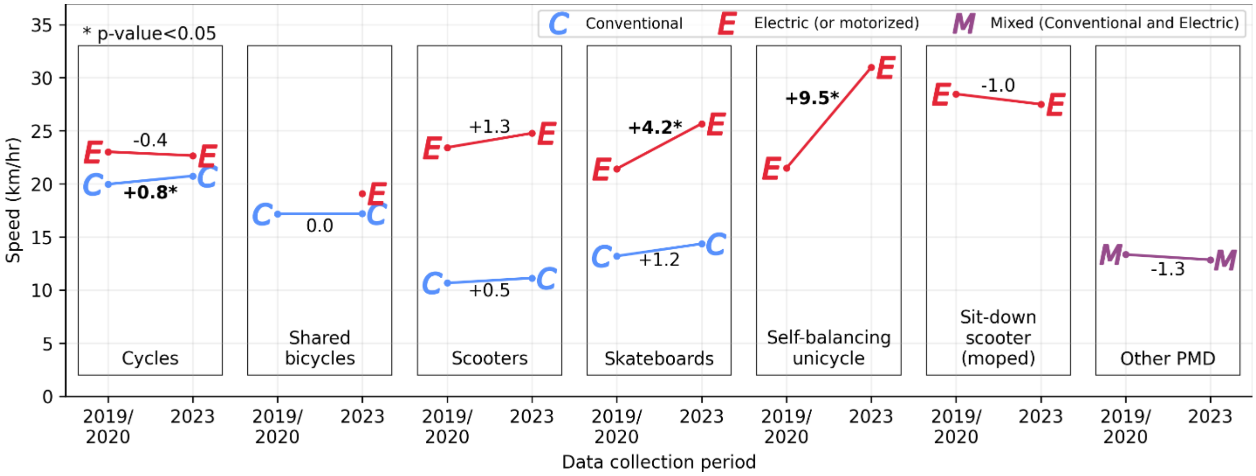


Figure 6. Illustration of the modelled trend and electric-assist effects on speed by PMD type, after controlling for weather, path volume, and other contextual factors.

3.3 Effects of PMD on comfort

Figure 7 shows the previously reported PMD average speed versus average path user comfort sharing with that PMD, for each of the 23 PMD types and pedestrians included in the path user comfort survey,[2] grouped into 4 speed- and comfort-aligned clusters (41). The figure is enhanced to show the estimated changes in comfort based on speed for the 7 PMD types with significant differences in observed speed[3] between 2019-2020 and 2023 (Table 2). The arrows point from their baseline value recorded in 2019-2020 to their estimated value based on 2023 speeds. The PMD with significant speed increases include conventional skateboards and roller/inline skates from cluster 1, conventional bicycles from cluster 2, and electric bicycles, stand-up electric scooters, electric tricycles and self-balancing unicycles from cluster 3. At their significantly higher 2023 speeds, electric tricycles and self-balancing unicycles are projected to join sit-down electric scooters as the only 3 PMD that are uncomfortable for the average path user. If we also include non-significant speed changes, electric skateboards are also now expected to be uncomfortable for the average path user. Full comfort results are provided in Appendix F: Estimated path user comfort based on speed changes from 2019-2020 to 2023. In 2019-2020, average path user comfort weighted by mode shares of PMD was 4.4 on the scale of -10 (very uncomfortable) to 10 (very comfortable). With the new projected comfort levels and the new mode share data for 2023, average path user comfort is reduced to 3.6. Isolating the comfort ratings of pedestrians, the volume-weighted average pedestrian comfort level decreased from 2.6 in 2019-2020 to 1.8 in 2023. Despite the increased share of less-comfortable, motorized PMD, and the higher speeds of those PMD, most PMD in off-street paths are still conventional bicycles, with which most users (including pedestrians) are generally comfortable sharing.

---

[2] Shared bicycles, cargo cycles, and elliptical bicycles are excluded because of a lack of comfort data; their combined mode share was 3.4% in 2023 and 1.0% 2019–2020.

[3] We estimate comfort from observed speed difference (Table 2), rather than modelled speed difference (Figure 6), because it provides more disaggregate information.

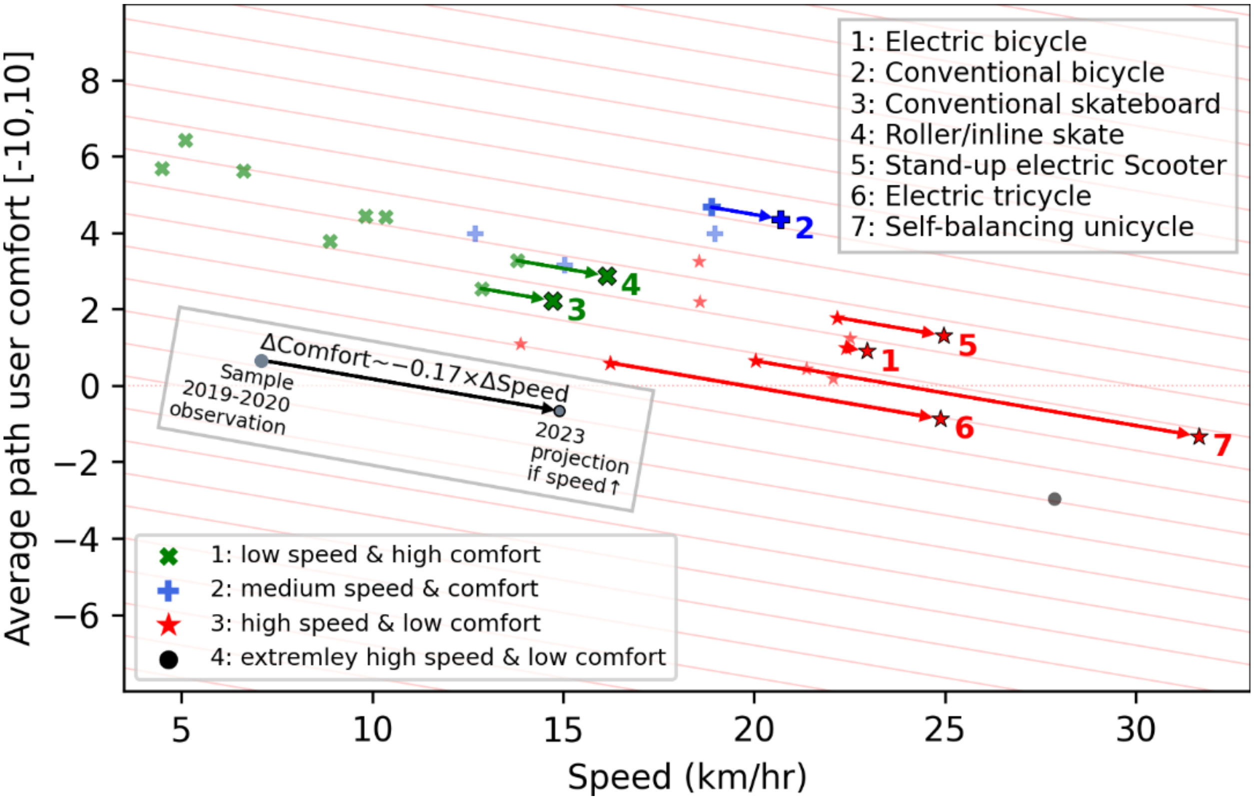


Figure 7. PMD average speed versus average path user comfort sharing with that PMD, with estimated changes in comfort for the seven PMD types with significant changes in observed speed over time.

4 DISCUSSION

4.1 Findings

The mode share of motorized PMD has quadrupled in 4 years. Figure 8 illustrates the mode shift for key PMD groups from 2019-2020 to 2023. In 2023, the mode share of motorized PMD (electric micromobility) had quadrupled since 2019-2020. This growth is primarily driven by increased usage of previously observed PMDs, particularly electric bicycles (in red) and stand-up electric scooters (in orange), as well as the introduction of new PMD such as electric shared bicycles (in green).

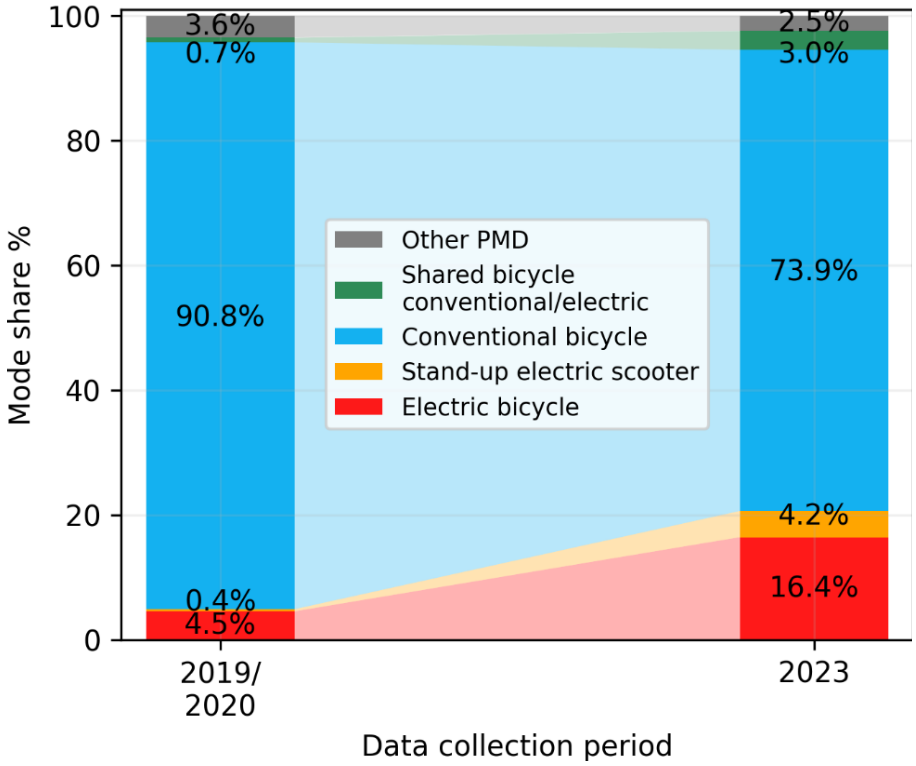


Figure 8. Aggregate mode shares of personal mobility devices in 2019-2020 and 2023.

Bikeshare represents a small but an increasing portion of PMD use – especially motorized PMD. The ratio of shared to private PMD in use has increased dramatically, reflecting increasing availability and popularity of shared micromobility in the region. In 2019-2020, for every 100 personal conventional bicycles observed, 0.8 shared bicycles were observed. By 2023, that number became 2.8 – a factor of 4 increase (see Appendix B: Shared personal mobility devices). No shared electric bicycles existed in metropolitan Vancouver in 2019-2020, but in 2023 the ratio was 5.5 shared electric bicycles observed for each 100 private electric bicycles, indicating faster uptake of electric PMD in shared versus private use.

The average speed in off-street facilities increased by 11% or 2 km/hr. This change was driven by the increasing share of motorized PMD (which are faster than non-motorized PMD), and an increase in the speed of the remaining non-motorized PMD (particularly the dominant conventional bicycles). Increasing speed of non-motorized PMD could be due to speed adaptation on cycling paths, with people on non-motorized PMD going faster in response to an increasing share of motorized PMD which operate at higher speeds.

Conventional and electric bicycle speeds are more similar now. After controlling for contextual factors, the speed difference between electric and conventional bicycles fell by 1.1 km/hr (from 3.1 to 1.9 km/hr).

This homogenization of bicycle speeds could be partially due to slower riders on conventional bicycles disproportionately switching to electric bicycles (compared to faster riders), which would simultaneously increase the mean speed of the remaining riders on conventional bicycles and reduce the mean speed of electric bicycle riders.

Speeds increased dramatically for some less common motorized PMD. Several motorized PMD had substantial speed increases to become among the fastest observed PMD, including self-balancing unicycles (+12 km/hr), electric tricycles (+9 km/hr), electric skateboards (+5 km/hr), and stand-up electric scooters (+3 km/hr). Self-balancing unicycles are now the fastest PMD in use (averaging 32 km/hr), both faster and more prevalent than sit-down electric (moped-style) scooters (averaging 28 km/hr), which were the previous PMD of primary concern in off-street paths. Electric skateboards (averaging 27 km/hr) are also now almost as fast and prevalent as sit-down electric scooters, while stand-up electric scooters (averaging 25 km/hr) are only slightly slower and 16 times more prevalent. Electric tricycles are also relatively fast (averaging 24 km/hr), but very rare (just 6 observations).

These mode share and speed changes will degrade path user comfort, although the average path user is expected to still be moderately comfortable with most other path users. Due to speed increases, self-balancing unicycles, electric tricycles, and electric skateboards are now expected to be uncomfortable for the average path user, which was only previously the case for sit-down electric (moped-style) scooters. Speed increases and the shift toward motorized PMD have led to a small but notable decline in volume-weighted average comfort for users of off-street cycling facilities and multi-use paths. However, conventional bicycles are still the dominant PMD type with a 74% mode share, and most other path users (including pedestrians) are moderately comfortable sharing with them.

4.2 Comparison to other data sources

The mode share results are similar to mode share data collected by the City of Vancouver at 5 locations in August 2023, which indicate mode shares of 78%, 15%, and 5% for conventional bicycles, electric bicycles, and electric kick scooters, respectively. The mode shares we observed at the three locations closest to the City of Vancouver's dataset (Richard Street, York Avenue, and Central Valley Greenway) are similar but with a higher percentage of electric bicycles (+3.1%pt) and stand-up electric scooters (+2.2%pt) – see Appendix A: Count and mode share data collected by City of Vancouver.

We observed that 30% of shared bicycles were electric, which aligns with a 29% electric share of Mobi bikeshare trips in Vancouver (see Appendix B: Shared personal mobility devices), but is lower than the average electric share of bikeshare trips in North America of 39% (50). The findings of this study align with those from New Zealand, where the mode share of electric bicycles increased two- to three-fold between 2017 and 2020 while their average speed remained consistent (17).

4.3 Impacts of changes in policy and sharing services

Reflecting on the policy and service changes since 2019-2020 (see Section 1.2), the service area expansion for Mobi bikeshare, introduction of electric bicycles into Mobi bikeshare, and introduction of Lime shared electric bicycles seem to have led to a large increase in the proportion of shared PMD (especially motorized) in off-street paths. The Province of BC’s electric kick scooter pilot program may have indirectly contributed to the increase in mode share for stand-up electric scooters region-wide. However, the 4%pt mode share increase was consistent between municipalities that did and did not participate in the pilot program, and so local legal status does not appear to have been impactful for stand-up electric scooter adoption. Compared to electric bicycles, growth in stand-up electric scooter use lagged in absolute terms (+4%pt vs. +12%pt for electric bicycles), but led in relative terms (x12 vs. x4 for electric bicycles).

The pilot program restricted the motor-assist speed of stand-up electric scooters to 24 km/hr, but we observed that average stand-up electric scooter speeds increased from 22.4 km/hr before the pilot to 25.1 km/hr afterward, with 58% of observed stand-up electric scooters going faster than the motor-assist limit

of 24 km/hr (and 51% faster than the updated limit of 25 km/hr). In comparison, 6% of observed electric bicycles exceeded the motor-assist limit of 32 km/hr for motor assisted cycles, while 11% of stand-up electric scooters exceed this limit. The pilot program does not seem to be effective in moderating speeds for stand-up electric scooters. There are no e-scooter sharing services in the Vancouver region (which typically control speeds), and so most are privately owned and apparently capable of exceeding the motor-assist limit. Even within the city vendors offer e-scooters for sale that far exceed the 24 km/hr limit (51). This problem does not seem as pervasive for private electric bicycles, perhaps because of the maturity of the market and the near uniformity of the 32 km/hr limit across North America (52). Looking forward, a shared stand-up electric scooter service launched in the City of Vancouver in 2024, which will likely increase the mode share and decrease the average speed of stand-up electric scooters overall.

4.4 Limitations

This study relies on pneumatic tubes for counting PMDs, which may miss certain devices, such as skateboarders jumping over the tubes. Given that metropolitan Vancouver spans 2,700 km² and has an extensive cycling network, the representativeness of the 12 sampling locations is uncertain, potentially limiting the generalizability of the findings across the region. Additionally, findings of this study may not be generalizable beyond metropolitan Vancouver, as PMD usage is strongly influenced by local policies, regulatory frameworks, market dynamics, and the availability of sharing services, which can vary significantly by region. The 12 sampling locations were limited to straight segments of the network to measure cruising speeds, and future research should investigate PMD speeds in mixed traffic, on horizontal curves and more widely varying grades, and with conflict points such as intersections and bus stops. Furthermore, this study does not include other important PMD characteristics such as size, weight, turning radii, and stopping sight distance, which are important for facility design.

We only examine speed-related changes in path user comfort, which assumes uniformity of the effect of speed on comfort across different PMDs. Future research should explore whether this relationship varies by PMD type to enhance our understanding of path user comfort in cycling facilities. In addition, baseline comfort may change over time due to evolving device characteristics besides operating speed. Furthermore, speed is not the only factor influencing comfort, as infrastructure features, path volumes, and path user characteristics (e.g., age, physical ability) also play a role (34). Future research should examine PMD rider behaviour with respect to interaction characteristics such as yielding and overtaking, and determine how those behaviours may impact path user comfort differently for different PMD types.

Weighted average path user comfort based on mode share is an illustrative measure but does not necessarily represent the overall experience of using a pathway because it assumes that the impact of each PMD type on path user comfort is directly proportional to its mode share. This approach neglects the possibility that certain modes with low mode shares might disproportionately affect comfort perceptions due to factors like novelty. For instance, self-balancing unicycles are increasingly in the news (53–55) and may attract disproportionate attention of path users. The comfort estimates also neglect the disproportionate impact on comfort that highly uncomfortable interactions may have. For example, one very comfortable experience likely does not negate an equally uncomfortable experience. Furthermore, it neglects the interaction between speed and volume, wherein path users are more likely to encounter (be passed by) faster-moving PMD. Lastly, this method does not consider variations in comfort across path users, which is influenced by personal factors such as age, gender, and experience (34,56,57).

5 CONCLUSIONS

The findings of this study have several important implications for researchers, policymakers, and practitioners. Our previous study concluded that the Vancouver region was ready to accommodate new PMD in off-street paths without major effects on speeds and with only slight reductions in path user comfort (41). That has proven to be largely true following a 4-fold increase in motorized PMD use over the intervening 4 years. However, a few types of PMD showed unexpectedly large speed increases (self-balancing unicycles, electric skateboards), which is a concerning trend and requires further monitoring and evaluation.

Significant increases in the mode shares of electric bicycles and stand-up electric scooters over 4 years reflect the impact of changing policy and sharing systems on micromobility use in metropolitan Vancouver, in addition to broader trends in motorized PMD growth. Along with a more than 10-fold increase in usage, average stand-up electric scooter speeds have risen to 25 km/hr, exceeding the pilot program's motor-assist limit. This finding suggests a need for mitigation measures in the market for private stand-up electric scooters. In contrast, we previously concluded that the 32 km/hr motor-assist limit for electric bicycles was effective (29), and that seems to still be the case.

The wide range of average speeds among PMD types, ranging from 10 to 32 km/hr, necessitates reconsideration of design guidance for off-street cycling facilities and multi-use paths. We previously found that a 30 km/hr design speed encompassed the 85th percentile for all PMD types except sit-down electric (moped-style) scooters and electric skateboards (29). In 2023, 2 other PMD types also had an 85th percentile speed above 30 km/hr (self-balancing unicycle and stand-up electric scooter) and overall 85th percentile speed increased by 2.0 km/hr to 27.9 km/hr. Our new results suggest that a 30 km/hr design speed is still marginally conservative, but may require upward adjustment to 32 or 35 km/hr in the future if current trends continue, or in locations with particularly high shares of motorized PMD. In addition, with these large speed disparities more frequent overtaking will occur, at larger speed differentials. To accommodate this safely and comfortably, wider paths may need to be provided, particularly on steep grades.

The increases in mode share and speed for motorized PMD has reduced comfort in off-street cycling facilities and multi-use paths, although most PMD are still moderately comfortable for the average path user. The exceptions that are uncomfortable on average (self-balancing unicycles, electric tricycles, electric skateboards, and sit-down electric scooters) currently have a low combined mode share of just 0.8%. However, monitoring is needed to see if shares or speeds for these PMD increase further. Our previous study concluded that we should work to eliminate the use of sit-down electric (moped-style) scooters on off-street facilities, because they were clear speed and comfort outliers (41). Our new results suggest that sit-down electric scooters are no longer as isolated, and we should also consider ways to mitigate the impacts of self-balancing unicycles and electric skateboards, either through speed management or removal from off-street facilities – particularly those shared with pedestrians. In addition, the deterioration in comfort for pedestrians in multi-use paths further supports our previous recommendation to lower the volume thresholds for separating pedestrians from PMD when motorized PMD are allowed (41). Ongoing monitoring and study of evolving PMD is crucial to ensure that the benefits of improved accessibility from electric-assist devices are not negated by erosion of the active travel experience.

6 REFERENCES

1. Bretones A, Marquet O. Riding to health: Investigating the relationship between micromobility use and objective physical activity in Barcelona adults. Journal of Transport & Health. 2023 Mar 1;29:101588.

2. Castro A, Gaupp-Berghausen M, Dons E, Standaert A, Laeremans M, Clark A, et al. Physical activity of electric bicycle users compared to conventional bicycle users and non-cyclists: Insights based on health and transport data from an online survey in seven European cities. Transportation Research Interdisciplinary Perspectives. 2019 Jun 1;1:100017.

3. Gössling S, Choi AS. Transport transitions in Copenhagen: Comparing the cost of cars and bicycles. Ecological Economics. 2015 May 1;113:106–13.

4. Hosseinzadeh A, Algomaiah M, Kluger R, Li Z. E-scooters and sustainability: Investigating the relationship between the density of E-scooter trips and characteristics of sustainable urban development. Sustainable Cities and Society. 2021 Mar 1;66:102624.

5. Olabi AG, Wilberforce T, Obaideen K, Sayed ET, Shehata N, Alami AH, et al. Micromobility: Progress, benefits, challenges, policy and regulations, energy sources and storage, and its role in achieving sustainable development goals. International Journal of Thermofluids. 2023 Feb 1;17:100292.

6. Sanders RL, da Silva Brum-Bastos V, Nelson TA. Insights from a pilot investigating the impacts of shared E-scooter use on physical activity using a single-case design methodology. Journal of Transport & Health. 2022 Jun 1;25:101379.

7. Velotric. Velotric. 2023 [cited 2024 Mar 14]. E-bike vs. Car: Which One Should You Choose? Available from: https://www.velotricbike.com/blogs/story-landing/ebike-vs-car

8. Hassanpour A, Bigazzi A. What is on the bicycle paths? A detailed vehicle taxonomy with mode share data for off-street paths in metropolitan Vancouver, Canada. Transportation Research Record. 2023 Apr 27;03611981231165017.

9. Zagorskas J, Burinskienė M. Challenges Caused by Increased Use of E-Powered Personal Mobility Vehicles in European Cities. Sustainability. 2020 Jan;12(1):273.

10. Lee K, Sener IN. Emerging data for pedestrian and bicycle monitoring: Sources and applications. Transportation Research Interdisciplinary Perspectives. 2020 Mar 1;4:100095.

11. Schumann HH, Haitao H, Quddus M. Passively generated big data for micro-mobility: State-of-the-art and future research directions. Transportation Research Part D: Transport and Environment. 2023 Aug 1;121:103795.

12. R.A. Malatest & Associates Ltd., Associated Engineering. 2021 North Shore Transportation Survey [Internet]. 2022. Available from: https://www.cnv.org/-/media/City-of-North-Vancouver/Documents/Transportation-Plan/2021-North-Shore-Transportation-Survey-Report.pdf

13. R.A. Malatest & Associates Ltd., Associated Engineering. 2023 North Shore Transportation Survey [Internet]. 2024. Available from: https://www.cnv.org/-/media/City-of-North-Vancouver/Documents/Transportation-Plan/2023-North-Shore-Transportation-Survey-Report.pdf

14. City of Vancouver. Vancouver Transportation Fall Survey [Internet]. 2023. Available from: https://vancouver.ca/files/cov/2022-transportation-survey-report.pdf

15. Schepers JP, Fishman E, den Hertog P, Wolt KK, Schwab AL. The safety of electrically assisted bicycles compared to classic bicycles. Accident Analysis & Prevention. 2014 Dec 1;73:174–80.

16. Ozan E, Searcy S, Geiger BC, Vaughan C, Carnes C, Baird C, et al. State-of-the-art approaches to bicycle and pedestrian counters [Internet]. North Carolina Department of Transportation; 2021 [cited 2023 Apr 7] p. 84. Report No.: FHWA/NC/2020-39. Available from: https://trid.trb.org/view/1999400

17. ViaStrada. Speed survey of powered transport devices [Internet]. 2022. Available from: https://viastrada.nz/sites/default/files/2022-10/Speed-and-Geometry-study-ForPublication4.pdf

18. Hassanpour A, Bigazzi A, MacKenzie D. What Can Publicly Available API Data Tell Us about Supply and Demand for New Mobility Services? Transportation Research Record [Internet]. 2020 Jan 15 [cited 2020 Mar 5]; Available from: https://journals.sagepub.com/eprint/PPTBIJNEPPSFUTST44TS/full

19. National Association of City Transportation Officials. A micromobility record: 157 million trips on bike share and scooter share in 2023 [Internet]. 2024. Available from: https://nacto.org/wp-content/uploads/2024/08/Shared-micro-in-2023-snapshot_FINAL_July22-2024.pdf

20. Arellano JF (Frank), Fang K. Sunday drivers, or too fast and too furious? Findings [Internet]. 2019 Dec 30 [cited 2023 May 15]; Available from: https://findingspress.org/article/11210

21. Flügel S, Hulleberg N, Fyhri A, Weber C, Ævarsson G. Empirical speed models for cycling in the Oslo road network. Transportation. 2019 Aug 1;46(4):1395–419.

22. Mohamed A, Bigazzi A. Speed and road grade dynamics of urban trips on electric and conventional bicycles. Transportmetrica B: Transport Dynamics. 2019 Dec 23;7(1):1467–80.

23. Pashkevich A, Burghardt TE, Puławska-Obiedowska S, Šucha M. Visual attention and speeds of pedestrians, cyclists, and electric scooter riders when using shared road – a field eye tracker experiment. Case Studies on Transport Policy. 2022 Mar 1;10(1):549–58.

24. Twisk D, Stelling A, Van Gent P, De Groot J, Vlakveld W. Speed characteristics of speed pedelecs, pedelecs and conventional bicycles in naturalistic urban and rural traffic conditions. Accident Analysis & Prevention. 2021 Feb 1;150:105940.

25. Zuniga-Garcia N, Ruiz Juri N, Perrine KA, Machemehl RB. E-scooters in urban infrastructure: Understanding sidewalk, bike lane, and roadway usage from trajectory data. Case Studies on Transport Policy. 2021 Sep 1;9(3):983–94.

26. Bell J, Rogers S, Mathew J, Li H, Bullock D. Comparing speed distribution of micro-mobility modes. International Conference on Transportation and Development. 2020 Aug 31;59–67.

27. Fang K, Handy S. Skateboarding for transportation: exploring the factors behind an unconventional mode choice among university skateboard commuters. Transportation. 2019 Feb 1;46(1):263–83.

28. Federal Highway Administration. Characteristics of emerging road users and their safety [Internet]. 2004 Oct. Report No.: FHWA-HRT-04-103. Available from: https://www.fhwa.dot.gov/publications/research/safety/04103/04103.pdf

29. Hassanpour A, Bigazzi A. Operating speed distributions in off-street cycling facilities by vehicle type and motorization. Journal of Cycling and Micromobility Research. 2024 Dec 1;2:100021.

30. Boglietti S, Barabino B, Maternini G. Survey on e-Powered Micro Personal Mobility Vehicles: Exploring Current Issues towards Future Developments. Sustainability. 2021 Jan;13(7):3692.

31. British Columbia Ministry of Transportation and Infrastructure. British Columbia Active Transportation Design Guide [Internet]. Victoria, Canada: Province of British Columbia; 2019 [cited 2019 Aug 12]. Available from: https://www2.gov.bc.ca/gov/content/transportation/funding-engagement-permits/funding-grants/cycling-infrastructure-funding/active-transportation-design-guide

32. Ryus P, Ferguson E, Laustsen KM, Schneider RJ, Proulx FR, Hull T, et al. Guidebook on Pedestrian and Bicycle Volume Data Collection [Internet]. Washington, D.C.: Transportation Research Board; 2014 Jan [cited 2022 Dec 6] p. 22223. Report No.: NCHRP Report 797. Available from: https://www.nap.edu/catalog/22223

33. U.S. Federal Highway Administration. Traffic Monitoring Guide [Internet]. Washington, D.C.: U.S. Department of Transportation; 2016 [cited 2022 Dec 6]. Available from: https://www.fhwa.dot.gov/policyinformation/tmguide/

34. Hassanpour A, Bigazzi A. Perceptions towards personal mobility devices in off-street cycling facilities in metropolitan Vancouver, Canada. [Manuscript in preparation]. 2024;

35. Mobi. Mobi. 2022 [cited 2024 Sep 19]. Mobi by Shaw Go Launches Ebikes Mobi by Shaw Go celebrates its 6th anniversary and 4 million trips by launching 500 ebikes. Available from: https://www.mobibikes.ca/en/news/e-bikes-join-mobi-fleet

36. Chan K. Daily Hive. 2023 [cited 2024 Sep 19]. Vancouver’s Mobi bike share system now expanded to UBC campus | Urbanized. Available from: https://dailyhive.com/vancouver/vancouver-mobi-bike-share-ubc-campus-expansion-locations

37. City of North Vancouver. E-Bike Share Program [Internet]. 2023 [cited 2024 Nov 27]. Available from: https://www.cnv.org/Streets-Transportation/Travel-Options/E-Bike-Share-Program

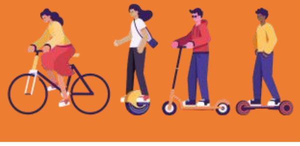
38. Ministry of Transportation and Infrastructure. BC Government News. 2021 [cited 2021 Nov 26]. E-mobility pilot project gets green light. Available from: https://news.gov.bc.ca/releases/2021TRAN0042-000523

39. McHugh ML. Interrater reliability: the kappa statistic. Biochemia Medica. 2012 Oct 15;22(3):276–82.

40. Mobibikes. System data | Vancouver Bike Share [Internet]. [cited 2022 Jul 14]. Available from: https://www.mobibikes.ca/en/system-data

41. Hassanpour A, Bigazzi A. Clustering Micromobility Devices based on Speed and Comfort. Findings [Internet]. 2024 Sep 9 [cited 2024 Sep 16]; Available from: https://findingspress.org/article/123208-clustering-micromobility-devices-based-on-speed-and-comfort

42. Environment and Climate Change Canada. Historical Climate Data [Internet]. 2024 [cited 2024 Oct 8]. Available from: https://climate.weather.gc.ca/historical_data/search_historic_data_e.html



43. Brooks ME, Kristensen K, Benthem KJ van, Magnusson A, Berg CW, Nielsen A, et al. glmmTMB Balances Speed and Flexibility Among Packages for Zero-inflated Generalized Linear Mixed Modeling. The R Journal. 2017;9(2):378–400.

44. Taiyun W. R package “corrplot”: Visualization of a Correlation Matrix (Version 0.90) [Internet]. 2024 [cited 2024 Mar 25]. Available from: https://github.com/taiyun/corrplot

45. Harris CR, Millman KJ, van der Walt SJ, Gommers R, Virtanen P, Cournapeau D, et al. Array programming with NumPy. Nature. 2020 Sep;585(7825):357–62.

46. Hunter JD. Matplotlib: A 2D Graphics Environment. Computing in Science & Engineering. 2007 May;9(3):90–5.

47. Seabold S, Perktold J. Statsmodels: Econometric and Statistical Modeling with Python - SciPy Proceedings [Internet]. 2010 [cited 2024 Oct 8]. Available from: https://proceedings.scipy.org/articles/Majora-92bf1922-011

48. The pandas development team. pandas-dev/pandas: Pandas [Internet]. Zenodo; 2022 [cited 2022 Nov 9]. Available from: https://zenodo.org/record/7093122

49. Ministry of Transportation and Infrastructure. E-bike rules of the road [Internet]. Province of British Columbia; 2024 [cited 2024 Jul 2]. Available from: https://www2.gov.bc.ca/gov/content/transportation/driving-and-cycling/cycling/e-bike-rules-of-the-road

50. North American Bikeshare & Scootershare Association. 5th Annual Shared Micromobility State of the Industry Report [Internet]. 2023. Available from: https://nabsa.net/about/industry/

51. Fatwhip Scooters. Teverun - Blade Mini Pro SE [Internet]. Vancouver’s Electric Scooter Shop. [cited 2024 Nov 15]. Available from: https://www.fatwhip.com/product/teverun-blade-mini-pro-se/

52. MacArthur J, Kobel N. Regulations of E-Bikes in North America: A Policy Review [Internet]. Portland, Oregon: National Institute for Transportation and Communities; 2014 Aug [cited 2016 Jan 6]. Report No.: NITC-RR-564. Available from: http://trid.trb.org/view.aspx?id=1324907

53. Ballard J. Electric unicycle riders call for clearer regulation in B.C. as many report receiving $598 tickets. CBC News [Internet]. 2023 Jul 18 [cited 2024 Jun 10]; Available from: https://www.cbc.ca/news/canada/british-columbia/electric-unicycle-regulations-bc-fines-insurance-1.6909463

54. Delvin M. Daily Hive | Urnabized. 2023 [cited 2024 Oct 3]. Electric unicycles are illegal on BC streets: Government responds to tickets. Available from: https://dailyhive.com/vancouver/electric-unicycles-illegal-vancouver-streets

55. Larsen K. CBC News. 2022 [cited 2024 Oct 3]. Move over e-bikes, electric unicycles gaining ground on Vancouver streets. Available from: https://www.cbc.ca/news/canada/british-columbia/electric-unicycles-gain-ground-on-vancouver-streets-1.6475801

56. Kaparias I, Bell MGH, Miri A, Chan C, Mount B. Analysing the perceptions of pedestrians and drivers to shared space. Transportation Research Part F: Traffic Psychology and Behaviour. 2012 May 1;15(3):297–310.

57. Sucha M, Dostal D, Risser R. Pedestrian-driver communication and decision strategies at marked crossings. Accident Analysis & Prevention. 2017 May 1;102:41–50.

58. Statistics Canada. Monthly average retail prices for gasoline and fuel oil, by geography [Internet]. 2024 [cited 2024 Oct 8]. Available from: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1810000101

7 APPENDIX

7.1 Appendix A: Count and mode share data collected by City of Vancouver

City of Vancouver collected data on mode share at 5 locations in cycling and mixed-use facilities in 2023. Data were collected for 1 weekday from 7 am to 7 pm (12 hours) at Union St (Between Main St & Gore Ave), Dunsmuir St (Between Seymour St & Richards St), Adanac St (Between Clark Dr & Mclean Dr), Beach Ave (Between Bidwell St & Cardero St), and Adanac St (Between Rupert St & Cassiar St). The number of observations for of each PMD category at each location as well as overall mode share are provided in Table 6. The mode share observed in this study at the three locations closest to the City of Vancouver's data collection sites—Richard Street, York Avenue, and Central Valley Greenway—was compared to the City's data. The results indicate a higher percentage of electric bicycles (+3.1%pt) and stand-up electric scooters (+2.2%pt) in our study; and consequently, lower percentage of conventional bicycles (-6.2%pt).

Table 6. Count and mode share of personal mobility devices at 5 locations in Vancouver collected by City of Vancouver in August 2023

	Data collection location							
Personal mobility device type	1600 Beach	1400 Adanac	3300 Adanac	500 Dunsmuir	200 Union	Total	Mode share	Mode share this study*
Conventional bicycle	4531	2529	659	1866	3361	12946	78.1%	71.9%
Electric bicycle	809	560	157	326	602	2454	14.8%	17.9%
Stand-up electric scooter	181	124	40	269	210	824	5.0%	7.2%
Sit-down electric scooter	16	22	18	6	22	84	0.5%	0.5%
Conventional skateboard	19	7	0	26	17	69	0.4%	0.5%
Mobility assist devices (conventional/electric)	9	4	0	11	36	60	0.4%	0.4%
Self-balancing unicycle	8	9	4	11	14	46	0.3%	0.4%
Roller/inline skate	40	2	0	2	1	45	0.3%	0.1%
Other electric device (e-skateboard, etc.)	16	6	0	6	8	36	0.2%	1.0%
Conventional kick scooter	1	2	0	4	2	9	0.1%	0.1%
Total	5630	3265	878	2527	4273	16573	100%	100%

* At three closest locations to City of Vancouver’s data collection locations: Richard Street, York Avenue, and Central Valley Greenway.

7.2 Appendix B: Shared personal mobility devices

Figure 9 presents number of trips made by Mobibikes, Vancouver's bike sharing system, in the month of July from 2017 to 2023. Mobibikes introduced electric bicycles and expanded its service area in 2023, contributing to increased usage (35,36).

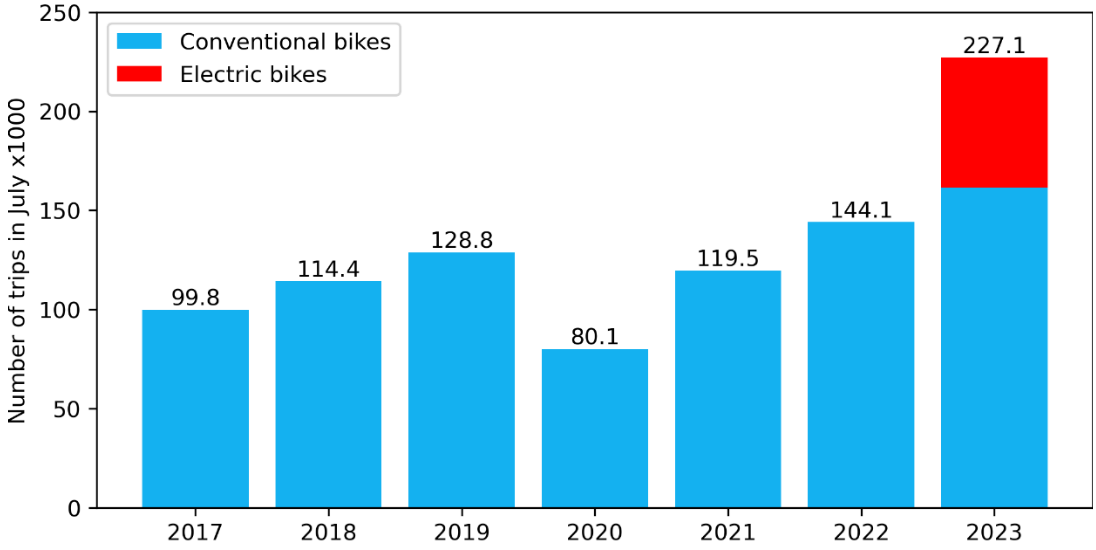


Figure 9. Number of shared bicycle (conventional and electric) trips made in the month of July using Mobibikes, Vancouver's bikesharing system.

Table 7 presents the ratio of shared versus personal conventional and electric bicycles observed in the 2019-2020 and the 2023 data suggesting an upwards trend in the use of shared micromobility.

Table 7. Ratio of shared versus personal conventional and electric bicycles in metropolitan Vancouver in 2019-2020 and 2023

	2019-2020 Mode share %		Shared versus 100 personal devices	2023 Mode share %		Shared versus 100 personal devices
Personal mobility type	Personal	Shared		Personal	Shared	
Conventional bicycles	90.8	0.7	0.8	73.9	2.1	2.8
Electric bicycles	4.5	0.0	0.0	16.4	0.9	5.5

7.3 Appendix C: Spatial pattern of PMD use

Table 8 and Table 9 present location-specific statistics on PMD usage at the 12 sampling locations.

Table 8. Location-specific volume, mode share, and speed statistics in 2023

	Spirit trail	West esplanade	Richard street	Point grey road	York avenue	Central valley	Arbutus Greenway	Highland park line	BC parkway	Wesbrook mall	Thunderbird park	Railway greenway
Number of observations	2038	246	1965	3909	2515	1716	2439	335	497	122	247	1391
Average hourly volume	123.6	16.0	101.0	210.3	135.1	93.8	141.2	21.3	25.9	7.2	18.3	74.6
Mode share (%)												
Balance bicycle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.2	0.0	0.0	0.0
C*-bicycle	75.3	78.9	47.2	79.7	81.2	72.8	76.7	66.6	62.0	68.0	69.6	82.4
C-cargocycle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C-recumbent bicycle	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0
C-recumbent tricycle	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C-skateboard	0.5	0.4	1.1	0.1	0.2	0.4	0.1	0.6	0.6	0.8	2.4	0.6
C-tandem bicycle	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.1
C-tricycle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
C-unicycle	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C-wheelchair	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
E**-bicycle	20.2	13.8	21.2	14.1	11.4	18.9	17.8	17.9	28.6	18.0	13.8	11.9
E-cargocycle	0.3	0.4	1.3	0.3	0.1	0.1	0.1	0.0	0.2	0.8	0.8	0.1
E-recumbent bicycle	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
E-recumbent tricycle	0.1	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.2	0.0	0.0	0.0
E-skateboard	0.2	0.0	0.6	0.0	0.4	0.2	0.1	0.3	0.0	0.0	0.0	0.1
E-tandem bicycle	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
E-tricycle	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0
E-wheelchair	0.0	0.0	0.1	0.1	0.4	0.1	0.0	0.0	0.0	0.0	1.6	0.0
Elliptical bicycle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
Mobility scooter	0.0	0.0	0.4	0.0	0.1	0.2	0.0	0.0	0.2	0.0	0.0	0.1
Motor vehicle or golf cart	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Push/kick scooter	0.2	0.0	0.2	0.1	0.0	0.0	0.0	0.3	0.6	0.0	2.0	0.2
Roller/inline skate	0.3	0.0	0.1	0.1	0.0	0.0	0.5	0.3	0.0	0.0	0.4	1.1
SB*** stand-up scooter	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
SB stand-up unicycle	0.2	0.4	0.4	0.1	0.2	0.6	0.5	0.6	2.6	0.0	0.0	0.3
Shared c-bicycle	0.0	0.0	9.7	2.6	1.7	0.0	0.6	0.0	0.0	2.5	2.4	0.0
Shared e-bicycle	0.9	1.6	3.4	0.8	0.7	0.1	0.7	0.0	0.0	0.0	0.0	0.1
Sit-down e-scooter	0.2	0.0	0.8	0.1	0.2	0.6	0.2	0.9	0.0	0.0	0.0	0.3
Stand-up e-scooter	1.6	4.1	13.6	1.6	3.3	5.7	2.4	10.8	4.8	9.8	6.9	2.4
Speed (km/hr)												
Average	21.6	23.9	21.3	18.9	22.8	21.9	26.4	18.4	19.6	20.3	14.2	19.2
Standard deviation	6.1	4.6	5.9	5.6	5.6	6.3	5.7	5.8	7.1	6.3	5.7	5.2
85th percentile	27.5	28.3	27.3	24.5	28.3	28.2	31.8	24.3	27.0	25.6	19.4	24.4
Percent above 24 km/hr	29.6%	45.7%	30.1%	13.6%	33.7%	23.2%	62.0%	13.7%	20.6%	14.8%	7.6%	14.8%
Percent above 32 km/hr	2.4%	4.0%	4.0%	1.0%	3.0%	3.1%	12.8%	1.5%	3.0%	1.6%	0.2%	0.8%

* Conventional ** Electric *** Self balancing

Table 9. Location-specific volume, mode share, and speed statistics in 2019-2020

	Spirit trail	West esplanade	Richard street	Point grey road	York avenue	Central valley	Arbutus Greenway	Highland park line	BC parkway	Wesbrook mall	Thunderbird park	Railway greenway
Number of observations	1652	231	537	3547	5104	2468	1409	661	473	135	348	1208
Average hourly volume	45.9	6.2	17.4	97.9	113.0	78.7	59.5	17.2	18.3	5.1	21.2	49.9
Mode share (%)												
Balance bicycle	0.2	0.4	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.6	0.0
C-bicycle	85.7	87.5	78.8	92.8	94.0	92.6	90.8	88.2	85.0	89.6	83.3	89.5
C-cargocycle	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0
C-recumbent bicycle	0.1	0.4	0.0	0.2	0.1	0.2	0.1	0.0	0.4	0.0	0.0	0.0
C-recumbent tricycle	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
C-skateboard	1.0	1.3	0.7	0.9	0.5	0.7	1.2	1.5	1.9	2.2	2.0	1.1
C-tandem bicycle	0.1	0.0	0.0	0.1	0.0	0.2	0.0	0.0	0.2	0.0	0.0	0.1
C-tricycle	0.3	0.0	0.0	0.0	0.0	0.3	0.0	0.2	0.0	0.0	0.3	0.0
C-unicycle	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
C-wheelchair	0.1	0.4	0.2	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.9	0.2
E-bicycle	8.5	7.4	7.3	4.5	3.2	4.0	4.5	5.5	9.9	2.2	2.6	2.2
E-cargocycle	0.1	0.0	0.0	0.3	0.1	0.0	0.2	0.0	0.0	0.7	0.0	0.0
E-recumbent bicycle	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
E-recumbent tricycle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
E-skateboard	0.0	0.4	0.0	0.1	0.0	0.0	0.2	0.2	0.2	0.0	0.0	0.0
E-tandem bicycle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
E-tricycle	0.1	0.0	0.2	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
E-wheelchair	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Elliptical bicycle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mobility scooter	0.1	0.4	1.5	0.1	0.1	0.3	0.2	0.5	0.0	0.0	0.6	0.1
Motor vehicle or golf cart	0.1	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.2	0.0	0.6	0.1
Push/kick scooter	1.8	0.4	0.4	0.1	0.0	0.1	1.3	1.5	0.0	0.0	2.6	0.6
Roller/inline skate	1.1	0.0	0.4	0.1	0.2	0.1	0.3	0.5	0.0	0.0	0.6	5.6
SB stand-up scooter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0
SB stand-up unicycle	0.3	0.0	0.4	0.0	0.0	0.0	0.1	0.3	1.1	0.0	0.3	0.0
Shared c-bicycle	0.0	0.0	5.4	0.4	1.2	0.0	0.4	0.0	0.0	2.2	4.6	0.0
Shared e-bicycle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sit-down e-scooter	0.2	0.9	2.2	0.1	0.1	0.5	0.0	0.9	0.6	0.7	0.3	0.3
Stand-up e-scooter	0.0	0.4	2.4	0.3	0.3	0.3	0.1	0.2	0.4	0.7	0.9	0.5
Speed (km/hr)												
Average	19.1	23.0	20.9	15.1	21.7	18.6	24.5	17.4	16.6	18.7	17.1	17.5
Standard deviation	6.2	5.6	6.0	5.9	4.9	5.6	6.2	5.6	6.5	4.5	5.4	5.4
85th percentile	25.6	28.6	27.3	21.6	26.8	24.4	30.6	22.9	23.6	22.4	22.7	23.4
Percent above 24 km/hr	29.6%	45.7%	30.1%	13.6%	33.7%	23.2%	62.0%	13.7%	20.6%	14.8%	7.6%	14.8%
Percent above 32 km/hr	2.4%	4.0%	4.0%	1.0%	3.0%	3.1%	12.8%	1.5%	3.0%	1.6%	0.2%	0.8%

* Conventional ** Electric *** Self balancing

7.4 Appendix D: Temporal pattern of PMD use and hourly volume model

Figure 10 presents the temporal pattern of hourly PMD volume at all sampling locations (gray), and total average for *before* (blue) and *after* (orange) data, along with Mobi's average hourly usage in Vancouver in July 2023. Hourly volumes are normalized to total daily volume for each sampling location. Similar patterns of PMD traffic can be observed over time within weekdays and weekend.

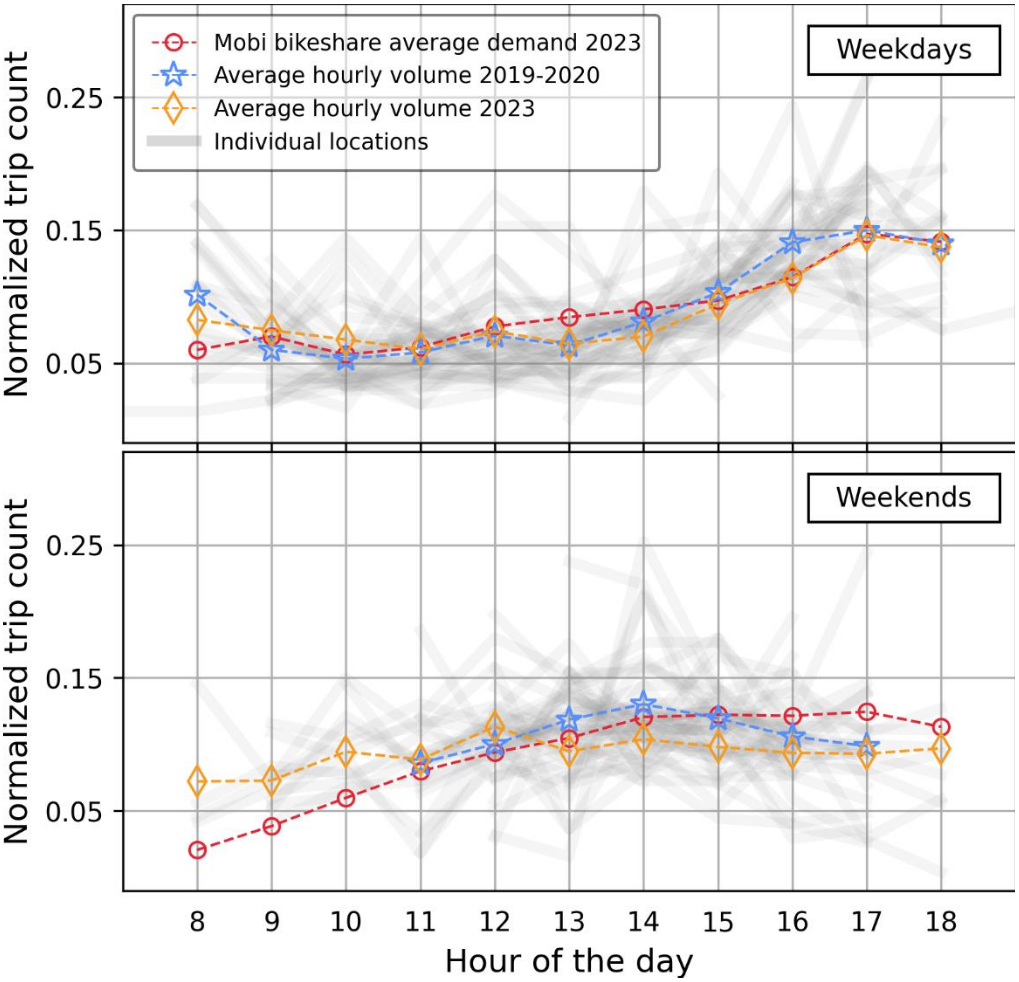


Figure 10. Hourly distribution of observed personal mobility device volumes, in comparison to average hourly Mobi bikeshare usage in Vancouver in July 2023.

A mixed-effects negative binomial regression model was used to investigate the changes in hourly traffic volume at the sampling locations over time. The following fixed effect variables were included in the model:

- **Study effect:** A binary *after* variable indicates whether the observations are from the 2023 dataset versus the 2019-2020 dataset.
- **Facility:** A binary variable indicating a *multi-use path* shared with pedestrians (versus cycling-exclusive facilities with a parallel facility for pedestrians).
- **Context controls:** Two continuous variables for *temperature* and *rain* (defined in section 2.3), and average monthly *fuel price* (centers per litre, ¢/L) (58)
- **Temporal controls:** Three binary variables for *peak hour*, *weekend*, and *COVID lockdown* (defined in section 2.3).

Incidence rate ratios (IRR) are calculated by exponentiating the estimated coefficients of the negative binomial model. IRR represents the multiplicative change in the expected hourly traffic volume for each one-unit increase in the continuous predictor variables or for the presence of a binary predictor. An IRR of greater than 1 indicates an increase in traffic volume, whereas an IRR less than 1 indicates a decrease.

Table 10 presents the estimated mixed effects negative binomial regression model of hourly PMD volumes, which yielded a conditional R^2 of 0.93 and marginal R^2 of 0.32. Results indicate that *temperature* and *fuel price* have significant positive associations with PMD volume, while *rain* has a significant negative association, as expected. PMD volume was also significantly higher on *weekends* and during the *COVID-19 lockdown* period.

The *after* variable parameter indicates a PMD hourly volume decrease of 13% from 2019-2020 to 2023, after controlling for the effects of contextual factors, however it was not statistically significant, possibly related to strong correlations with the *temperature* (0.81) and *fuel price* (0.88) variables.

Table 10. Negative binomial regression model of hourly PMD hourly volume with location random effects

Variable	Descriptive statistics[1]	Coefficient	Incidence rate ratio	Standard error	P-value
Hourly volume	60.94 (68.36)	NA	NA	NA	NA
Intercept	NA	1.712	5.539	0.599	<0.01
Temperature (°Celsius)	15.08 (6.66)	0.057	1.059	0.006	<0.01
Rain (mm)	1.02 (2.45)	-0.085	0.918	0.013	<0.01
Fuel price ($/L)	154.43 (36.00)	0.628	1.875	0.325	0.05
Multi-use path (binary)	55%	0.087	1.091	0.471	0.85
Peak hour (binary)	27%	0.076	1.079	0.044	0.09
Weekend (binary)	45%	0.249	1.283	0.043	<0.01
COVID 19 lockdown (binary)	20%	0.913	2.492	0.154	<0.01
After (binary)	35%	-0.141	0.869	0.180	0.43

Number of observations: 655
Number of locations (random effects): 12
Standard deviation of location effects: 0.80
Conditional R^2: 0.93; Marginal R^2: 0.32
[1] Mean (standard deviation) for continuous variables, and % true for binary variables

7.5 Appendix E: PMD speed statistics

Figure 11 presents the speed distribution of PMD in 2019-2020 and 2023. Table 11 provides data regarding percent of observations for each PMD type exceeding the British Columbia Motor Vehicle Act's new motor-assist limit of 25 km/hr for stand-up electric scooters. PMD with fewer than 3 observations in either dataset are not included in the figure or the table.

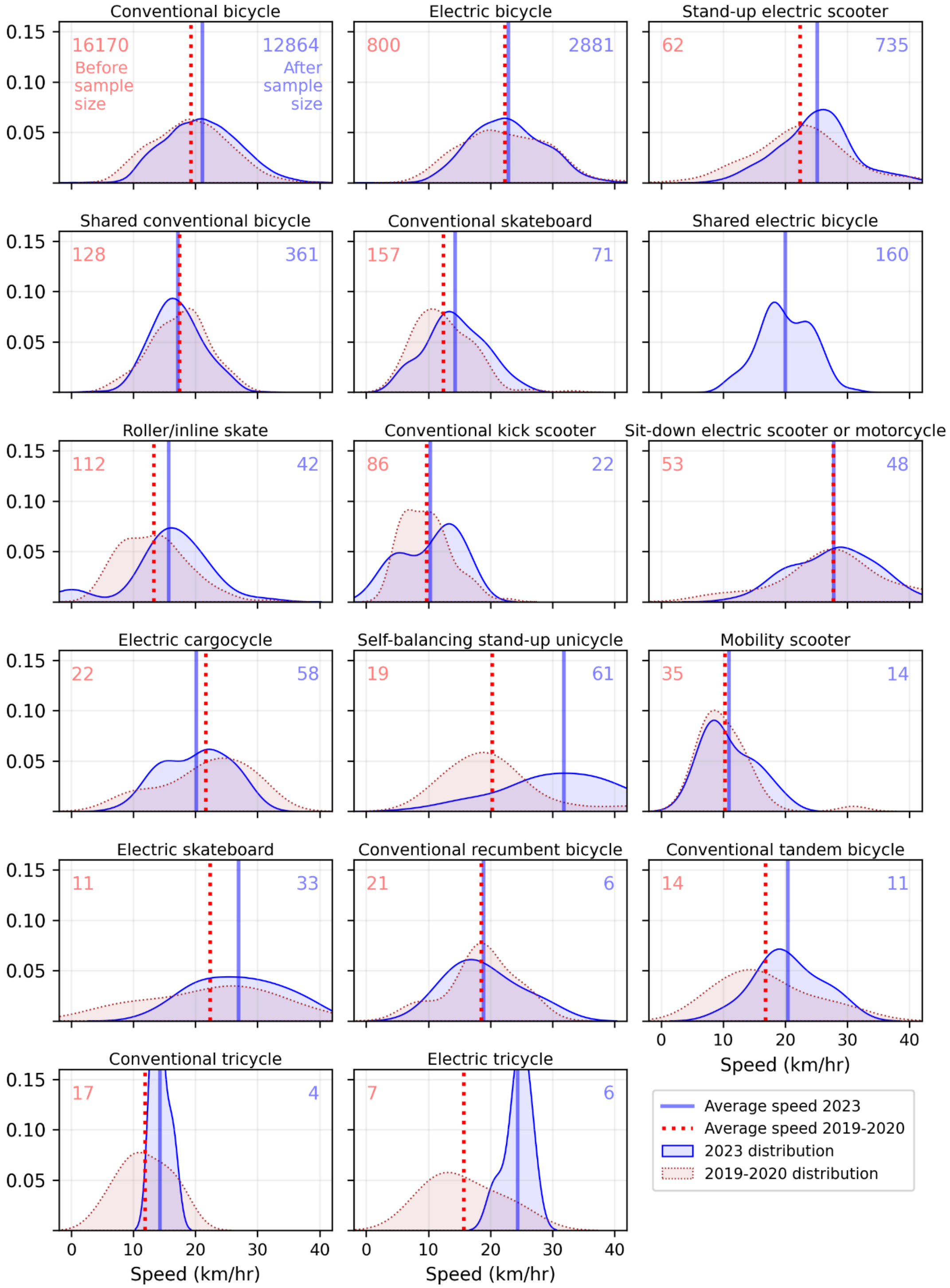


Figure 11. Speed distributions of PMDs (with N≥3 in before and after dataset)

Table 11. Percent of observations above British Columbia Motor Vehicle Act's new motor-assist limit of 25 km/hr for stand-up electric

	Percent over 25 km/hr	
Personal mobility device name	2023	2019-2020
Self-balancing unicycle	80.3	15.8
Sit-down electric scooter	68.8	67.9
Electric skateboard	57.6	45.5
Stand-up electric scooter	50.5	33.9
Electric bicycle	34.5	35.8
Electric cargocycle	24.1	36.4
Conventional bicycle	25.5	17.9
Electric tricycle	33.3	14.3
Conventional recumbent bicycle	16.7	14.3
Conventional tandem bicycle	18.2	21.4
Shared conventional bicycle	4.2	5.5
Conventional recumbent tricycle	25.0	0.0
Roller/inline skate	4.8	1.8
Conventional skateboard	1.4	1.9
Conventional tricycle	0.0	0.0
Mobility scooter	0.0	2.9
Conventional kick scooter	0.0	0.0
Overall	27.6	18.4

7.6 Appendix F: Estimated path user comfort based on speed changes from 2019-2020 to 2023

The projected average comfort level of path users toward PMDs, reflecting significant speed changes from 2019-2020 to 2023, is shown in Table 12. In terms of both speed and path user perceived comfort, conventional and electric bicycles are now more closely aligned. However, stand-up electric scooters are now perceived as uncomfortable on average, due to their significant speed increase. Despite these changes, the average path user continues to report a moderate level of comfort (3.6 on a scale of -10 to 10) when using off-street cycling facilities and multi-use paths. Average pedestrian is also comfortable in cycling facilities and multi-use paths with a rating of 1.7, however,

Table 12. Estimated average path user comfort sharing path with PMD in 2019-2020 and 2023.

		Mode Share %					
Personal mobility device name	Speed change (km/hr)	After (2023)	Before (2019-2020)	Average path user comfort [-10,10] in 2019-2020	Projected average path user comfort [-10,10] in 2023	Average pedestrian comfort [-10,10] in 2019-2020	Projected average pedestrian comfort [-10,10] in 2023
Self-balancing unicycle	11.6*	0.35	0.11	0.64	-1.33	0.14	-1.83
Sit-down electric scooter	0.06	0.27	0.30	-2.97	-2.98	-2.98	-2.99
Electric skateboard	4.60	0.19	0.06	0.45	-0.34	-0.16	-0.94
Stand-up electric scooter	2.78*	4.20	0.35	1.78	1.31	0.86	0.39
Electric bicycle	0.54*	16.40	4.51	0.99	0.90	-0.68	-0.77
Conventional bicycle	1.81*	73.91	90.84	4.67	4.36	2.72	2.41
Electric tricycle	8.66*	0.03	0.04	0.59	-0.88	-0.87	-2.35
Conventional recumbent bicycle	0.38	0.03	0.12	3.96	3.90	2.07	2.01
Conventional tandem bicycle	3.58	0.06	0.08	3.15	2.54	1.13	0.52
Conventional recumbent tricycle	5.49	0.02	0.02	3.25	2.32	1.83	0.89
Roller/inline skate	2.35*	0.29	0.66	3.27	2.87	3.23	2.83
Conventional skateboard	1.87*	0.42	0.92	2.54	2.22	1.80	1.49
Conventional tricycle	2.42	0.02	0.11	3.96	3.55	2.78	2.37
Mobility scooter	0.61	0.08	0.19	4.42	4.31	5.47	5.37
Conventional kick scooter	0.59	0.13	0.53	4.43	4.33	4.65	4.55
Conventional wheelchair	NA**	0.01	0.08	6.42	6.42	8.03	8.03
Electric wheelchair	NA	0.12	0.01	5.62	5.62	6.53	6.53
Conventional unicycle	NA	0.01	0.02	3.78	3.78	3.12	3.12
Electric Tandem bicycle	NA	0.01	0.01	2.20	2.20	1.14	1.14
Electric recumbent bicycle	NA	0.01	0.01	1.23	1.23	-0.06	-0.06
Self-balancing scooter	NA	0.03	0.01	1.10	1.10	0.70	0.70
Electric recumbent tricycle	NA	0.03	0.01	0.19	0.19	-0.46	-0.46
Average overall path user comfort in off-street cycling facilities and multi-use paths				4.42	3.57	2.55	1.75

* p-value ≤0.05

** Not Applicable as speed change not calculated due to small sample size