Human-electric hybrid vehicles: Implications of new non-auto mobility options for street design and policy in the Vancouver region

Final Report

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1 Executive Summary

1.1 Background and objectives

The focus of urban transportation planning and design has shifted towards more multi-modal systems that provide travellers with enhanced transportation options. At the same time, technological and commercial developments have increased the availability and perceived popularity of low-power vehicles such as electric bicycles, scooters, and skateboards. These new mobility options create opportunities to address enduring challenges related to traffic congestion, air pollution, climate change, public health, and energy consumption. However, due to the variety of sizes and speeds that these vehicles come in, they may present new challenges to urban transport systems, in particular regarding street space allocation and design. Already, pedestrian-bicycle interactions in spaces shared by non-automobile travellers are seen as a safety issue, supported by surprisingly high numbers of incidents with physical contact between travellers (Gkekas, Bigazzi, and Gill 2020). Therefore, it is paramount that we capture the potential benefits of more diverse travel options while mitigating the risks of a wider variety of vehicles within constrained city street spaces, especially in places like Metro Vancouver, where walking and cycling are already at relatively high levels.

The objectives of this research are to address the following questions:

- How will new non-auto mobility options (electric bicycles and other no-/low-power vehicles) impact speed dynamics on non-auto facilities and interactions among non-auto travellers? How are the speeds of vehicles and the perceptions of comfort for non-auto travellers influenced by the presence of electric-assist and microenvironment factors (path grade, facility design, season, other path users, etc.)?
- Given these new non-auto mobility options, what transportation system policies, plans, and designs are needed to mitigate conflicts among non-auto modes? Is the Vancouver region ready to accommodate these new modes with existing infrastructure and policies?

1.2 Overview of methods

The study methods are summarized in Figure 1. The project included an extensive data collection campaign at 12 sampling locations across Metro Vancouver (over 4 seasons) to gather information on mode shares and speed profiles of all types of vehicles used in off-street paths, and path users' comfort in sharing the path with each vehicle type.

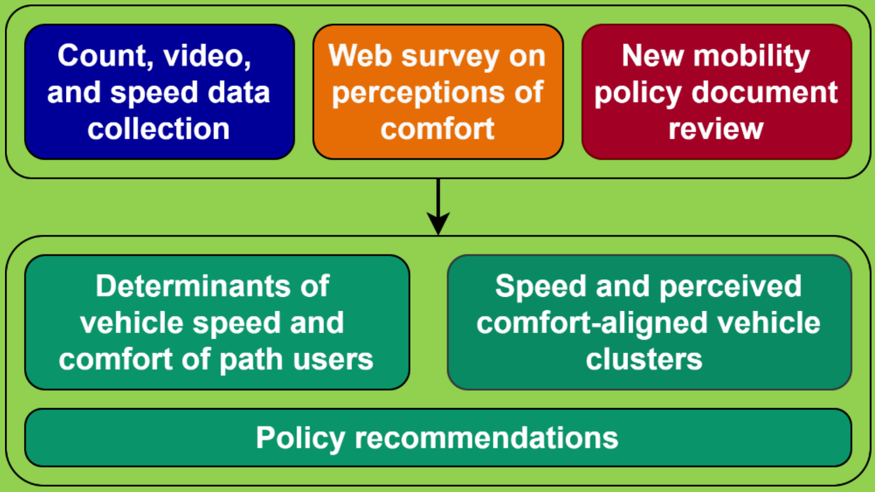

Figure 1. Study methods

After data collection, the following processed datasets were created: 1) mode share and speed profile datasets based on 25,282 observations of passing vehicles, and 2) a comfort rating dataset based on 1,054 survey responses from path users (Figure 2). Speeds and comfort ratings were investigated using mixed-effects regression models to analyze the effects of electric-assist, microenvironment factors, and sociodemographic indicators on speed and comfort. K-means clustering was used to group 25 vehicle types into four speed and comfort-aligned clusters (Figure 3). Lastly, a review of transportation policy, planning, and design documents in Metro Vancouver related to these emerging vehicles was conducted to examine alignment with the empirical results and to identify opportunities to better prepare for increased usage of new mobility devices.

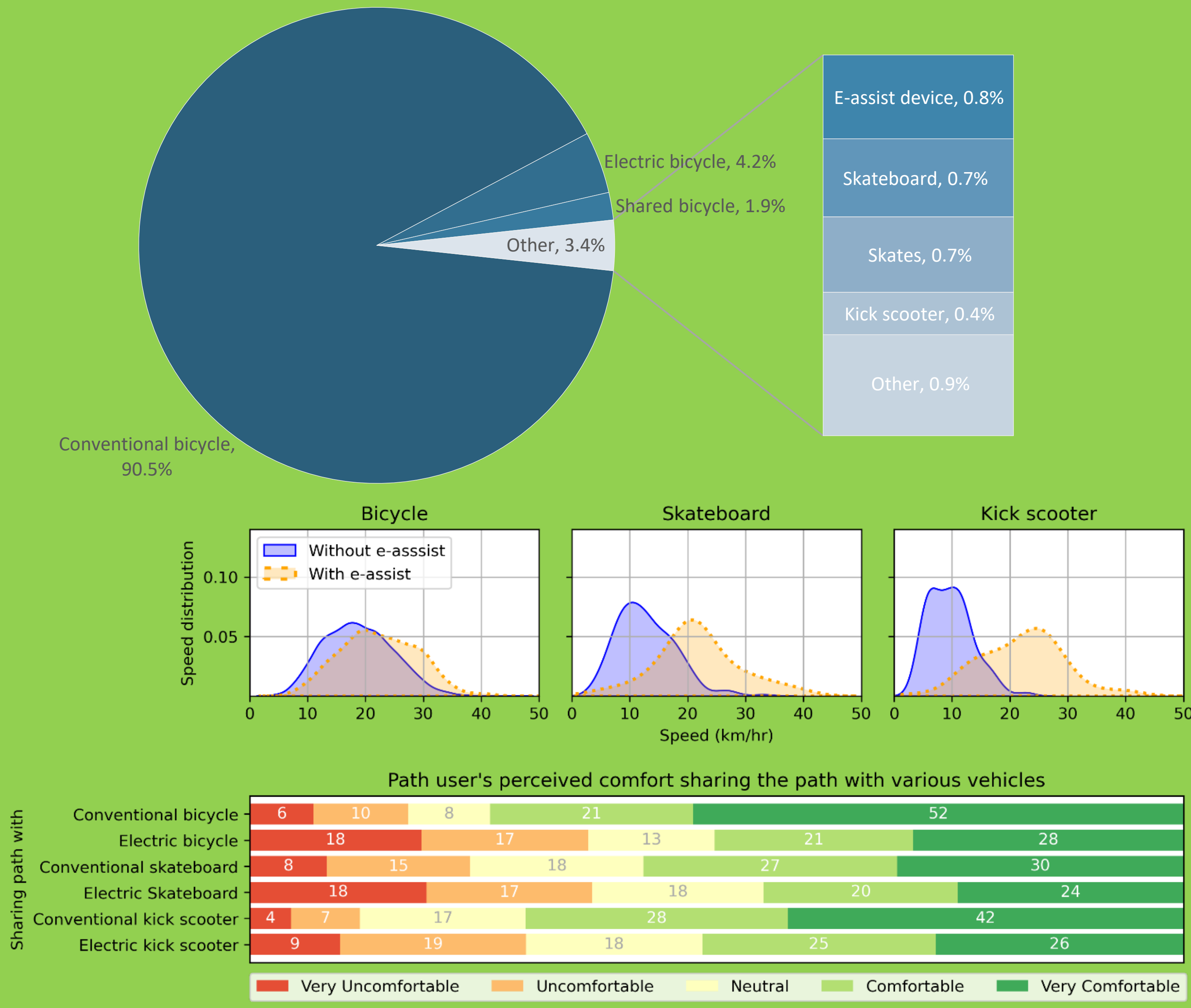

Figure 2. Observed mode shares (top) and speed profiles (middle), along with path users' comfort sharing the path with each vehicle type (bottom).

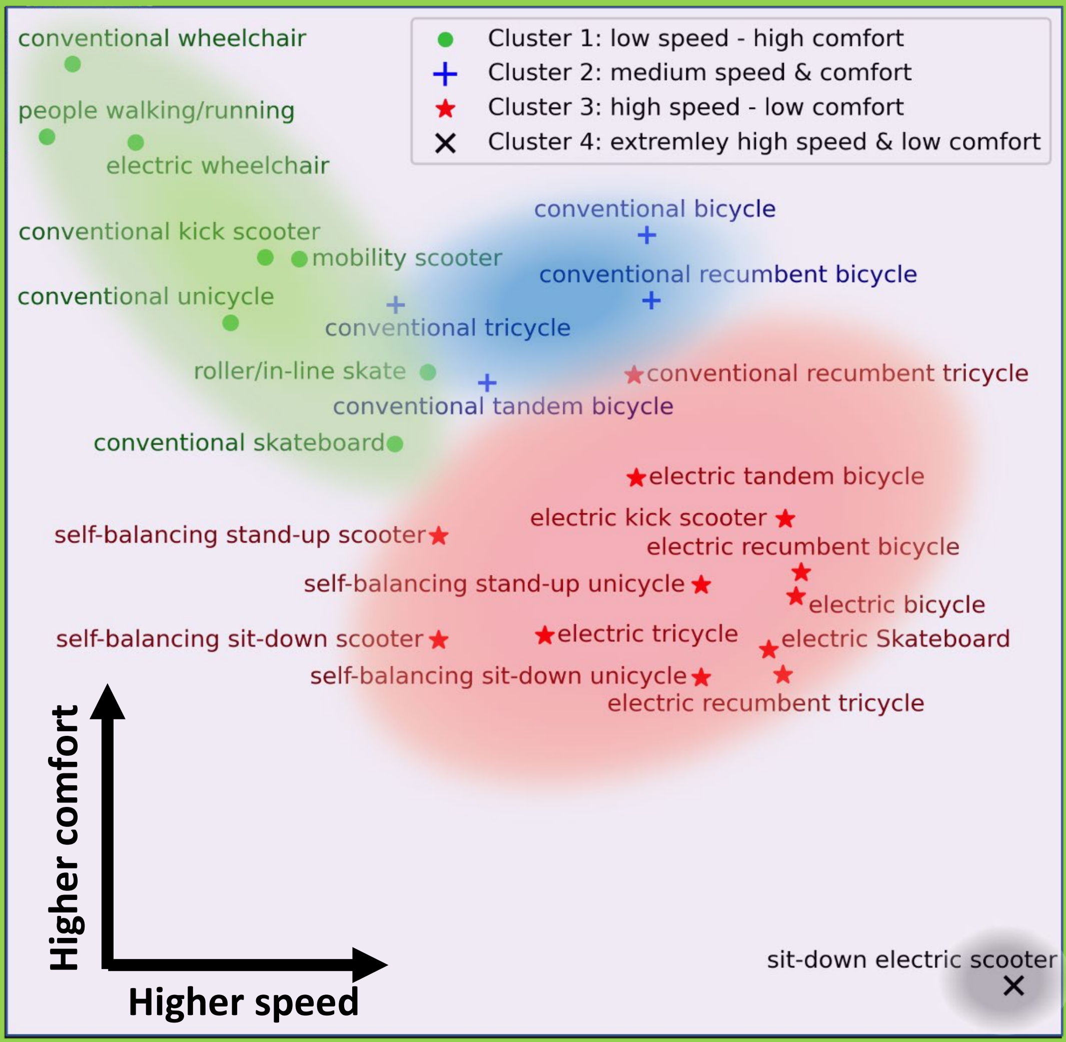

Figure 3. Clustering of vehicles into four speed and comfort-aligned clusters

1.3 Key findings

1. Conventional bicycles are still the dominant vehicle on off-street paths, with a mode share of more than 90%; a wide range of new mobility devices are present in cycling facilities, but their mode share is currently extremely low (far less than perceived by the public).

2. On average, electric-assist increases bicycle, skateboard, and kick scooter speeds by 4, 10, and 14 km/hr (21%, 83%, and 156%), respectively, over human-powered speeds (more on up-hills). This effect tends to homogenize average speeds around 20-22 km/hr, which may provide a potential safety benefit due to reduced frequency of overtaking conflicts and reduced speed differences while overtaking.

3. Except for sit-down electric scooters (moped-style motorcycles), electric-assist vehicles on paths rarely exceed the 32 km/hr regulatory limit for motor assisted cycles (7% - much less than car speed

violations). However, 44% of the observed electric kick scooter speeds would violate the 24 km/hr limit in the new Provincial electric kick scooter pilot project regulations.

4. Most travellers, including pedestrians, are comfortable sharing off-street paths with all the observed vehicle types except sit-down electric scooters.
5. Electric-assist in a vehicle reduces comfort for other path users equivalent to a 9 km/hr faster vehicle, all else (including speed) equal. Previous experience of an incident reduces traveller comfort equivalent to an 11 km/hr faster vehicle (all else equal).
6. The effect of electric-assist on speed is less than commonly perceived by the public; eliminating this perception bias would have the same effect on comfort as a 2 km/hr decrease in actual speeds.
7. We propose four speed- and comfort-aligned clusters of non-automobile vehicles using off-street paths for design and policy (Figure 3): 1) low-speed, 2) conventional bicycles, 3) electric-assist, and 4) moped-style scooters.
8. The negative impact on path user comfort of each additional Cluster 2 vehicle (conventional bicycle) is equivalent to 2.1 Cluster 1 vehicles (e.g., wheelchair); the negative impact of each additional Cluster 3 vehicle (electric-assist device) is equivalent to 1.3 Cluster 2 vehicles or 2.8 Cluster 1 vehicles. These comfort-equivalents can be used to make volume adjustments for new mobility devices in multi-use path design, such as thresholds for pedestrian segregation.

1.4 Conclusion and recommendations

1. The region is generally ready to accommodate new mobility devices in off-street paths without major effects on speeds and with only slight reductions in path user comfort (even with much higher mode shares of electric-assist vehicles).
2. Pedestrian discomfort justifies reduced volume thresholds for separating pedestrians from other travellers on multi-use paths and greenways that accommodate new mobility devices.
3. We should work to eliminate the use of (moped-style) sit-down electric scooters on off-street paths and cycling facilities, which are clear speed and comfort outliers.
4. Other than for moped-style scooters, the current 32 km/hr regulatory limit on electric-assist cycle speeds appears to be effective, and further enforcement is not needed at this time. However, achieving lower speeds for other electric-assist devices (e.g., the 24 km/hr limit in the Provincial electric kick scooter pilot) may require additional vehicle-level speed control strategies. Monitoring of electric kick scooter speeds during the pilot program is recommended.
5. Active transportation design guidelines should be updated to reflect real-world speeds, particularly for electric-assist bicycles and devices. The 30 km/hr design speed for cycling facilities suggested in the B.C. Active Transportation Design Guidelines is appropriate, even for facilities with a large share of electric-assist new mobility devices (as currently used). Further research is needed to include other design aspects of new devices such as stopping distances and turning radii.

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2 Introduction

2.1 Background

The focus of urban transportation has shifted towards multi-modal systems that provide travellers with more transportation options. This trend has accelerated with the advent of low-power vehicles such as electric-assist bicycles, scooters, and skateboards that are gaining popularity. These new mobility options can create opportunities to address enduring challenges in the transport sector related to traffic congestion, air pollution, climate change, public health, and energy consumption. Furthermore, a wider variety of mobility options can help make paths more equitable. For instance, as presented in Figure 4 by Robert Wood Johnson Foundation (2017), various forms of bicycles (recumbent, handcycle, strider, etc.) can help advance health equity by providing appropriate modes of travel for all.

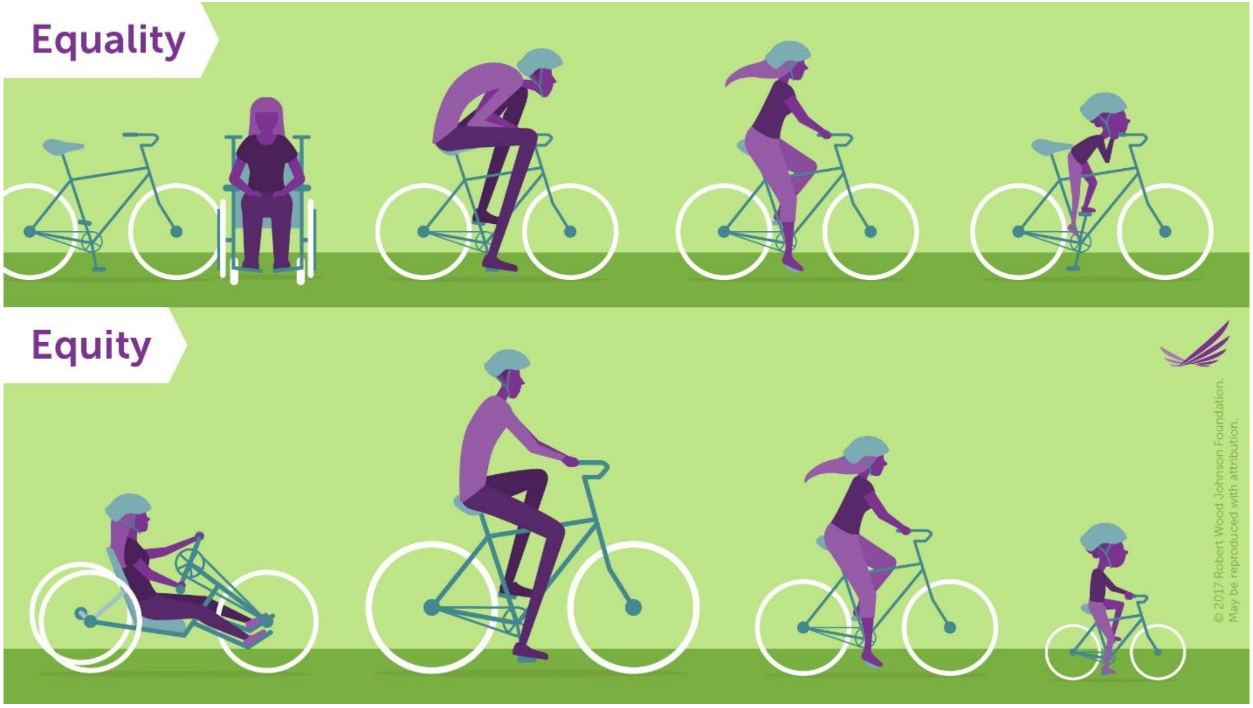


Figure 4. Visualizing health equity using bicycles (Robert Wood Johnson Foundation 2017)

These new mobility options come in a variety of sizes and configurations that may present new challenges for urban transport systems in Metro Vancouver, where there is already competition for space and access among travellers. Lack of adequate space results in a wider variety of vehicle sizes and speeds using the same facilities. This can lead to more interactions and conflicts, making cycle lanes less attractive for everyday travel. For instance, a recent study on the University of British Columbia (UBC) campus found that 70% of people consider pedestrian-bicycle interactions to be a safety issue (more than any other mode pairing) and that those perceptions were supported by surprisingly high numbers of incidents with physical contact (for 25% of respondents) (Gkekas, Bigazzi, and Gill 2020). Therefore, it is paramount that we capture the potential benefits of more diverse travel options while mitigating the risks of a wider variety of vehicles within constrained city street spaces in Metro Vancouver, where walking and cycling are already at comparatively high levels.

The hypothesized challenges associated with the new mobility options have led to various policy responses to mitigate conflicts, rarely informed by empirical evidence due to the limited research and knowledge in this area. For instance, electric bicycles (motor assisted cycles) are regulated in the Motor Vehicle Act to operate on streets but with motors not capable of propelling the bicycle at a speed greater than 32 km/hr. Electric skateboards are banned from the streets, and riding one can result in tickets as high as $600 (Mooney 2017). Electric kick scooters have also been banned from the streets until recently when personal electric kick scooters were allowed to operate on local streets and protected cycle lanes (excluding Vancouver seawall) with a speed limit of 24 km/hr (Ministry of Transportation and Infrastructure 2021a). As summarized in a recent media article, the increase in electric bicycles is "creating unique challenges" for transportation planners in the region, who must "take into consideration their variability of speed compared to conventional bicycles and how to keep everyone […] feeling safe" (Bartel 2018). This statement is reinforced by a recent study on the perspectives of stakeholders on electric bicycles policy that found that the current classification of electric bicycles under the Motor Vehicle Act poorly matched the vehicle operating differences and that a revision of vehicle classification and facility operating regulations was needed (Aono and Bigazzi 2019).

Policy on emerging transportation options should be informed by sound evidence to ensure a smooth introduction of new mobility devices on city streets. However, research on emerging personal transportation options is either non-existent or in its infancy. We even lack basic mode share data for the diversity of path users using non-auto facilities in the region, from which projections and forecasts can be made.

2.2 Literature review

A sizeable body of research on the development of electric bicycles is available that in some cases dates back to the late 19th century (Hung and Lim 2020), and research on topics such as user behaviour, planning, policy, health, and safety for electric bicycles has gained momentum since 2012 (O'Hern and Estgfaeller 2020). While there has recently been a small amount of research on stand-up electric scooters spawned by public sharing systems, research on other new mobility devices such as electric skateboards, and self-balancing scooters and unicycles is almost non-existent (O'Hern and Estgfaeller 2020). With an increase in the popularity of these modes, increased research on a wider array of personal mobility devices is needed.

To our knowledge, no existing studies have generated classified volume information for all types of vehicles/devices on paths or streets, anywhere in the world. Few studies have even examined electric bicycle share among bicyclists. Using travel survey data, Schepers et al. (2014) report that in 2007, 4% of cyclists older than 16 years were using electric bicycles in the Netherlands, and that number grew to 10% in 2013. In a survey study among participants of the 2016 Bike to Work campaign in Switzerland, 16% of survey respondents used electric bicycles for their commute (Rérat 2021). This upward trend can also be seen through electric bicycle sales in Switzerland, as reported by Rérat (2021), which shows the share of electric bicycles sold in Switzerland increased from 1% to 36% between 2006 and 2019. No similar data have been reported for North America, where most travel surveys do not distinguish between electric and non-electric bicycles.

More research has investigated the speeds of conventional and electric bicycles. A naturalistic study on 12 conventional bicycles riders, 14 pedal electric bicycle (electric bicycle) riders, and 20 speed pedal electric bicycle (classified as mopeds with max speed 45 km/hr) riders in the Netherlands showed that the average speed of each type of rider was 18, 21, and 30 km/hr, respectively (Twisk et al. 2021). The same study found that the speed differences between conventional and electric bicycles were higher in suburban areas where distances were longer. A study in the city of Kunming, China, found the average speed of conventional and electric bicycles to be 15 km/hr and 22 km/hr, respectively (Lin et al. 2008). This study also found that age and gender were factors that affected the speeds of cyclists. The average speed of electric bicycles were observed at 23 km/hr during the e-bikeSAFE study in Sweden, which was 9 km/hr higher than conventional bicycles (Dozza, Werneke, and Mackenzie 2013). In a naturalistic study of 6 cyclists on conventional and electric bicycles in Sweden, researchers found that transitioning to an electric bicycle increased average speed of cyclists from 17 to 20 km/hr (Huertas-Leyva, Dozza, and Baldanzini 2018). No similar information on the speeds of other types of new mobility devices are available.

Regarding interactions among path users, local research on the UBC campus showed that the majority of path users believe that conflicts among pedestrians and cyclists are a safety issue[1], with speed considered a primary factor in conflicts and incidents (Gkekas, Bigazzi, and Gill 2020). They also found that incidents with physical contact between non-auto travellers were surprisingly common, although injuries were extremely rare. A European study found that underestimation of electric bicycle speeds contributed to incidents with other road users (cyclists, pedestrians, and drivers) (Haustein and Møller 2016). A 2018 report on electric scooters in Portland, Oregon, deemed electric scooters to be appropriate to operate on cycling facilities but not on sidewalks, based on assumptions about pedestrian safety and comfort related to high e-scooter speeds (Portland Bureau of Transportation 2018). Another local study showed that perceived safety and comfort for pedestrians are strongly related but distinct, and that these perceptions can vary substantially across individuals, particularly with their travel habits (Gill, Bigazzi, and Winters 2022; Bigazzi, Gill, and Winters 2021). Research on interactions, conflicts, and incidents between new mobility devices and other path users is extremely limited, and much of information in public discourse and policy-making appears to be anecdotal or presumptive.

2.3 Objectives

To address the existing gaps in knowledge, the objectives of this research are to address the following questions:

1. How will new non-auto mobility options (electric bicycles and other no-/low-power vehicles) impact speed dynamics on non-auto facilities and interactions among non-auto travellers? Within this objective, we will address the following research sub-questions:
    - What are representative mode shares and speed distributions for the new non-auto mobility options with and without electric-assist, and how are the speeds influenced by microenvironment factors (path grade, facility design characteristics, season, number/type/speed of other path users, etc.)?
    - How are perceptions of comfort and safety for non-auto travellers influenced by the same set of microenvironment factors, and are those effects mediated by electric-assist?
2. Given these new non-auto mobility options, what transportation system policies, plans, and designs are needed to mitigate conflicts among non-auto modes? Within this objective, we will address the following research sub-questions:
    - What are the current vehicle type-based regulations and type-based operating restrictions in the federal, regional, and municipal documents?
    - To what extent have various agencies planned for and implemented strategies that support diverse mode choice for non-auto personal travel?
    - Is the Vancouver region ready to accommodate these new modes with existing infrastructure and policies?

2.4 Overview of study methods

The study framework is summarized in Figure 5. The project objectives required an extensive data collection campaign to gather information on mode shares and speed profiles of all types of vehicles used in off-street paths,

[1] Conflicts with motor vehicles were perceived as less of a safety issue on campus, likely because most of campus is a "Pedestrian Priority Zone" with little or no motor vehicle activity.

as well as path users' comfort in sharing the path with each vehicle type. The count and speed data collection was conducted over 4 seasons at 12 sampling locations across Metro Vancouver using pneumatic tube counters and sport cameras installed at each location. A researcher (classifying assistant) reviewed all vehicle observations matched with the count/speed data to manually classify the vehicles using visually identifiable objective features such as the number of wheels, the number of seats, the existence of a battery/motor, etc. A web survey was conducted with recruitment at the same sampling locations to collect information on how comfortable path users are in sharing the path with various types of vehicles. The research methods were approved by the Behavioural Research Ethics Boards of the University of British Columbia, under approval H19-02066.

Following the data collection period, three datasets were created: 1) a mode share dataset, 2) a speed profile dataset, and 3) a comfort rating dataset. Each dataset was thoroughly inspected, processed, and filtered and then described and visualized in Python 3.7 to create baseline descriptive data for mode share and speed profile of each vehicle type, and also path user's comfort in sharing the path with each vehicle. Speed and comfort rating modelling were also conducted with mixed-effect regression models to analyze the effects of electric-assist, microenvironment factors, and sociodemographic indicators on speed and comfort. Lastly, k-means clustering was used to group all transportation modes into four speed and comfort-aligned clusters. Finally, a review of transportation policy, planning, and design documents related to the emerging transportation options in municipalities Metro Vancouver Regional District, as well as regional, provincial, and federal entities was conducted.

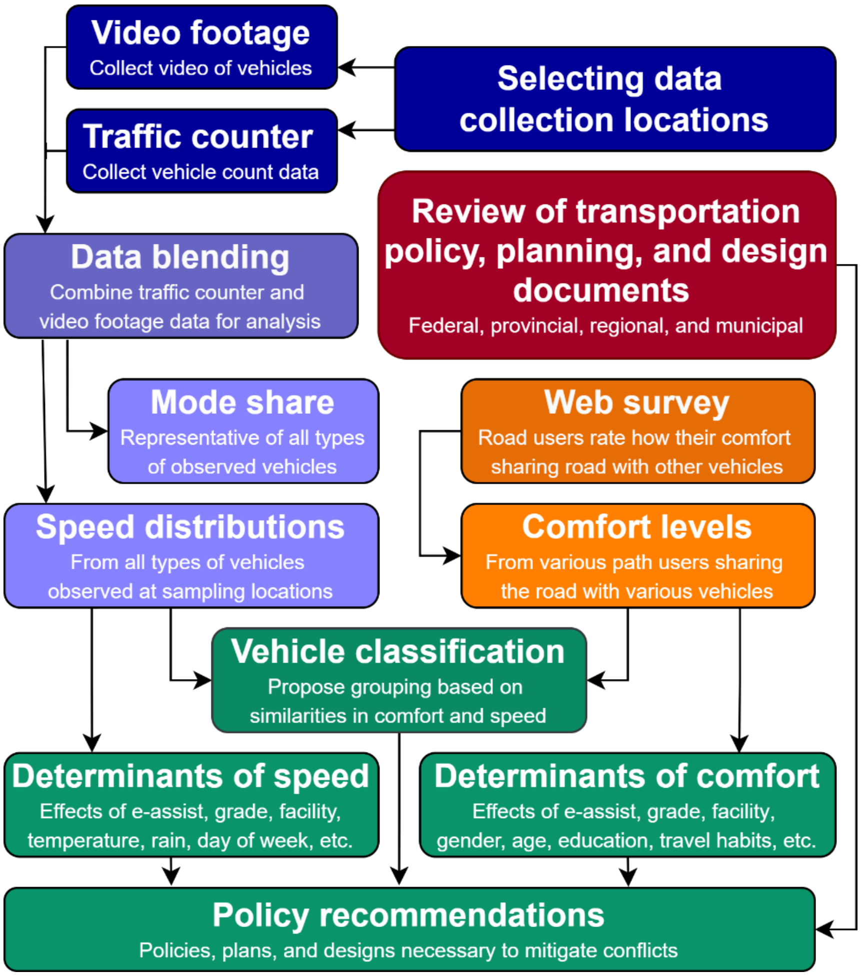


Figure 5. Study framework

3 Methods

3.1 Sampling locations

A substantial field data collection was undertaken to address the objectives of this study. First, 12 locations on off-street cycling facilities (excluding roadways) in Metro Vancouver were selected at which to collect data (see Appendix A: Sampling location selection for the sampling location selection procedure.) Figure 6 shows the 12 selected sampling locations in the Metro Vancouver area for data collection. Each of the cities of West Vancouver, North Vancouver, New Westminster, and Richmond were represented in this study by one sampling location. There were also two sampling locations in Burnaby and two in the University Endowment Lands (University of British Columbia). Lastly, there were four sampling locations in the City of Vancouver. Five of the sampling locations (2, 3, 4, 5, and 9 in Figure 6) were physically separated cycle paths with no pedestrian access (and parallel pedestrian facilities); the other 7 sampling locations were multi-use paths shared with pedestrians.

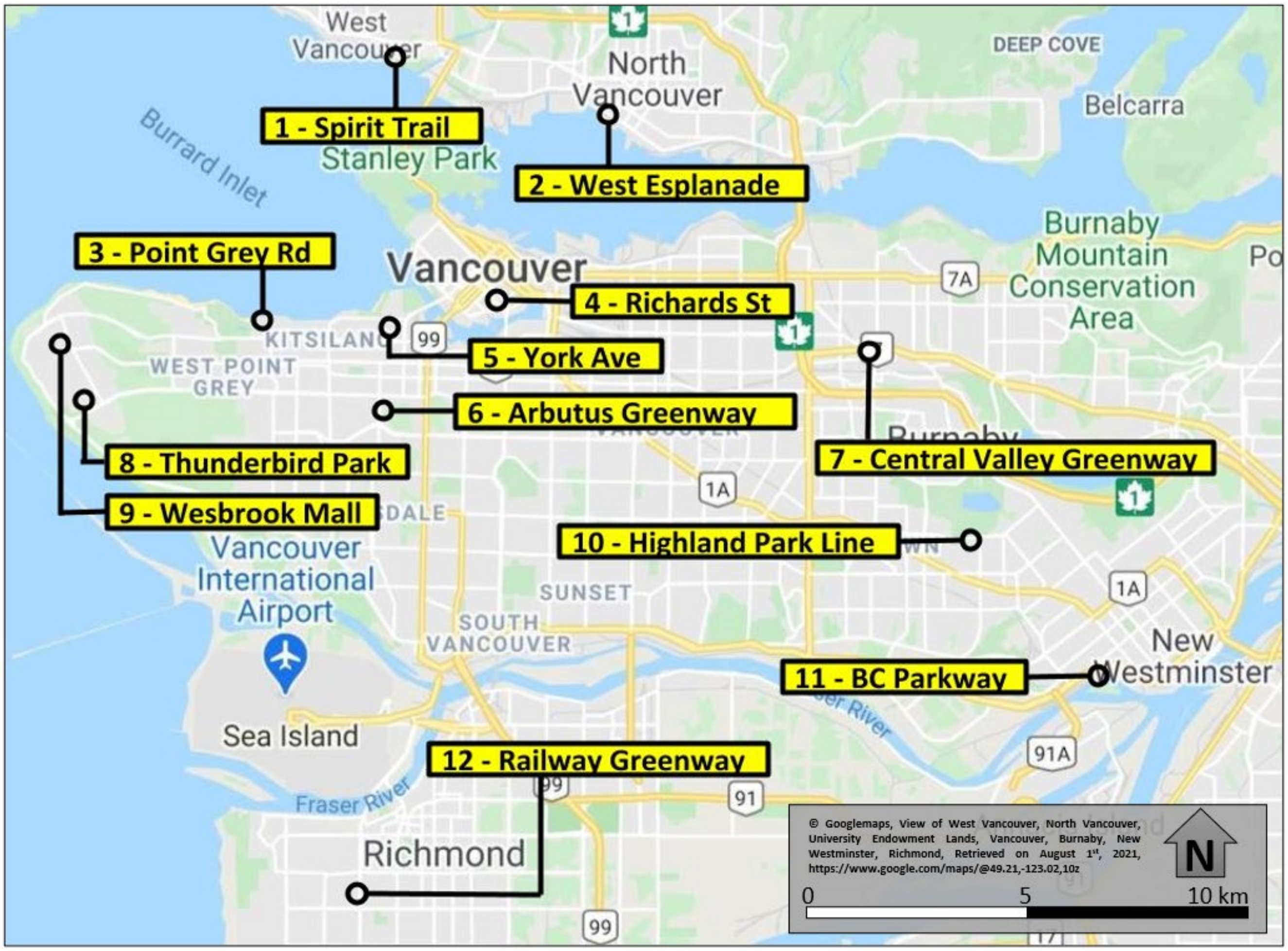


Figure 6. The 12 selected sampling locations for data collection in Metro Vancouver area (Google, n.d.)

3.2 Classified count and speed data collection

Vehicle count and speed surveys were conducted at the 12 sampling locations in 4 seasons (see Appendix B: Data collection schedule). After studying the pros and cons of various methods of collecting the above data (see Appendix C: Decision matrix for selection of classified count and speed data collection methods), pneumatic tubes counters (MetroCount RidePod® BTcombined) with a sport camera (GoPro) were selected as the instruments for data collection (Figure 7). Pneumatic tubes were placed across the path to record the number of passing vehicles and their individual speeds. In addition, the GoPro camera was installed on a pole next to the path to record simultaneous video images. The video footage was later synchronized with the MetroCount timestamp data, and the vehicles were manually coded according to the vehicle type categories described in Appendix G: Vehicle classification method.

Figure 7. Classified count and speed data collection instrument (pneumatic tubes and a camera)

To ensure the accuracy of count and speed measurements, count and speed accuracy tests were run on the pneumatic tubes against ground truth measurements of count and speed. The pneumatic tubes showed 100% accuracy in counts and consistently less than 5% error in speed measurements. Further investigation of the pneumatic tubes proved that they are an effective tool in measuring naturalistic speed of cycling with little to no intrusion to the cruising speed of cyclists (see Appendix D: Post-evaluation of classified count and speed data collection instruments for details).

3.3 Path user comfort web survey

A web intercept survey was designed and advertised to collect data on the nature of interactions among users of non-auto road facilities, particularly their comfort level in sharing the path with various vehicles. The survey was created using the UBC survey tool, Qualtrics, and advertised using sandwich boards at the same sampling locations where count and speed data were collected (Figure 8, see Appendix E: Web survey data collection.) The survey began with a consent form, followed by questions regarding the sampling location at which they saw the survey advertisement and the mode of travel they used while coming across the survey advertisement. Afterwards, a series of images, each representing a type of vehicle observed on the paths (diagrams in Appendix H: Diagram of observed vehicles), were shown to the survey respondents with a prompt to indicate their level of comfort sharing that path with each vehicle while using the mode they were using on the day they came across the survey. Next, respondents were asked if they had experienced any incidents in which they fell to avoid contact, caused someone to fall, or made contact with another person or wheeled vehicle. The questions regarding past experiences were followed by a one-page set of travel habit and demographic questions: frequency of travel by different modes, frequency of travel in the sampling location, age, gender, education, household income, and level of comfort taking risks (Based on Glanz et al. 2016).

Figure 8. Sandwich board poster containing the web survey advertisement

3.4 Modeling

Two mixed-effects regression models and a k-means clustering model were created for in-depth analysis of the speed and comfort data in this report. In the first model, speed of conventional and electric bicycles, scooters, and skateboards were estimated using a mixed-effect regression model with *sampling locations* as the mixed-effects groups. Independent variables in the model included variables that explained the effects of the built environment, vehicle, weather, and time on speed. Built environment variables included *uphill grade* which was created as a binary variable which indicated 1 for observations in sampling location-directions with grades higher than 3%, and 0 for otherwise. A facility type variable was created as a binary variable (*multi-use path*) which indicated 1 if the observations were made in multi-use paths (shared with pedestrians), and 0 if the observations were made on off-street cycling facilities separated from pedestrians. *Traffic volume* variable was created that showed the hourly count of vehicles passing the pneumatic tubes at the hour the observation was made. Vehicle variables include *electric-assist* which was a binary variable that indicated if the observed vehicle had electric-assist (1) or not (0). Furthermore, the number of human riders (adult or child) on an observed vehicle was created as an integer variable with values 1 to 3. Weather variables include *temperature* in degrees Celsius, and *hourly rain* in millimetres, and the time variables included the binary *weekend* variables which indicated if the observation was made on the weekend (1) or on the weekdays (0). Furthermore, a binary *COVID lockdown* variable was created that indicated 1 if the observation was made after March 18th, 2020, when the government of British Columbia declared a provincial state of emergency over the COVID-19 pandemic, and 0 if the observation was made before that time. The data collection period did not include dates after April 20th, 2020, around the time when the province announced success in flattening the COVID-19 curve and promised to lift some restrictions (Kotyk 2021).

In the second model, the survey respondents' perceived comfort towards sharing path with various vehicles was estimated using a mixed-effect regression model with *sampling locations* and *survey respondents* as the mixed-effects groups. Independent variables in the model included variables that explained the effects of the perceiver, vehicle, and built environment on comfort. Perceiver variables included binary variables such as gender variable *male* (1: male, 0: other genders), education variable *university degree* (1: Bachelor's degree or higher, 0: lower than bachelor's degree), and *experienced incident* which indicated 1 if the perceiver was involved in an incident where they fell to avoid contact, causing them to fall, or make contact with another path user (0: if no previous incident). Furthermore, *age*, *comfort taking risk*, and *active frequency* were among the perceiver variables in the model. *Comfort taking risk* was a self-reported value by the perceiver between -10 (most uncomfortable) and 10 (most comfortable), and *active frequency* was a value between -4 (only travelling by car every day) and 12 (travelling by walking, bus, and cycling every day and never driving). Perceiver variables include existence of *electric-assist* and *observed speed of vehicle* the perceiver rated their comfort against as observed in phase 1 of data collection, Classified count and speed data collection. Furthermore, a binary variable *alignment of modes* was created that indicated if the perceiver's mode of travel while answering the intercept survey was similar to the mode of travel against whom they were rating their comfort sharing path with. The outcomes of the *alignment of modes* variable are presented in Table 1. The built environment variable *multi-use* path which indicated the type of facility at which the perceiver answered the survey was also included in the model similarly to the speed model explained above.

Table 1. Outcomes of the alignment of modes variable depending on survey respondents' (perceivers') mode of travel and the mode of travel against whom they were rating their comfort sharing path with

		Modes of travel against whom survey respondents reported their comfort sharing path with		
		People walking/running	People riding conventional and electric bicycles	People riding all other types of vehicles
Survey respondents' mode of travel	People walking/running	1	0	0
	People riding conventional and electric bicycles	0	1	0
	People riding all other types of vehicles	0	0	1

Lastly, using k-means clustering algorithm the modes of travel against which survey respondents rated their comfort sharing path with were clustered into speed and comfort-aligned groups. In this model 1) the speed of each mode of travel, 2) the average comfort perceived by people walking/running, 3) average comfort perceived by people riding conventional and electric bicycles (current dominant rolling vehicles in cycling facilities), and 4) the average comfort perceived by people riding all other modes of travel were used as input variables for creating clusters. The modes of travel were first clustered into 2 and then 3 and 4 clusters. In each step, the clusters were created by minimizing within-cluster variances in the above four variables.

3.5 Policy review

A review of transportation policy, planning, and design documents related to the emerging transportation options in Metro Vancouver Regional District was conducted in Summer 2020. A better understanding of the current state of policy and design documents in various levels of government can help us bridge the gap that exists between advancement in the technological world of low-power personal vehicles, and public policy related to them. As the use of the emerging transportation options continue to rise, the need for well-informed policy, planning, and design guidance will rise as well.

The scope of this review was limited to the municipalities in partnership with Metro Vancouver Regional District. This includes 21 municipalities, Electoral Area A, and Tsawwassen First Nation. Further to the Metro Vancouver municipal partners, provincial and federal policies were also evaluated in light of how they affect said partners. This will help determine to what extent various agencies have planned for and implemented strategies that support diverse mode choice for non-auto personal travel.

Webpages for all 21 municipalities of Metro Vancouver, in addition to Electoral Area A and Tsawwassen First Nation were investigated for relevant emerging mobility policy in documents with topics related to transportation, environment, parks and trails, and major projects and land use plans. TransLink, Metro Vancouver, and Insurance Corporation of British Columbia (ICBC), Transport Canada, and Transportation Association of Canada were the agencies investigated for regional, provincial, and federal policies. Since each respective agency had a unique website, each site was examined according to its own layout (for instance pages such as "about us", strategies and plan, publications etc.) and the following keywords were searched for:

- Emerging mobility
- Emerging transportation
- Active transportation
- Scooter
- Micromobility
- New mobility
- Bicycle
- Electric bicycle
- Bikeshare
- Skateboard
- Rollerblade
- Unicycle

The review process involved two main parts: 1) with a focus on emerging new mobility vehicle-class based policies (i.e., restrictions), and 2) on broader emerging new mobility policy and planning actions. In part 1 of the review process, answers to the following three questions were sought:

- Are there vehicle class based device restrictions? (Constraints on the device's functionality or dimensions)
- Are there vehicle class based operating restrictions? (Constraints on how, where, and when the device may be operated)
- Are there vehicle class based facility design restrictions? (Constraints on how facilities must be designed to accommodate the device)

In part 2 of the review process, answers to the following questions were sought: Are there explicit instances of inclusion of emerging transportation devices? Are there planning guidelines for emerging transportation devices? Are emerging transportation devices promoted as a policy? Are there design recommendations regarding emerging transportation devices?

4 Results

4.1 Mode shares (count and classification)

In the raw count and classification dataset, 31,707 hits (tube compressions) were registered on the pneumatic tubes. Figure 9 shows samples of vehicles observed during the video recordings of the sampling locations. After three stages of data cleaning (C1, C2, and C3 in Figure 10), 6,425 observations were removed, leaving 25,282 observations for count and classification analysis (cleaned data). In the data cleaning process, observations that C1) were classified as non-vehicles, C2) did not have video footage (battery drainage, researcher error, etc.) or had video footage but were not visible (low lighting, heavy rain, etc.), or C3) were recorded due to pedestrians stepping on the pneumatic tubes (but were registered as vehicle) were removed. Each tile on this figure represents 500 observations. For more detailed information regarding data processing and filtering, please read Appendix F: Data processing and filtering.

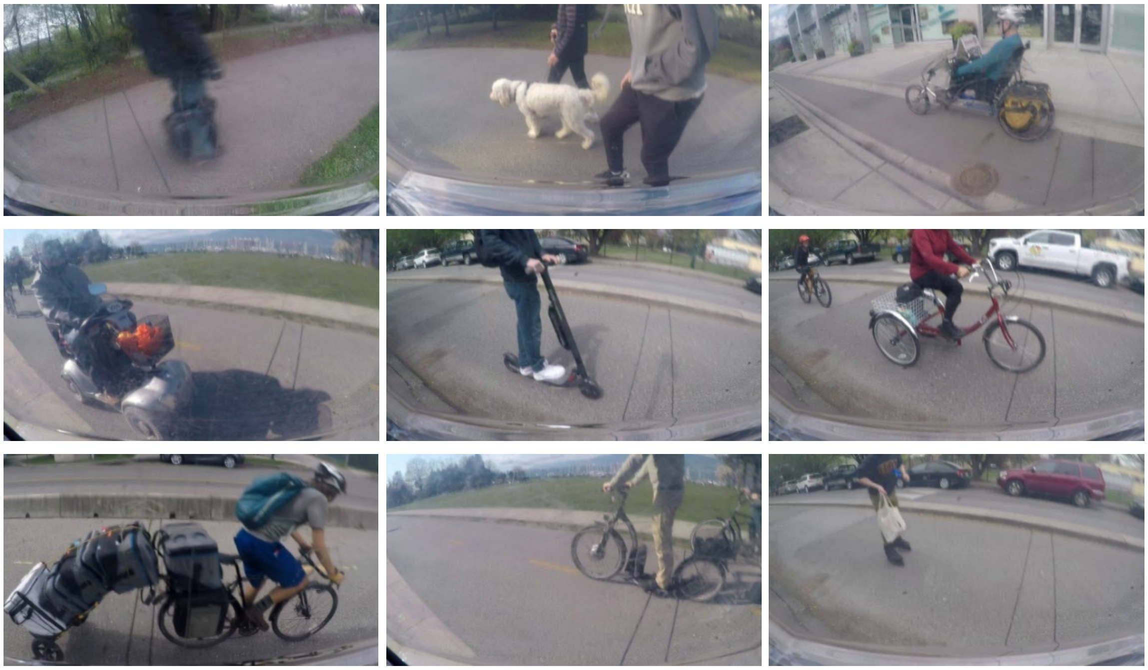


Figure 9. Variety of types of personal vehicles observed at the sampling locations through the recorded video footage

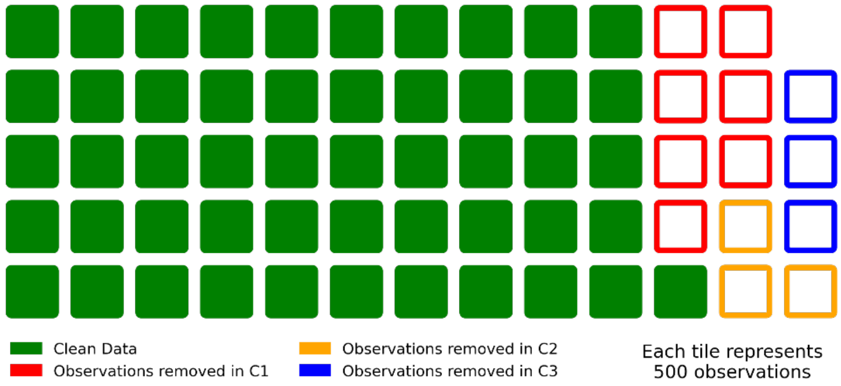


Figure 10. The number of observations removed data processing and cleaning of count and classification dataset

Table 2 shows the number of vehicles observed in the data collection process. The most dominant vehicle observed on the paths (22,885 times) were conventional (non-electric) bicycles. The second most common vehicles at the sampling locations were electric bicycles with a frequency of 1,062. The third most common vehicle was shared bicycles, which were observed 472 times. Shared bicycles observed at our sampling locations were HOPR bikes (at UBC campus), Mobi bikes (in Vancouver), and U-cycle bikes (in Richmond). The rest of the vehicles comprise a small share of the observed vehicles (less than 1%). Vehicles that we did not expect to observe were also recorded using the cycling facilities, including golf carts, private automobiles, and a truck.

Table 2. Count of every type of vehicle observed at sampling locations during data collection

Vehicle Type	Count
Conventional Bicycle	22885
Electric Bicycle	1062
Shared Bicycle	472
Conventional Skateboard	177
Roller/Inline Skate	171
Conventional Kick Scooter	96
Stand-Up Electric Scooter	78
Sit-Down Electric Scooter	56
Tandem Bicycle (E/non-E)	55
Mobility Scooter	40
Tricycle (E/non-E)	33
Recumbent Bicycle (E/non-E)	28
Self-Balancing Stand-Up Unicycle	28
Electric Skateboard	26
Conventional Wheelchair	17
Strider Bicycle	16
Golf Cart	12
Recumbent Tricycle (E/non-E)	8
Motorcycle	7
Conventional Unicycle	5
Car	5
Electric Wheelchair	2
Self-Balancing Stand-Up Scooter	2
Truck	1

Figure 11 shows the mode share of each vehicle in percentages. As stated above, conventional bicycles are the most dominant mode with mode share of 90.5%. Following conventional bicycles are electric bicycles with mode share of 4.2% and shared bicycles with mode share of 1.9%. No other vehicle type had a mode share above 1%, and only conventional skateboards and roller/inline skates had a mode share above 0.5%. The mode share of electric bicycles was lower than expected based on our personal experiences observing bicycles while cycling in the city and evidence from the City of Vancouver staff. Further testing and analysis were conducted which provided confirmatory evidence and strengthened our confidence in the methods used to distinguish between electric and conventional bicycles (see Appendix I: Coding electric bicycles).

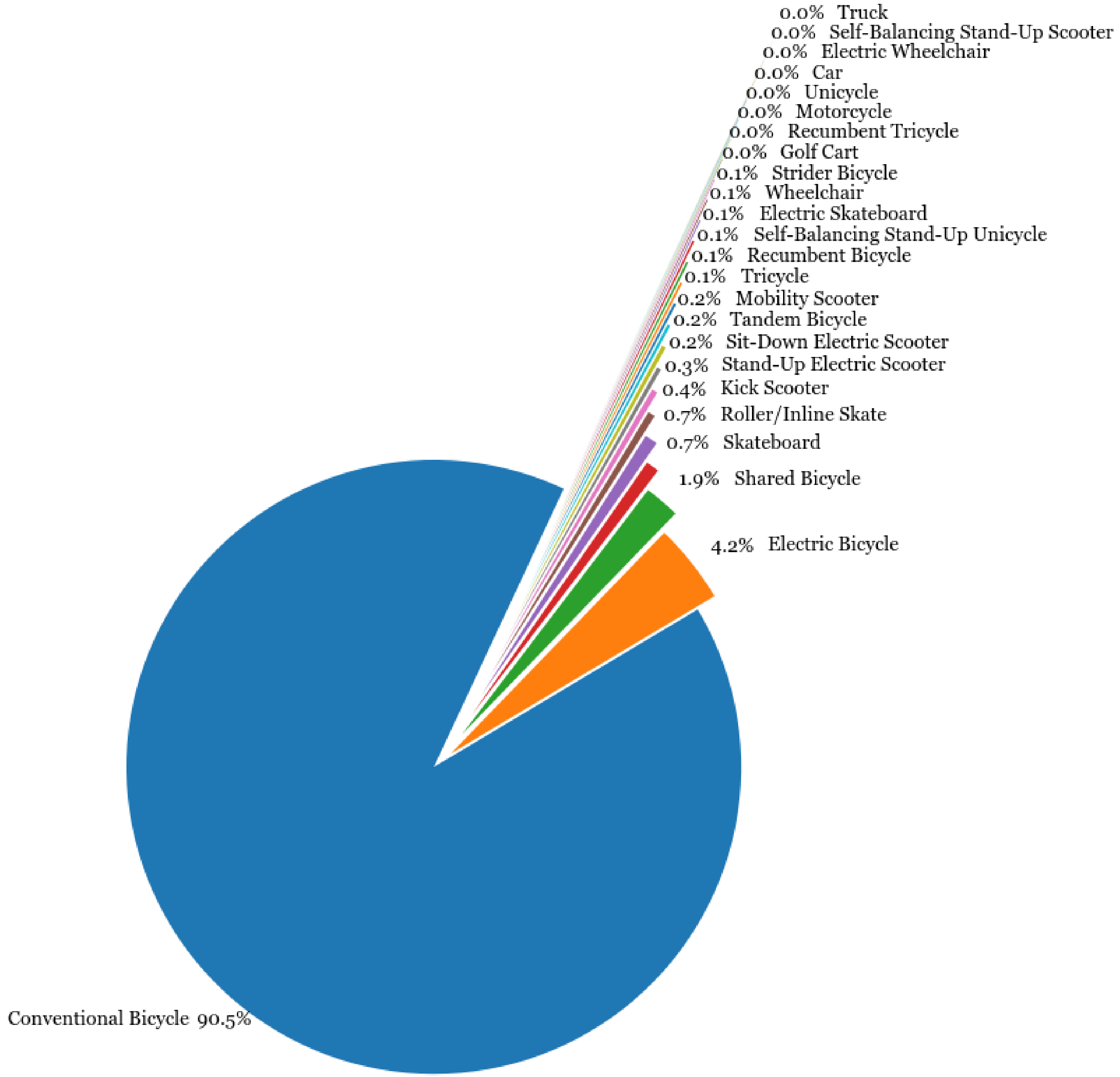


Figure 11. Pie chart of mode share of each type of vehicle in percentages

Figure 12 was created to show the temporal pattern of traffic at the sampling locations. Each green line represents hourly traffic normalized by total traffic at one sampling location at a day of data collection and the red line shows the average of all the green lines. The morning peak and the evening peak are visible at 8 am and 5 pm, respectively, in the weekday plot (top), and the afternoon peak is visible at 2 pm in the weekend plot (bottom).

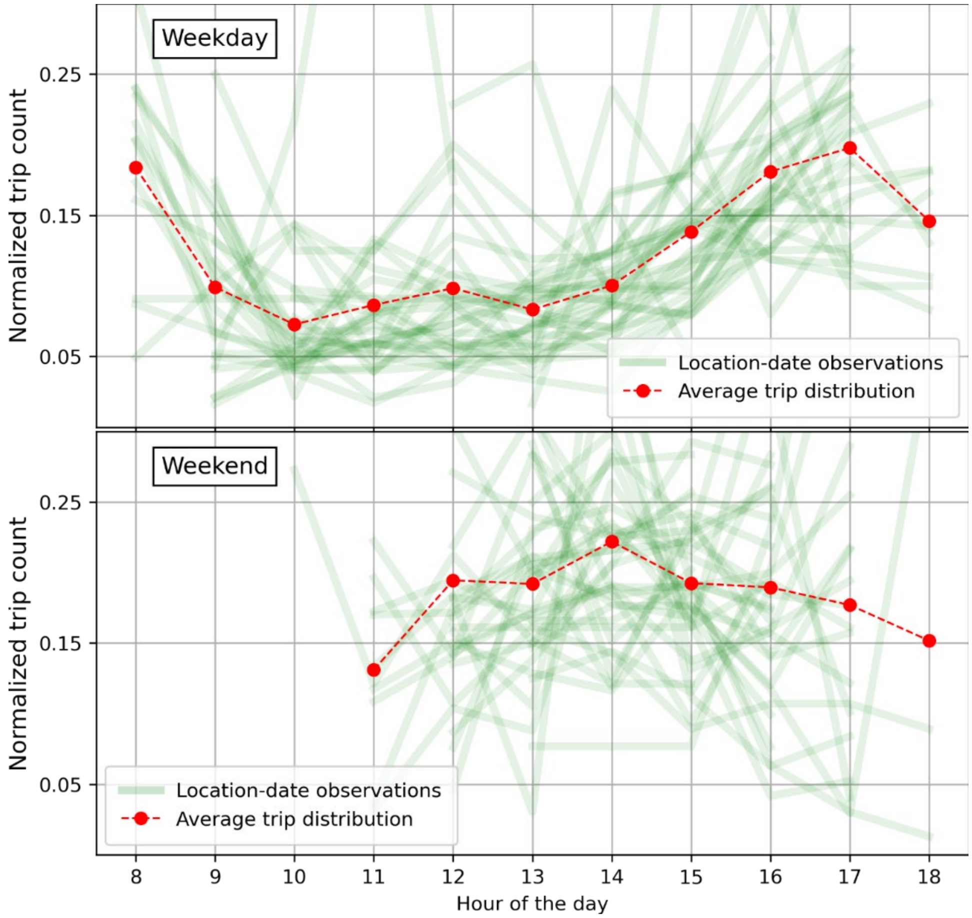


Figure 12. Temporal pattern of traffic at the sampling locations-dates

4.2 Speed profiles

The 25,282 vehicle observations reported in the count and classification section were studied for a fourth round of data cleaning (C4) as pneumatic tubes recorded incorrect speed data for some vehicles. In C4, observations in which 1) travellers jumped over the tubes with their vehicles (especially on skateboards), 2) two travellers crossed the tubes on their vehicles at the same time in opposite directions, and 3) pedestrians stepped on the tubes simultaneously with a person on a vehicle were studied for possible removal from the dataset. The pneumatic tubes were highly prone to erroneous measurement of speed in observations with the above characteristics and the C4 data cleaning process removed 422 observations from the speed dataset. Figure 13 shows the approximate number of observations removed in the speed data cleaning processes C1 to C4.

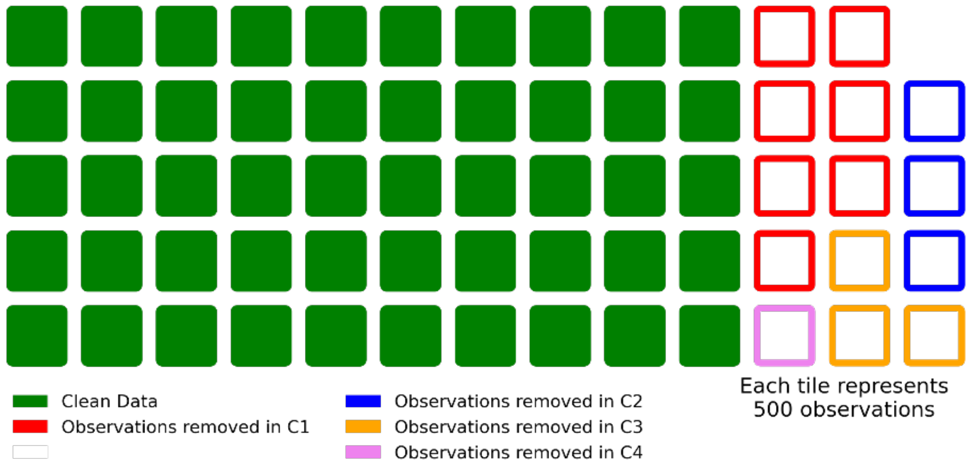


Figure 13. The number of observations removed in processing and filtering count and classification data

The distributions of speeds observed during the data collection period are presented in Figure 14 for 17 vehicles. Speed distributions are presented with a blue curve for each vehicle in a separate subplot and are sorted in a descending order of mean speed from top left to the bottom right corner. The solid green vertical line and the dotted red line represent the mean speed and the 85th percentile speeds of vehicles, respectively. Separate downhill/flat terrain (green solid line) and uphill terrain (red solid line) speed distributions are created for vehicles with more than 10 observations in each grade category. The red hatch lines on the two figures show the vehicles that are illegal to operate in the cycle lanes, namely sit-down electric scooters, gas-powered motorcycles, golf carts, automobiles, and a truck (others are also illegal under the MVA).

The fastest vehicles observed during the data collection period are sit-down electric scooters and gas-powered motorcycles with a mean observed speed of 28 km/hr. This was followed by electric bicycles with a mean observed speed of 22 km/hr. Conventional bicycles, the most dominant vehicle in the paths, were ranked 7th with mean observed speed of 19 km/hr, closely tied with recumbent bicycles/tricycles with similar speed ranked 6th. The emerging micromobility vehicles, i.e., electric push scooters, electric skateboards, and electric self-balancing unicycles, are among the fastest vehicles with mean observed speeds of 22, 22, 20 km/hr, respectively. As mentioned in the previous section, golf carts, cars, and trucks were also observed on paths with mean speed of 18 km/hr. The golf carts were mainly park/city service vehicles; the automobiles appeared to be private and were on average faster than the golf carts.

The slowest vehicles observed were conventional wheelchairs, conventional unicycles, conventional kick scooters, and mobility scooters with mean speeds of 10 km/hr or lower. Shared bicycles (Mobi, HOPR, and Ucycle) were among the medium speed vehicles along with tandem bicycles, roller/inline skate, tricycles, and conventional skateboards with mean speed of between 10 km/hr and 15 km/hr.

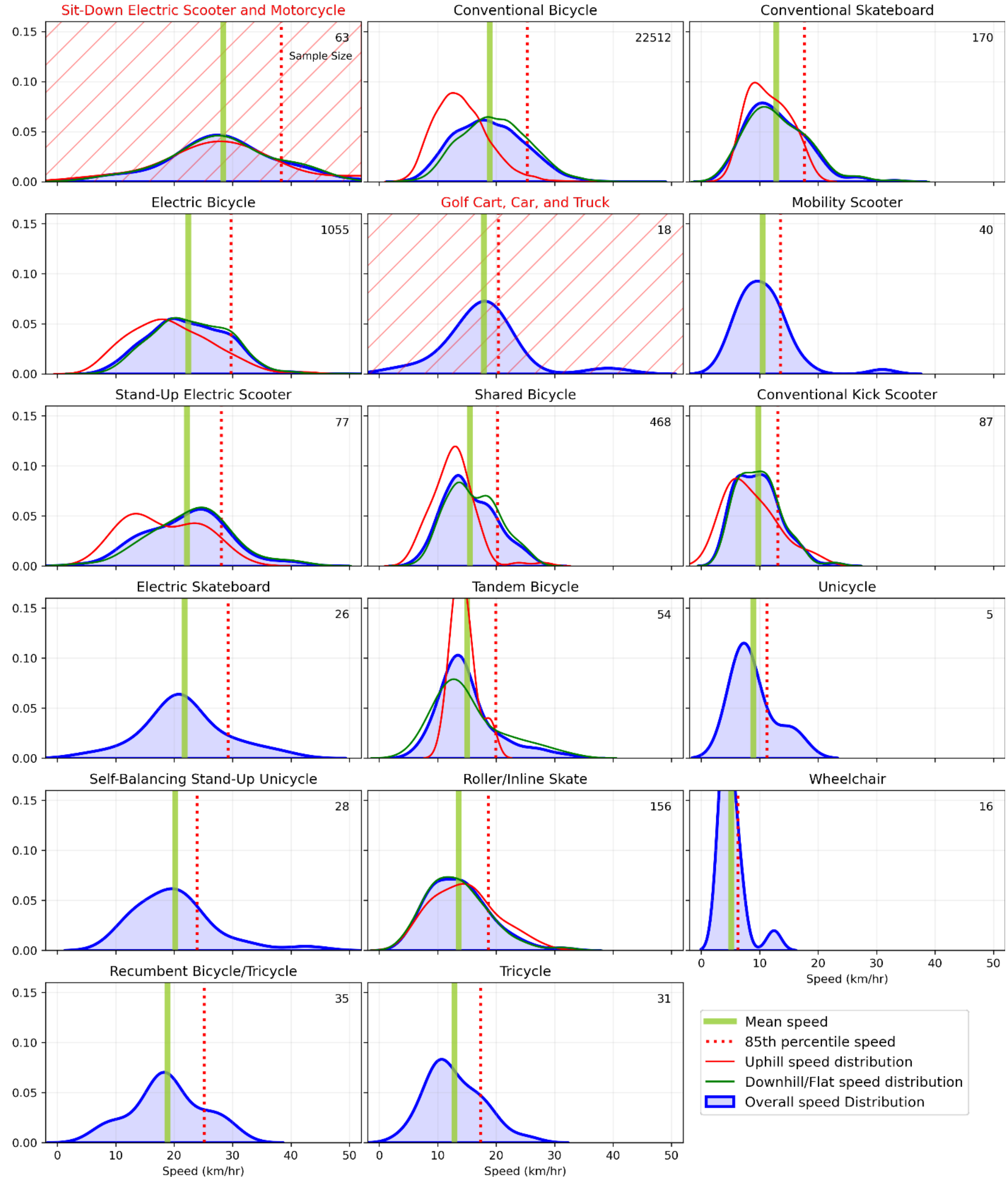


Figure 14. Speed distributions of vehicles observed on cycling facilities along with separate uphill and downhill/flat speed distributions and vertical lines indicating mean speed and 85th percentile speed.

Figure 15 illustrates the effect of electric-assist on vehicles of the same type. The green solid lines and the red dotted lines represent the mean observed speed and the 85th percentile observed speed of the vehicles, respectively. The red shaded part of the figure represents speeds higher than the maximum legal speed of motor assisted cycles (32 km/hr) according to the BC Motor Vehicle Act. Further in the figure, the percentage of observed vehicles with speeds above 32 km/hr are presented at the top.

Conventional bicycles, and conventional wheelchairs have the lowest speed difference from their electric counterpart (4 km/hr and 5 km/hr speed difference). This value of mean speed difference increases to 9 km/hr, 12km/hr, and 11 km/hr for skateboards, scooters, and unicycles. The last vehicle in this figure is sit-down electric scooters (moped-style) with mean speed of 28 km/hr and no non-electric version.

Conventional vehicles almost never travel over the 32 km/hr speed limit. Only 2% of conventional bicycles and 1 percent of conventional skateboards were observed above 32 km/hr. However, consistently 7% to 8% of electric bicycles, skateboards, scooters, and unicycles travel above 32 km/hr. The fastest vehicles are sit-down electric scooters (moped-style) with 30% of above the 32 km/hr MVA speed limit for motor assisted cycles.

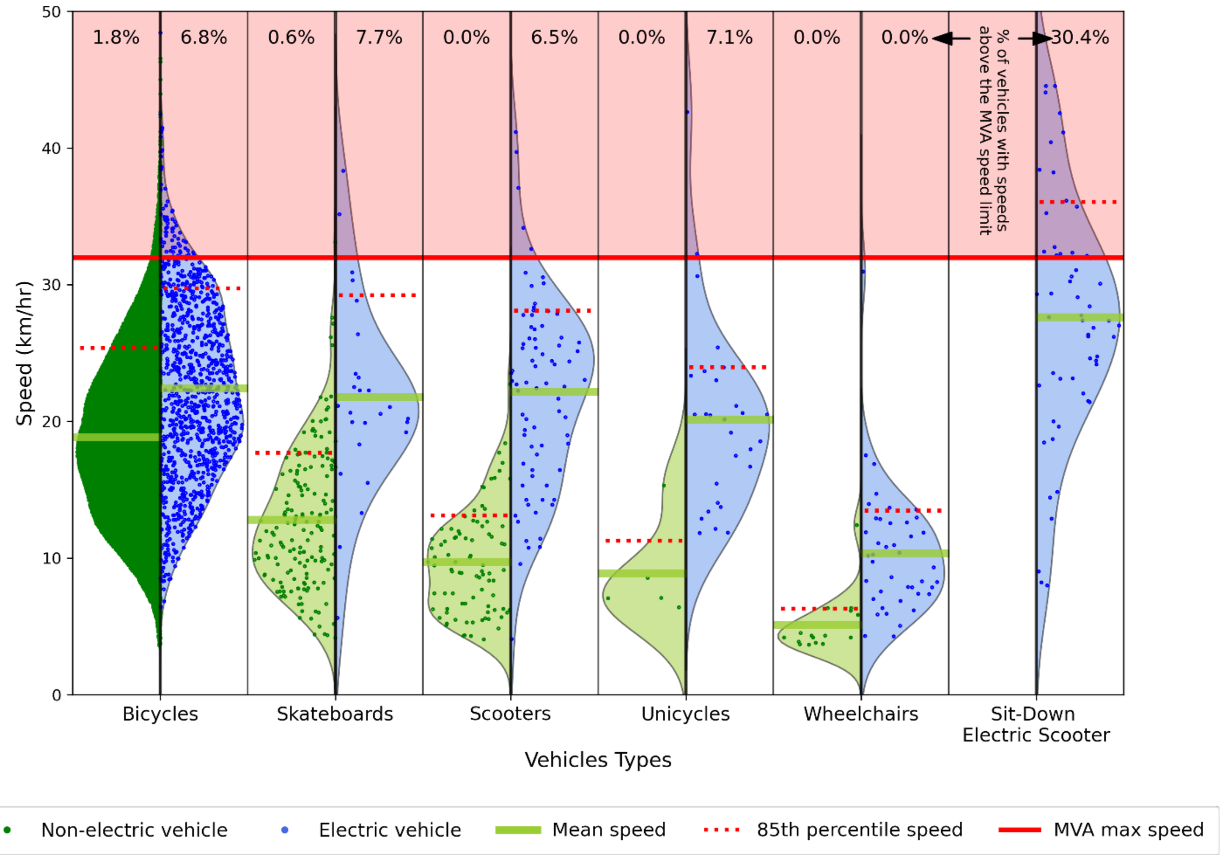


Figure 15. Speed distribution of bicycles, skateboards, scooters, unicycles, wheelchairs, with and without electric-assist, and sit-down-electric scooters (moped-style). The green solid indicates the mean speed and the red dotted lines indicate the 85th percentile speed. The red shaded part of the figure illustrates the speeds above the 32 km/hr MVA speed limit for motor assisted cycles.

The speed of bicycles with and without electric-assist are presented in Figure 16 in two types of facilities (shared with and separated from pedestrians), and two types of path grade conditions (uphill and downhill/flat). Cyclists are the fastest (24 km/hr) on paths separated from pedestrians, riding downhill with electric-assist, and slowest (14 km/hr) on paths shared with pedestrians, riding uphill without electric-assist. The effects of electric-assist on the speed of cyclists are highest when riding uphill with mean speed difference of 5 km/hr and 7 km/hr on paths shared with and separated from pedestrians, respectively. This value reduces to 3 km/hr when riding downhill or on flat surfaces for both facility types. Mean speed of bicycles are 2-4 km/hr higher in facilities separated from pedestrians that in facilities shared with pedestrians.

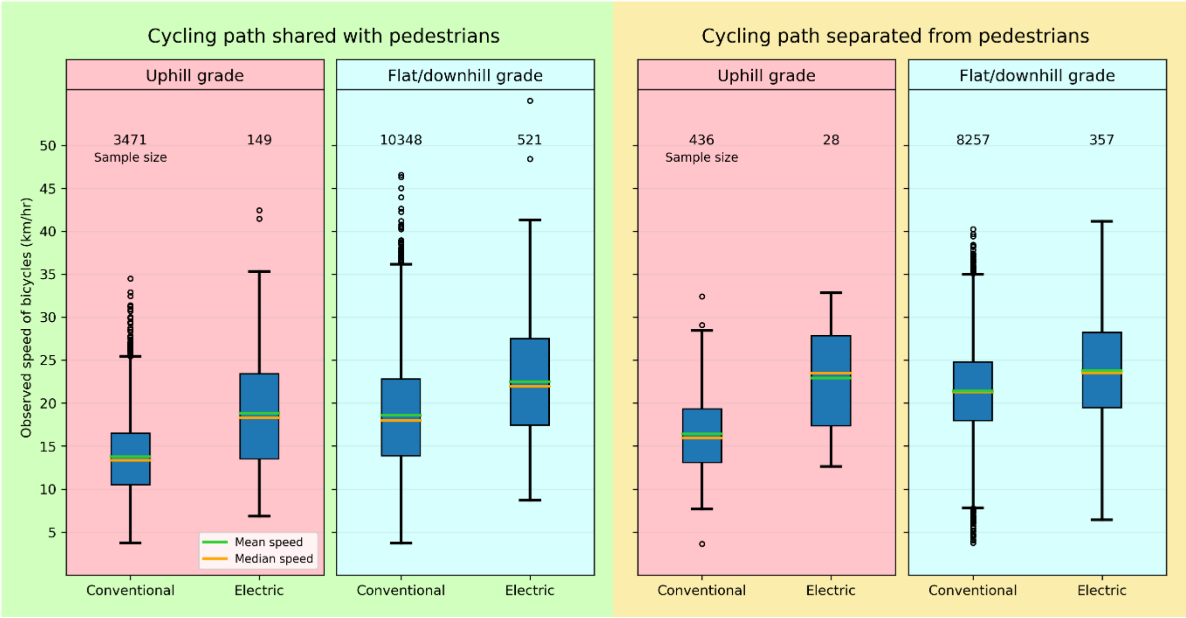


Figure 16. Speed distribution of conventional and electric bicycles, in two grade conditions of uphill and flat/downhill, and two facility types of shared with pedestrians and not shared with pedestrians. The green solid line represents the mean speed and the orange solid line presents the median speed.

A mixed-effect regression model was created using the data described in Appendix J: Modelling to analyze the effects of path grade and electric-assist on speed of bicycles, scooters, and skateboards. In this model the effects of weather (rain, and temperature), day of week, type of cycling facility, traffic volume, and number of riders on vehicle were controlled for as well as random spatial effects. A positive and significant association was observed between speed and temperature and traffic volume. However, this effect has been rather small with speed increase of 0.5 km/hr and 0.1 km/hr for a 10 degrees Celcius increase in temperature and a 100 vehicles/hr increase in traffic volume, respectively. A negative and significant association was observed between number of riders on a vehicle and the speed of the vehicle as every additional rider decreases the speed of the vehicle by 2.8 km/hr. The observed speed of vehicles is lower by 2.2 km/hr in cycling facilities shared with pedestrians as opposed to cycling facilities separated from pedestrians. On weekends, as well as after the COVID-19 lockdown, the speeds of vehicles are lower by 1.3 km/hr, and 1.4 km/hr, respectively.

Electric-assist and grade are also significantly associated with speed of vehicles. The modelled speed of bicycles, skateboards, and scooters with and without electric-assist and on two grade levels (uphill and downhill/flat paths) are illustrated in Figure 17. The values in Figure 17 are representative of a sunny weekday with a temperature of 15 degrees Celcius, in shared facilities with traffic of 150 vehicles per hour. Riders on bicycles, skateboards, and scooters are slower without electric-assist and while riding uphill. On average, electric-assist increase speed of bicycles, skateboards, and scooters by 4, 10, and 14 km/hr (21%, 83%, and 156%), respectively. Electric-assist is more effective in increasing speed of travellers while travelling uphill. The effect of electric-assist on speed was 73% higher when riding uphill compared to when riding downhill/flat. The same effect was observed in skateboards and scooters with smaller intensity: 23% and 17% higher uphill, respectively.

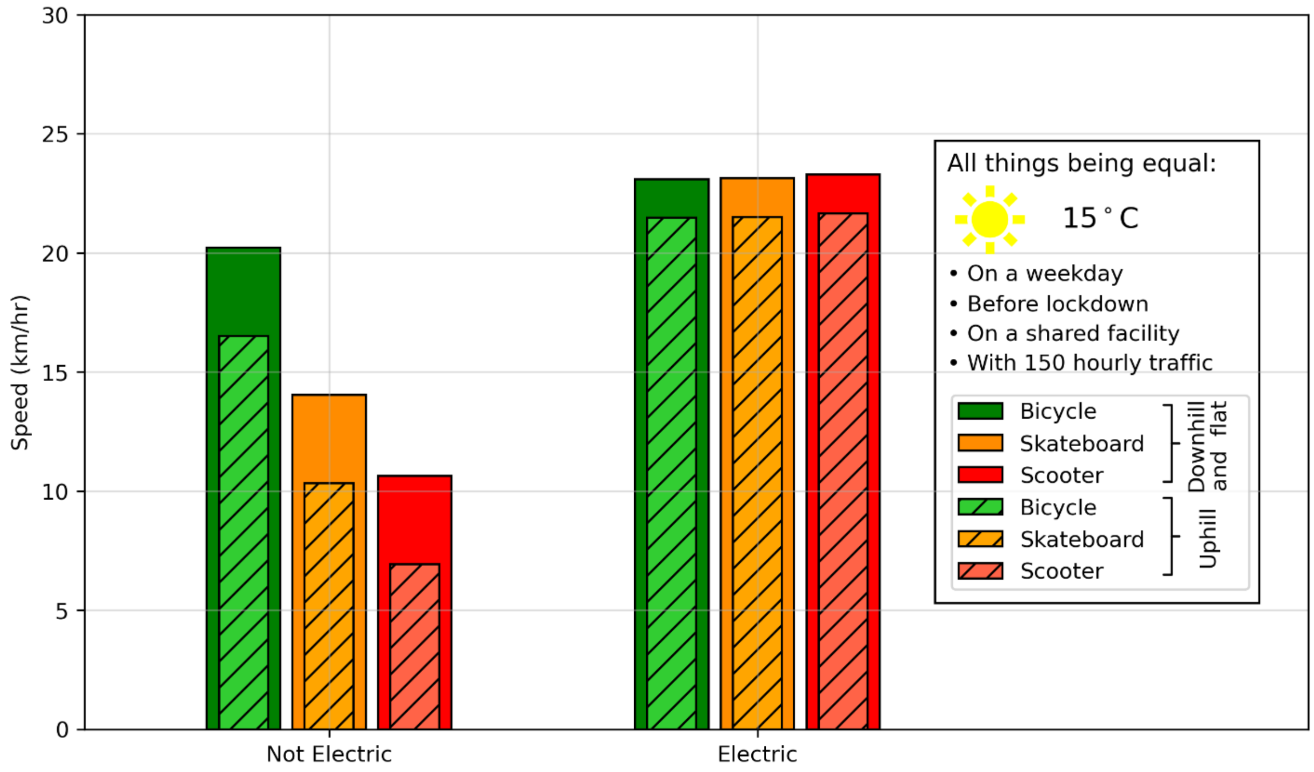


Figure 17. The effects of electric-assist and grade on speed all other things being equal (on a 15 degrees Celsius sunny weekday, on a cycling facility shared with pedestrians after lockdown with traffic of 150 vehicles per hour)

4.3 Perceptions towards vehicles

The survey was active from 09/21/2020 to 10/15/2020, and 1,343 responses were recorded. After two rounds of data cleaning (C1 and C2; explained more in Appendix F: Data processing and filtering), 289 observations were removed from the dataset, leaving 1,054 observations for analysis. Figure 18 illustrates the number of respondents who took the survey and the number of responses left in the dataset after data cleaning.

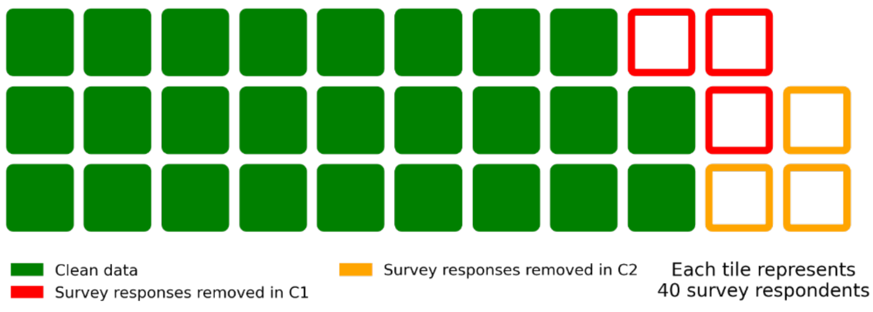
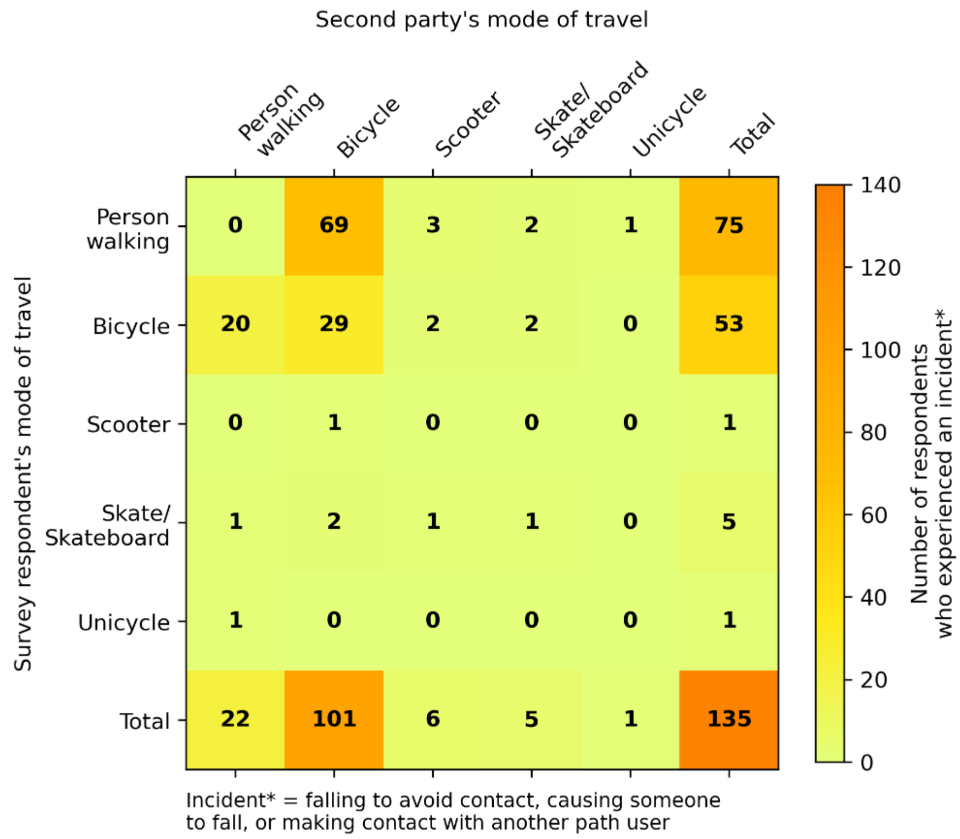


Figure 18. The number of observations removed in processing and filtering web survey response data

Detailed information on the socio demographics and travel habits of the survey respondents are available in Appendix E: Web survey data collection. The majority of survey respondents were between the ages of 20 and 80 years, with equal representation from the female and male populations. The existence of sample demographic bias cannot be tested due to a lack of data on the demographics of the study population (path users in Lower Mainland). For this reason, sampling weights were not used in the statistical analysis. A comparison to all residents of the Lower Mainland, BC shows that the sample contains a higher proportion of high income and university-educated individuals (Statistics Canada 2017, Table 12) – but this may well be representative of the sub-population of path users.

Among the 1,054 survey respondents, 135 (13%) reported that they had an incident while travelling on the same path they came across the survey ad, where they fell to avoid contact, caused someone to fall, or made contact with another person or wheeled vehicle, at least once in the past year. This rate is similar to results found by Gkekas, Bigazzi, and Gill (2020) on University of British Columbia campus (15% of pedestrians and 19% of cyclists reported having had at least one incident in the past 12 months). Similarly, respondents who at least occasionally bicycle on campus report having had at least one incident while cycling in the past 12 months.). The majority of the reported incidents, 66%, were between a pedestrian and a bicycle (electric or conventional), as depicted in Figure 19. Bicycle-bicycle interactions constituted another 21% of the reported incidents. The other 13% of incidents involved at least one other traveller on another vehicle type (scooter, skateboard, skates, unicycle, or tricycle). Put anther way, 85% of the non-pedestrians involved in incidents (147 out of 173) were on bicycles. As the mode share of bicycles on these paths we observed was 95%, this suggests that vehicles *other* than bicycles (scooters, skateboards, skates, unicycles, tricycles) were over-represented in the reported incidents – although the results should be viewed with caution due to the low total number of incidents involving non-bicycle vehicles that were reported (just 17).



	Person walking	Bicycle	Scooter	Skate/ Skateboard	Unicycle	Total
Person walking	0	69	3	2	1	75
Bicycle	20	29	2	2	0	53
Scooter	0	1	0	0	0	1
Skate/ Skateboard	1	2	1	1	0	5
Unicycle	1	0	0	0	0	1
Total	22	101	6	5	1	135

Figure 19. Survey respondent's frequency of experience incident with other path users in the year prior to taking the survey.

The severity of the incidents is illustrated in Figure 20, with the majority of the incidents causing no injury (64%) and another 33% causing minor scrapes and bruises. A small minority of the incidents (3%, or just 4 reports) caused serious injuries that needed hospital visits – and still not an overnight stay. Three of these 4 serious incidents were bicycle-bicycle, and the fourth was a person on a bicycle who experienced an incident with a pedestrian.

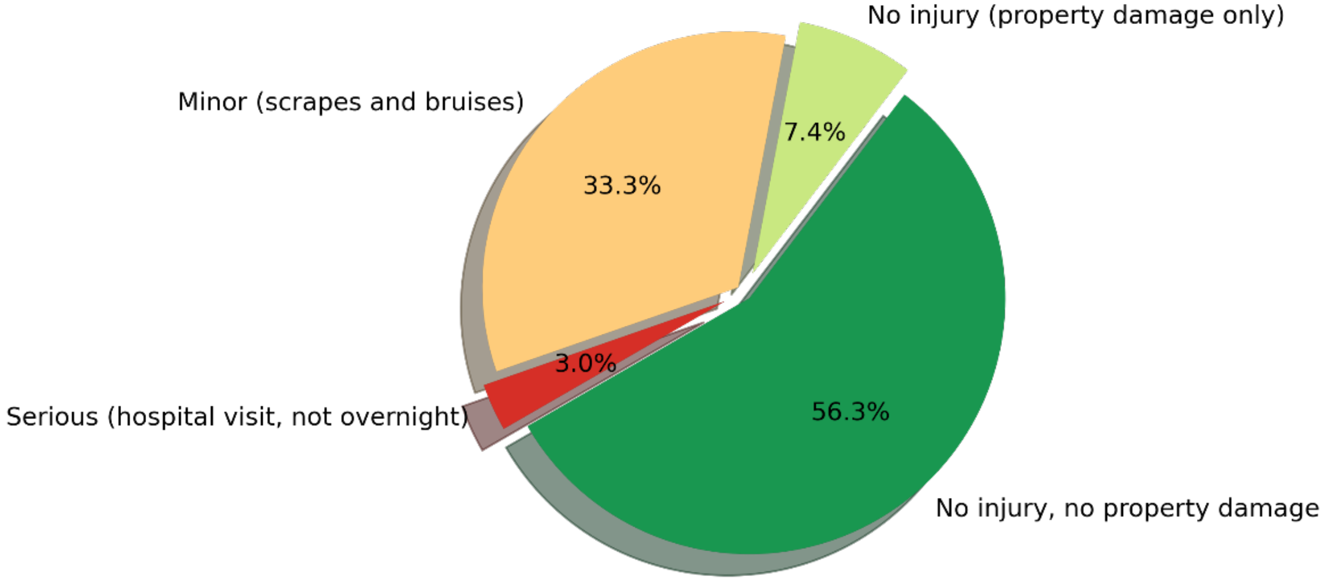


Figure 20. Reported severity of experienced incidents by survey respondents

Survey respondents were asked to estimate the mode share of conventional bicycles, electric bicycles, and all other vehicles on cycling facilities with three values that add up to 100%. Figure 21 shows the average estimated mode share reported by survey participants in comparison to mode share observed at the 12 sampling locations. Vehicles other than conventional bicycles were perceived to be approximately 3 times more prevalent than they actually were, indicating a cognitive bias of greater attention/memory for non-familiar modes.

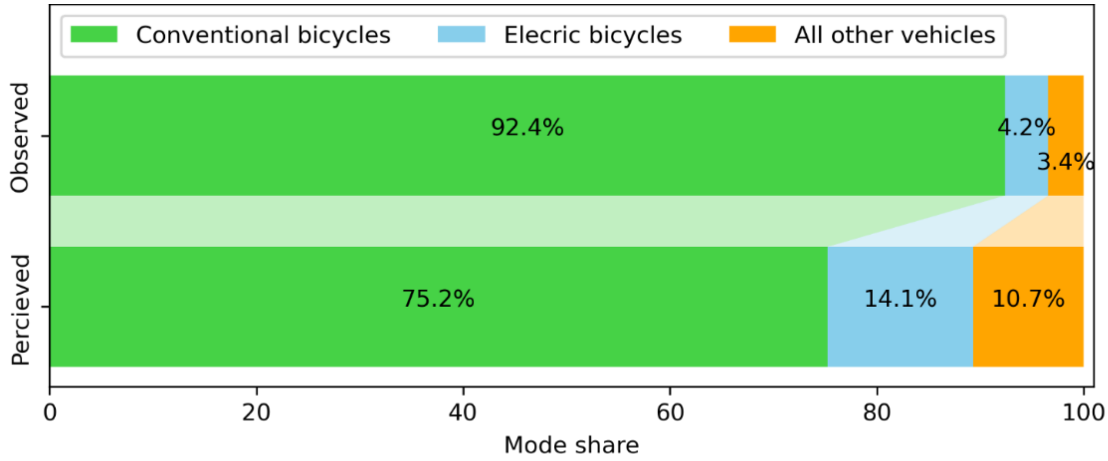


Figure 21. Perceived mode share of conventional bicycles, electric bicycles, and all other vehicles by survey respondents in comparison to observed mode share at 12 sampling locations

Additionally, survey respondents were asked to estimate the speed at which conventional and electric bicycles travel. Figure 22 illustrates the distribution of the responses as well as the distribution of observed speeds for conventional and electric bicycles. Comparison of the mean perceived and observed speeds suggests that path users estimated the speed of conventional bicycles with surprisingly high accuracy (within 1 km/hr); however, they overestimate the speed of electric bicycles by 4 km/hr. In other words, they estimate the effect of electric-assist on bicycle speed as approximately double the true value (8 versus 4 km/hr). The effects of this bias on perceived comfort sharing the path with a vehicle are investigated below.

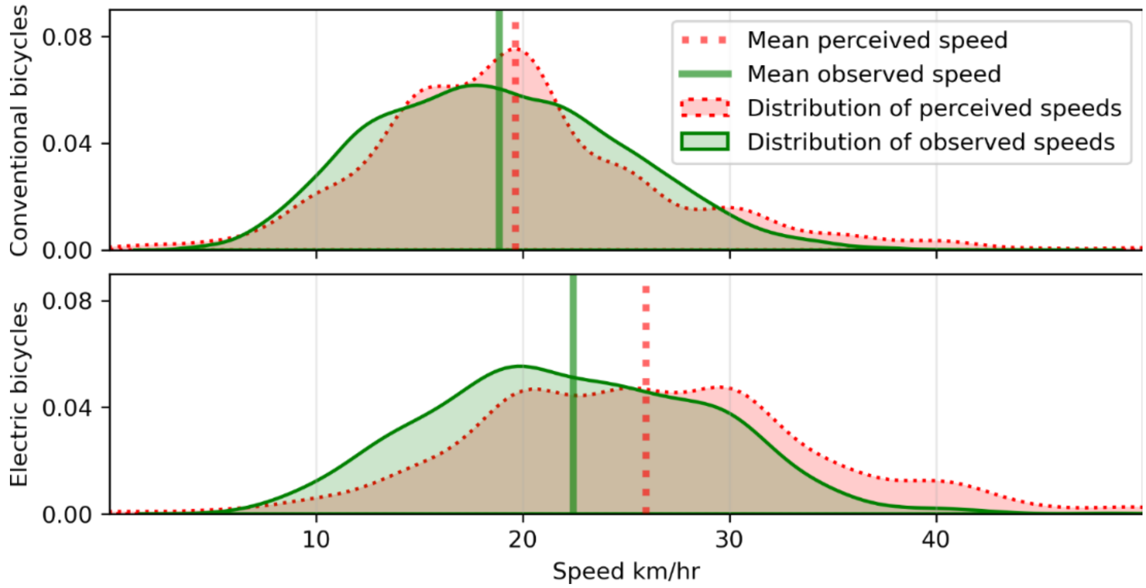


Figure 22. Comparison of the distribution of perceived and observed speed of conventional and electric bicycle along with their mean values

Survey respondents were prompted with images of various types of vehicles for each of which they rated their comfort sharing the path. The comfort ratings of path users sharing the path with all modes of travel are illustrated in Figure 23. Conventional wheelchairs were the most comfortable vehicle on paths across Greater Vancouver as 83% of path users reported they were comfortable sharing the path with them. In general, mobility aid vehicles, namely conventional wheelchairs, electric wheelchairs, and mobility scooters were among the comfortable vehicles to share the path with. 79%, and 71% of survey respondents reported they feel comfortable sharing the path with electric wheelchairs, and mobility scooters, respectively. Mobility aid vehicles were as comfortable to path users as pedestrians walking and running with 80% of path users reporting comfort sharing the path with them. Conventional bicycles were also among the most comfortable vehicles to share a path with, as they lie between electric wheelchairs and mobility scooters (73%).

On the other hand, path users were most uncomfortable sharing the path with sit-down electric scooters (moped-style, without pedals), with a high margin from the next vehicle, self-balancing sit-down scooter (Segway style). 26% of path users said they were comfortable sharing the path with sit-down electric scooters. Sharing with the next three least comfortable vehicles (self-balancing sit-down scooters, electric skateboards, and self-balancing sit-down unicycles) was comfortable for 44%, 44%, and 45% of respondents, respectively. This large gap could be caused by the exceptionally high speed of sit-down electric scooters in comparison to other vehicles, as reported in the Speed section of this report.

Conventional skateboards were in the middle of the list, with 57% of respondents comfortable sharing the path with them. All vehicles more comfortable than conventional skateboards were non-electric vehicles with the exception of electric wheelchairs and mobility scooters. All other electric vehicles were rated less comfortable to share paths with than conventional skateboards.

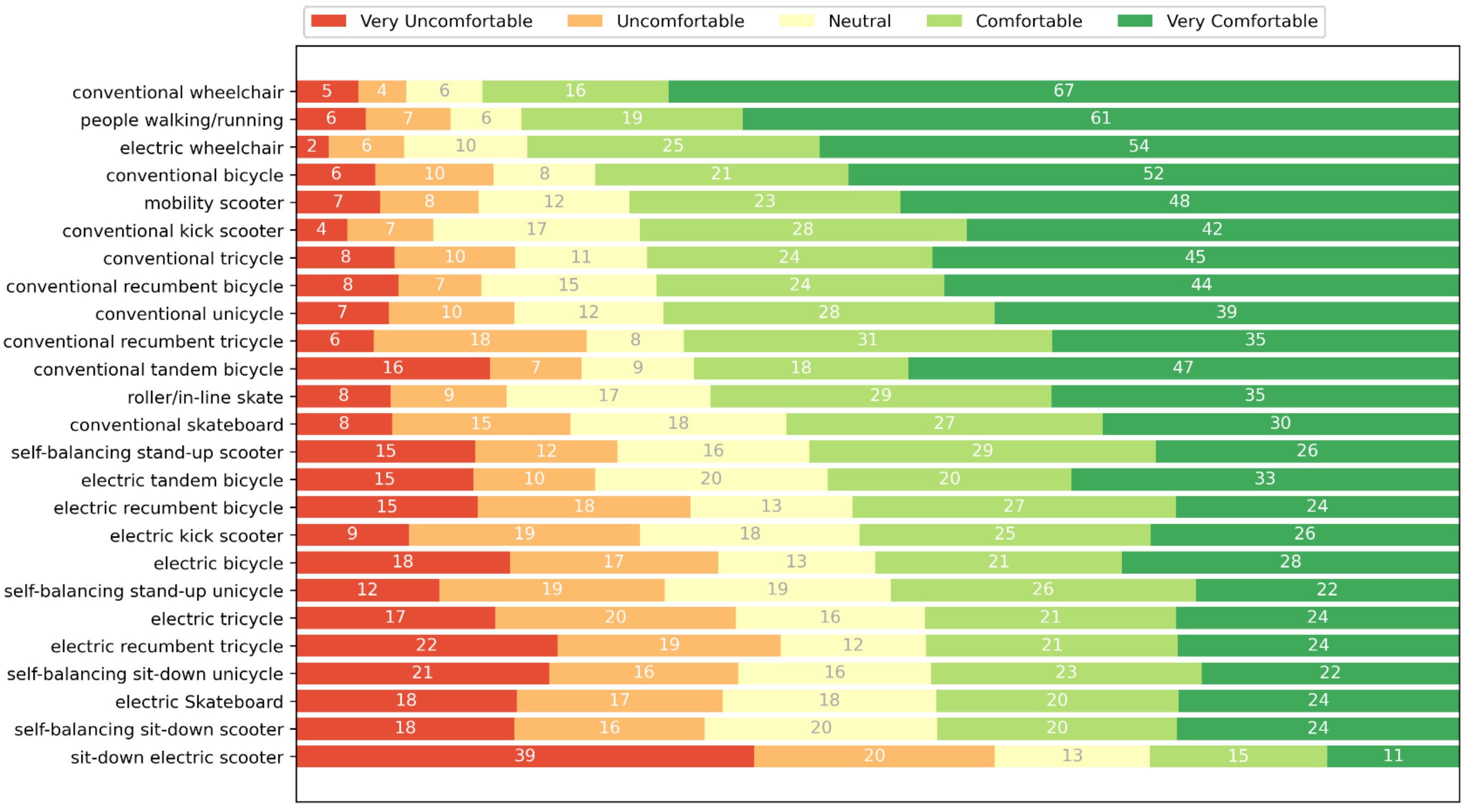


Figure 23. Comfort of off-street path users in sharing the path with various types of vehicles in Likert scale. The vehicles are sorted in descending order of comfort from top to bottom

A mixed-effect regression model was created using the data described in Appendix J: Modelling to analyze the association of sociodemographic indicators, environment factors, vehicle operation characteristics, etc., on path users' comfort in sharing the path with various types of vehicles. The model results are summarized in Figure 24 with factors that significantly decrease comfort and increase comfort, listed in the box with red and green colours, respectively. Having previously experienced an incident, and perceiving electric bicycles to be fast were factors in a path user that were significantly associated with lower comfort in sharing the path with a vehicle. Having electric-assist and being on average a faster (based on observed speed data) were factors in a vehicle that were significantly associated with lower comfort in sharing the path with that vehicle. Being younger, having higher risk tolerance, or using active transportation more were also significantly associated with higher comfort in sharing the path with a vehicle. Furthermore, path users were more likely to be comfortable with a vehicle if it was similar to their own vehicle they were travelling with. Lastly, factors such as gender, education, and type of cycling facility were not significantly associated with comfort sharing the path with a vehicle.

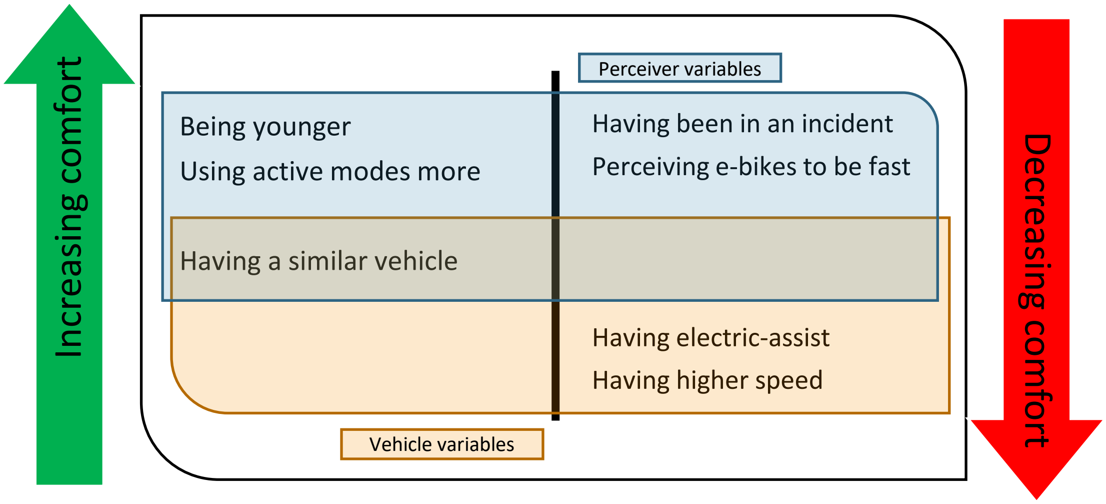


Figure 24. Summary of regression model estimated to explain path users' comfort in sharing the path with various vehicle types

To quantify the effects of the variables mentioned above on comfort, speed equivalent effect the variables are presented in Figure 25. For instance, the value 8.5 km/hr for 'Having electric-assist' means, an electric bicycle was perceived as comfortable as a conventional bicycle that was 8.5 km/hr faster, all else equal. As another example, a 40-year-old person perceived a vehicle as comfortable as a 30-year-old person perceives the same vehicle going 2.9 km/hr faster.

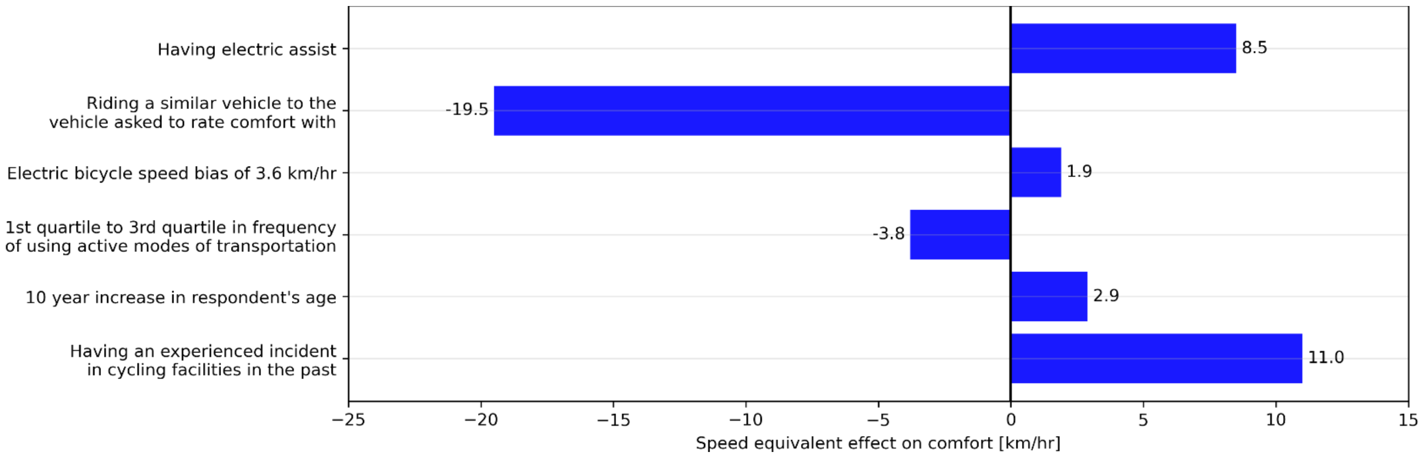


Figure 25. Speed equivalent effect of a change in variables that were significant in the comfort model

4.4 Vehicle groupings

The outcome of the clustering of all modes of travel are presented in Figure 26. Figure 27 shows the variation in the 4 input variables for the 4-cluster model. The two-cluster model almost perfectly separates people walking/running and conventional vehicles from the emerging transportation vehicles (vehicles with electric-assist) – with the exception of conventional recumbent tricycles that were clustered with the low comfort high speed vehicles. This model classifies the vehicles into two groups of low-speed and high comfort, and high-speed and low comfort vehicles. In the three-cluster model, the third cluster emerges out of the low-speed category, separating the conventional bicycles from low-speed vehicles, and in the four-cluster model, the fourth cluster emerges out of the emerging transportation vehicles, singling out sit-down electric scooters as a distinctly high-speed and low-comfort vehicle.

In the four-cluster model, the first cluster includes people walking/running and low-speed vehicles such as roller/in-line skates, conventional wheelchairs, electric wheelchairs, mobility scooters, conventional kick scooters, skateboards, and unicycles. People walking/running have high comfort sharing the path with vehicle in cluster 1, and people riding conventional and electric bicycles, and people riding all other vehicles have medium comfort. Vehicles in cluster 1 also have the lowest average speeds. Cluster 2 is the smallest cluster, and it includes conventional bicycles, conventional recumbent bicycles, conventional tandem bicycles, and conventional tricycles. Pedestrians have medium comfort sharing the path with the vehicle in cluster 2, and bicycles and other vehicles have high comfort. Vehicles in cluster 2 also have medium average speeds in comparison to other clusters. The third cluster includes all emerging transportation vehicles which are mainly high-speed and low-comfort vehicles such as electric bicycles, scooters, skateboards, self-balancing electric unicycles, and self-balancing stand-up scooters (Segways and hoverboards). Lastly, as previously mentioned the fourth cluster includes only sit-down electric scooters (moped style motorcycles) which were extremely high-speed and low-comfort vehicles in paths in Metro Vancouver. Figure 28 shows diagram of selected vehicles in each cluster in the four-cluster model; the clusters are named 1) *low-speed*, 2) *conventional bicycle*, 3) *electric-assist*, 4) *moped-style scooter*.

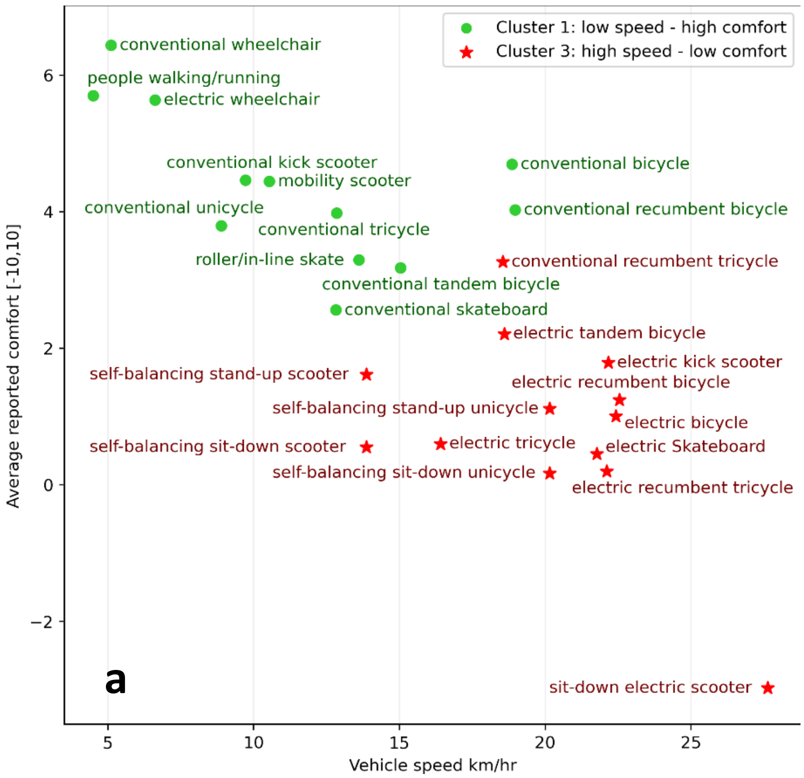
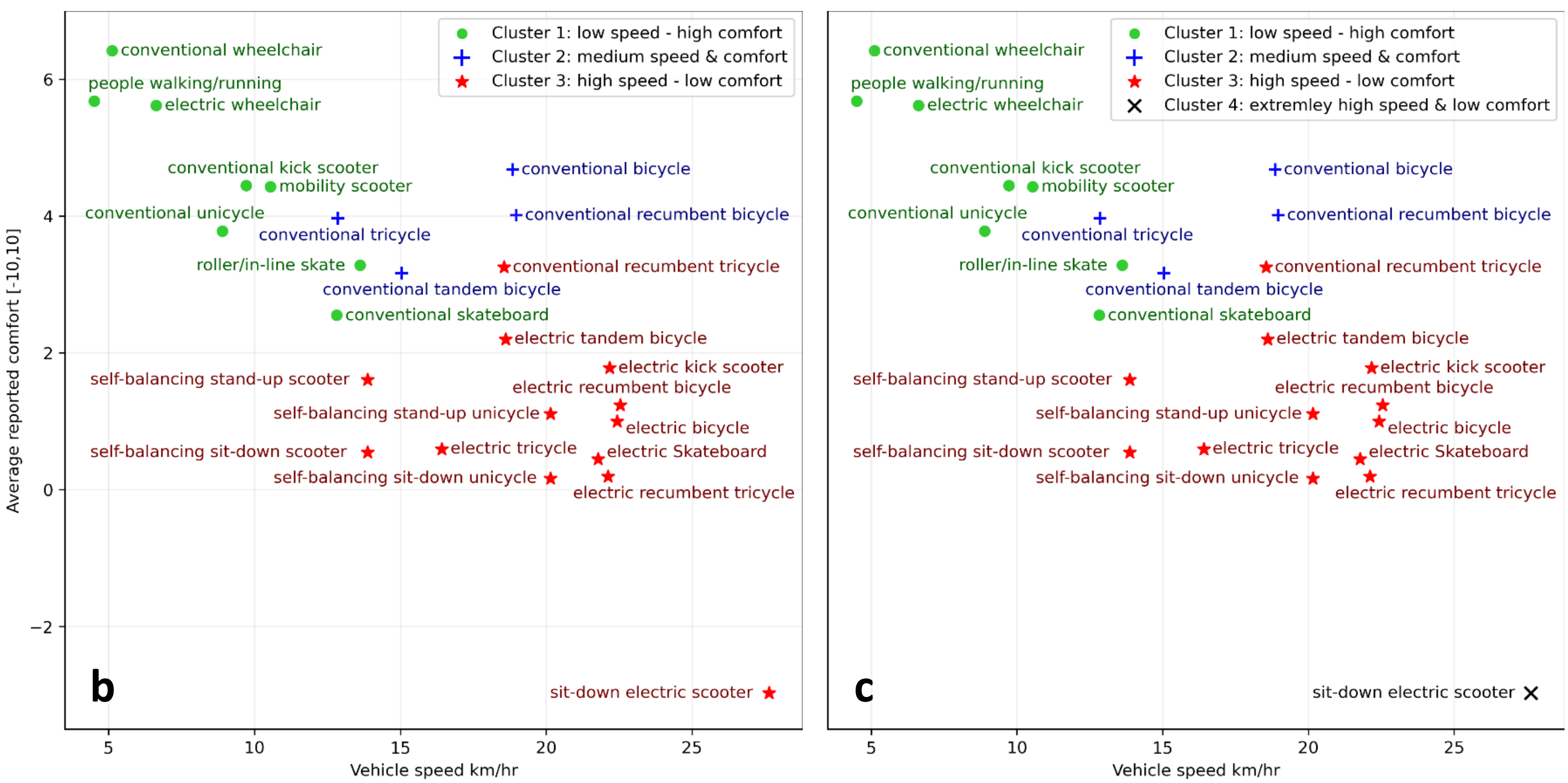


Figure 26. Average observed speed of all modes of travel plotted against average comfort of all travellers sharing path with them and clustering of vehicles into 2 (a), 3 (b), and 4 (c) clusters using k-mean clustering algorithm



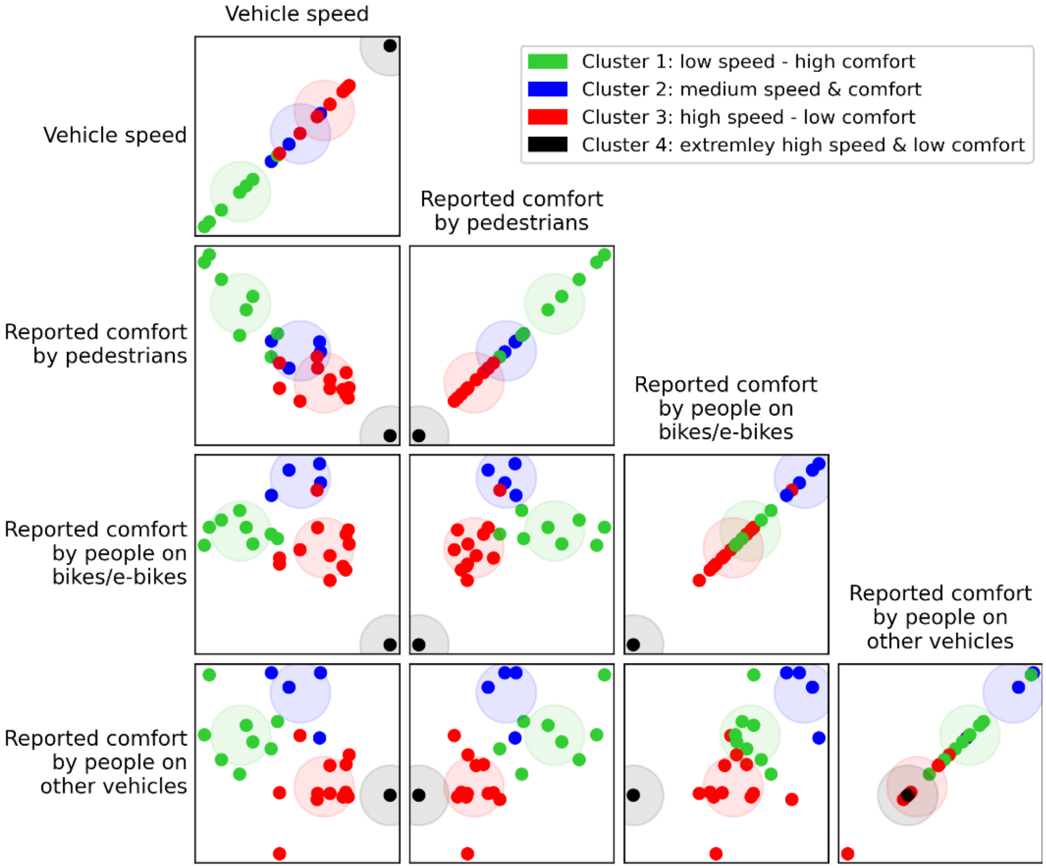


Figure 27. Variation in the four input variables for the four-cluster model

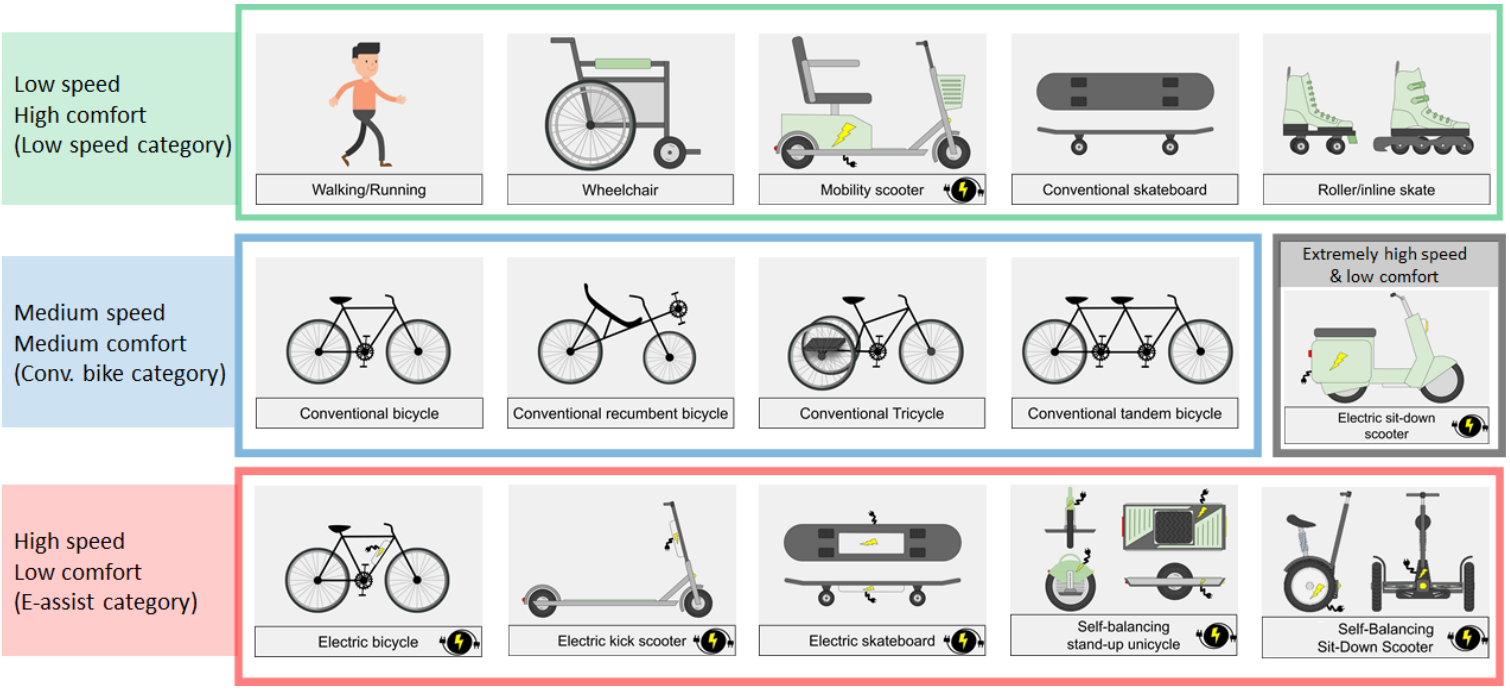


Figure 28. Diagram of select modes of travel in each cluster in the four-cluster model

4.5 Policy review

Results from the emerging mobility policy review are presented in two sections. The first section focuses on *specific policies* aimed at restricting vehicles based on functionality (power, brakes, etc.) or dimensions (height, wheel size, etc.), restricting operations of vehicles (based on time, location, etc.), and providing guidelines for designing path for new mobility vehicles. The second section focuses *broader policies* in the planning documents regarding explicit inclusion or promotion of new mobility vehicles, and presence of planning guidelines or design recommendations.

4.5.1 Specific policies

Table 3 provides a summary of regulating bodies and their respective domains. All vehicle-based restrictions were imposed by provincial legislation, the Motor Vehicle Act (MVA), or federal legislation, the Motor Vehicle Safety Act (MVSA). While there was no recognizable definition for emerging transportation vehicles, the following sections of the MVA and MVSA were used to restrict vehicles in general:

1. Motor Assisted Cycle Regulations (B.C. Reg. 151/2002)
2. Motor Vehicle Act Regulations (B.C. Reg. 26/58), and
3. Motor Vehicle Safety Regulations (C.R.C., c. 1038).

Table 3. Vehicle-class based regulating bodies and presence of vehicle restrictions, operating restrictions, and design recommendations specific to emerging transportation vehicles in their policy documents

Regulating body	Vehicle restrictions	Operating restrictions	Design recommendations
British Columbia (Motor Vehicle Act)	Yes	Yes	No
Canada (Motor Vehicle Safety Act)	Yes	Yes	No
Insurance Corporation of British Columbia	No	Yes	No
City of Vancouver	No	Yes	No
District of West Vancouver	No	Yes	No
City of North Vancouver	No	Yes	No
Other Metro Vancouver Municipalities	No	No*	No
TransLink	No	No*	No

* “No” indicating no restrictions beyond what is already imposed by the MVA or MVSA.

More information on type of vehicles included in the MVA and the MVSA are provided in Appendix K: Policy review. It is important to note that the Motor Vehicle Act is currently under review and subject to change. At the time of our search the Motor Vehicle Act was current to July 29, 2020. Operating restrictions on vehicle-classes were generally placed by regional and municipal agencies in addition to provincial and federal legislation. The Insurance Corporation of British Columbia imposes registration and insurance requirements based on vehicle-classes but leaves further operating restrictions to be placed by municipalities. Of all Metro Vancouver member municipalities, City of Vancouver, District of West Vancouver, and City of North Vancouver have adopted operating restrictions beyond those set forth by ICBC.

1. The City of Vancouver provides the most detailed guidance on various devices, banning three device types, electric skateboards, Segway, and hoverboards (self-balancing stand-up scooters).
2. Moreover, electric bicycles were banned from operating on the Seawall and park paths.
3. District of West Vancouver, and City of North Vancouver have adopted bylaws outlawing only skateboarding and rollerblading, respectively.

Currently, no design recommendations exist when designing facilities for emerging transportation vehicles excluding conventional and electric bicycles.

4.5.2 Broader policies

A review of 2 regional entities (TransLink, Metro Vancouver), 2 provincial entities (Ministry of Transportation Infrastructure, ICBC) and 2 federal entities (Transport Canada, Transportation Association of Canada) revealed that the primary driver of policies related to emerging mobility and active transportation were found at the provincial level. The regional-level entities lead adoption of the policies and federal entities provide the right of way for adoption. Active transportation is strongly supported by CleanBC's "Move. Commute. Connect." strategy, which linked together Motor Vehicle Act and ICBC policies, provided infrastructure grants, and led to the creation of the British Columbia Active Transportation Design Guide (BCATDG). A summary of the findings (inclusion of new mobility policy, planning vision, promotional programs, and design guidelines in planning documents) can be found in Table 4, and more information is provided in Appendix K: Policy review.

Table 4. Summary of broader emerging mobility policies in federal, provincial, regional, and municipal agencies

	Explicit new mobility inclusion	Planning vision	Promotional programs	Adopted design guidelines
TransLink	Yes	Yes	Yes	No
Metro Vancouver	Yes	Yes	No	No
Ministry of Transportation Infrastructure	Yes	Yes	Yes	No
ICBC	Yes	No	No	No
Transport Canada	No	No	No	No
Transportation Association of Canada	No	No	No	No
Individual Member Municipalities	No (19), Yes (4)	No (21), Yes (2)	No (21), Yes (2)	No

Four municipalities in Metro Vancouver had explicit emerging transportation plans in their most recent transportation planning documents. Three municipalities considered one or two emerging transportation vehicle and one municipality considered more than two. A summary of Metro Vancouver Partners with explicit emerging transportation plans is presented Table 5.

Table 5. Metro Vancouver partners with explicit emerging transportation plans

Municipality	Emerging transportation awareness	Number of vehicles mentioned excluding (e-)bicycles	Vehicles banned	Percentage of devices mentioned banned
Bowen Island	Yes	1	None	0%
City of North Vancouver	Yes	2	Skateboards, rollerblades	100%
District of West Vancouver	Yes	2	Skateboards, rollerblades	100%
City of Vancouver	Yes	9	Electric skateboards, rollerblades, Segways, hoverboards	44%

5 Discussion

5.1 Designing for new mobility

Despite the rapid emergence of new low-power personal transportation vehicles, conventional bicycles are still extremely dominant in cycling facilities. The emerging transportation options are not yet taking over off-street paths, and their mode share in Metro Vancouver in the data collection period was extremely low. Still, rapidly increasing sales of new mobility devices (McNalty 2020; Griffin 2019) suggest an expected strong upward trend in utilization. Thus, new mobility devices should be considered in the design of new off-street cycling facilities, and in the retrofit of existing ones, as all current facilities (both separated and shared with pedestrians) in Metro Vancouver were created with conventional bicycles as the design vehicle (Ministry of Transportation and Infrastructure 2019). The vehicles observed in this study can inform the selection of appropriate design, control, and managed vehicles for future versions of the BC Active Transportation Design Guide (BCATDG) (Ministry of Transportation and Infrastructure 2019). It is also important to continue detailed/classified count data collection to understand evolving adoption and use of each type of new vehicle.

This study provides evidence on volumes and design speeds, but further research is required for information regarding key design vehicle characteristics such as turning radii, stopping distances, and tire/wheel traction. These characteristics are particularly important to research due to the emergence of larger vehicles for cycling such as cargo bi/tri-cycles and bike buses. The Province has partnered with the City of Vancouver in a pilot project to support electric cargo bicycle uptake for urban freight to alleviate congestion and air pollution (Ministry of Transportation and Infrastructure 2021b). Bike buses have gained traction in Europe as a healthy and fun way for kids and parents to get to school (Messenger 2018; Lee 2017), and may be considered for School Active Travel Programs in the region. Further, quadricycles have recently been approved to operate in Vancouver (City of Vancouver 2022b). Evidence-based design guidance for these emerging larger cycling vehicles is still very limited.

The currently available information on new mobility options can be misleading when not based on empirical data. For instance, the British Columbia Active Transportation Design Guide (BCATDG) provides typical active transportation user speeds, but the values are not supported by clear evidence, and in some cases diverge greatly from our results. Figure 29 illustrates the reported typical speeds of different types of bicycles reported in the BCATDG (top), compared to the observed average speeds of these vehicles in our study (bottom). The observed speeds vary *less* across different vehicle types that suggested in the BCATDG (and elsewhere). Interestingly, existing practice guidance seems to reflect the public perception bias reported above of over-estimating the speeds of electric bicycles.

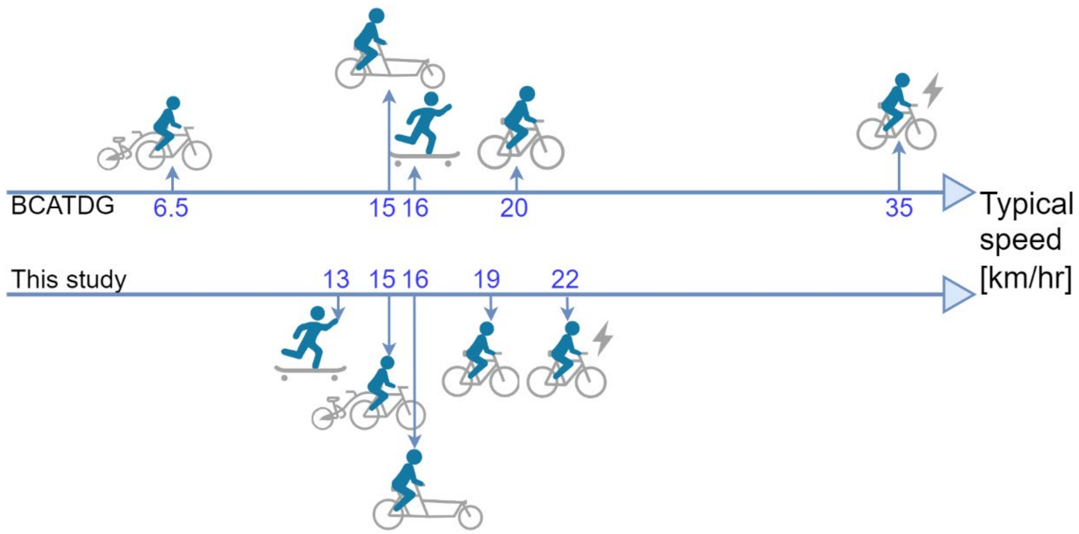


Figure 29. Typical speed of active transportation users (top) reported in British Columbia Active Transportation Design Guide (Ministry of Transportation and Infrastructure 2019) vs. mean observed speed (bottom) in this study

Design speed is a fundamental parameter used to determine geometric features of active transportation facilities as well as signal timing and road crossing parameters. In justifying the recommended 30 km/hr design speed for cycling facilities, the BCATDG suggests that "the typical adult [on a conventional bicycle] travels at average speeds of 15 km/h to 30 km/h" (without a clear data source). In our data, the speed of the middle 50% of conventional bicycles is between 14 and 23 km/hr, and the central 90% of conventional bicycle speeds are between 9 and 30 km/hr. The 85th percentile bicycle speed (a common engineering speed threshold) in cycling facilities is 26 km/hr. Given these results, the recommended design speed of 30 km/hr for conventional bicycles may be slightly conservative but is certainly reasonable.

An important question is how an increased use of electric bicycles and other new mobility devices will affect path speeds and the appropriate design speed. Using our results, Figure 30 shows boxplots of the expected speed distribution on off-street cycling facilities with scenarios of new mobility vehicle (including electric bicycle) mode share ranging from today's ~5% to a possible 95% penetration. Because typical electric bicycle speeds are only 4 km/hr faster than conventional bicycles, and electric-assist for other devices tend to increase their speeds only up to the typical range of bicycle speeds, new mobility vehicle penetration has only a small effect on cycling facility speeds. In these scenarios, even a nearly full penetration of new mobility (electric-assist) vehicles only increases the average speed on paths to around 22 km/hr, with an 85th percentile speed just under 30 km/hr. Hence, and somewhat surprisingly, the 30 km/hr design speed in the BCATDG may actually still be appropriate for future design accounting for new mobility devices, although somewhat less conservative.

The largest caveat to this finding would be that it is based on existing, observed new mobility vehicles and speeds, which largely operate below the 32 km/hr Provincial limit (even if they are not legal under the MVA). Other new devices with higher electric-assist thresholds could be introduced which could increase operating speeds. It also excludes the potential for a substantial increase in the mode share of (moped-style) sit-down electric scooters, which operate substantially faster than other motor-assisted vehicles, as described above.

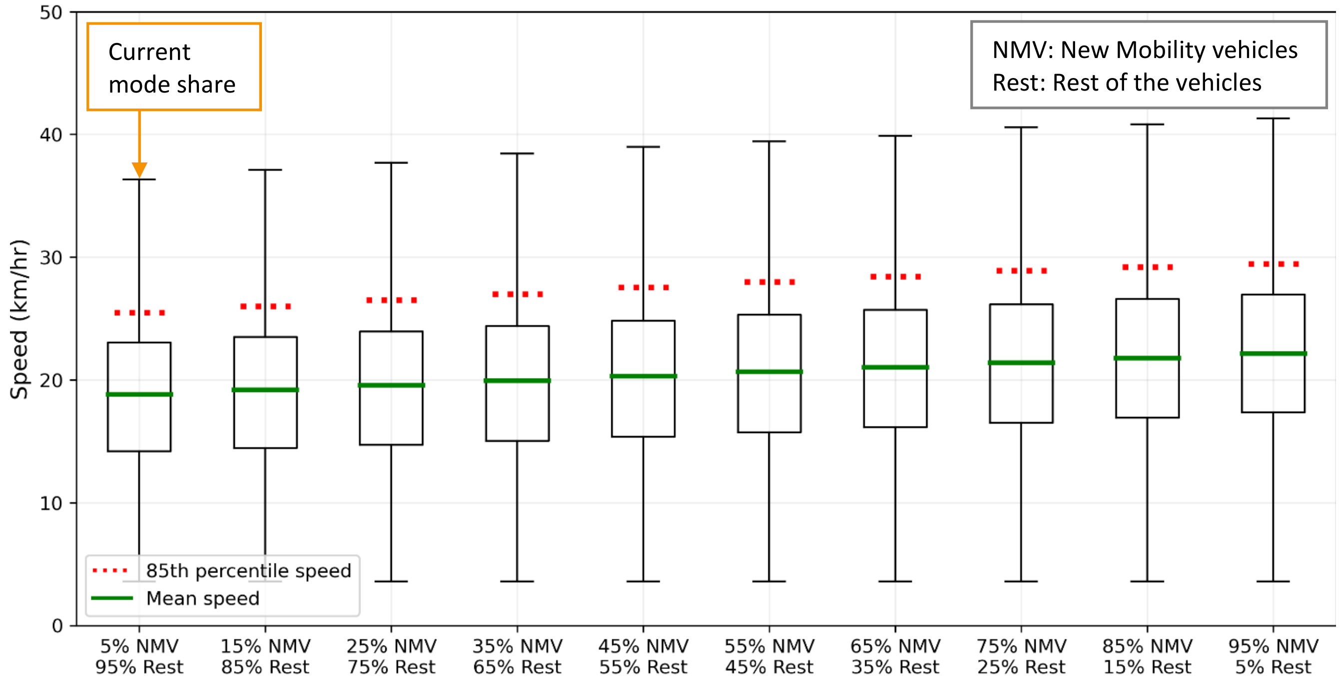


Figure 30. Speed distributions on cycling facilities at various scenarios of new mobility vehicle (NMV) penetration

Even with electric-assist, bicycles rarely (7%) go over the regulatory 32 km/hr limit imposed on motor-assistance by the BC Motor Vehicle Act. A 7% violation rate is less than half of what is typically assumed for car speed violations (15% using the 85th percentile rule-of-thumb). A recent addition to the MVA, added after this project's data collection, indicates that "the motor of an electric kick scooter must not be capable of propelling the electric kick scooter at a speed that exceeds 24 km/h". Our data reveal that 44% of electric kick scooters (which were not legal for public highway use under the MVA at the time of data collection) were travelling at speeds faster than 24 km/hr. It is unknown whether the new MVA regulation will reduce electric kick scooter speeds, either through new device controls or public information that alters behaviour. Future data collection is needed to inform appropriate electric kick scooter speed regulation, given consideration of compliance and enforcement options, effects on safety and comfort, and effects on scooter utility and adoption.

While conventional wheelchairs have the same average speed as pedestrians walking, other wheeled vehicles in this study such as conventional skateboards, kick scooters, mobility scooters, and even conventional unicycles had approximately double the typical walking speed of 3-5 km/hr (Bohannon and Williams Andrews 2011). With higher speeds, travellers can travel longer distances in a given amount of time and so improve their access to activity locations (Victoria Transport Policy Institute 2014). The observed speeds in this study can help us understand the effects of new mobility vehicles on accessibility. For example, the distance travelled in 5 minutes using conventional and electric bicycles, scooters, and skateboards are plotted in Figure 31 to the scale against the map of Downtown Vancouver. Note that the distances do not include the speed effects of road grade, stopping at intersections, traffic-related delays, etc.

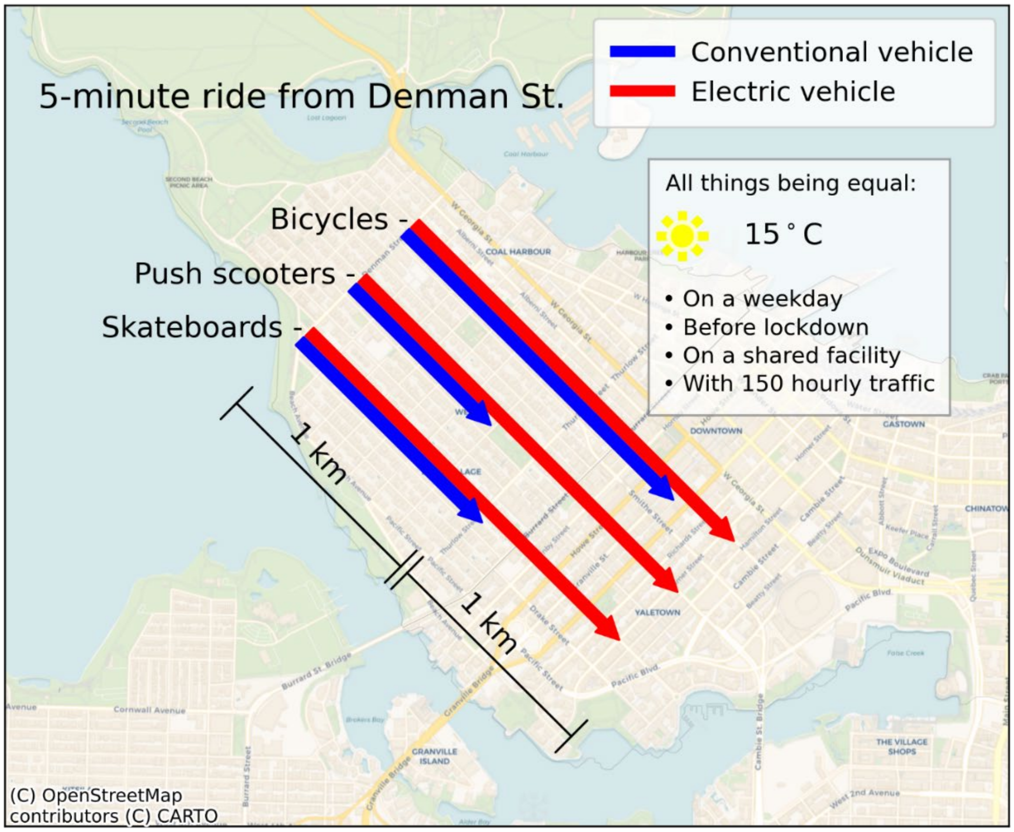


Figure 31. The Distanced travelled in 5 minutes on conventional and electric bicycles, scooters, and skateboards plotted to the scale against the map of Downtown Vancouver.

5.2 Perceptions and comfort

The public overestimates the prevalence of new mobility vehicles by more than three times their actual prevalence. This overestimation is possibly due to the "availability heuristic biases," which cause one to overestimate the likelihood of events with greater availability in memory (in this case, observing the new low-power vehicles). The "Baader-Meinhof" phenomenon, also known as the frequency illusion, would suggest that once someone encounters a new emerging vehicle on cycling facilities, it "suddenly seems to crop up everywhere" (Pacific Standard 2017). This effect could be higher in those who have a more emotionally charged memory of encountering the emerging vehicles (Manis et al. 1993). Travellers are more likely to recall seeing a person on a self-balancing unicycle overtaking them than a person on a bicycle doing the same, and the fact that travellers can more readily recall the former incident may cause them to overestimate the frequency of that incident as well.

The effect of electric-assist on speed is also often overestimated by the public. Electric-assist increases the average speed of bicycles by 4 km/hr – half of the 8 km/hr believed by the travelling public (on average). This overestimation is perhaps due to a combination of the availability heuristic biases mentioned above and the differential effects of electric-assist on speeds by road grade. Electric-assist is 73% more effective at increasing speeds when riding uphill than riding on flat or downhill paths, leading to greater speed differentials. Memories of electric bicycles overtaking other travellers going uphill would be both more prevalent and more intense due to the increased speed difference. Perceptions of electric bicycle speeds might also be influenced by exposure to electric-assisted scooters and skateboards, for which the effect of electric-assist on speed is 4 and 7 times greater than for bicycles, respectively (although the electric-assisted speed is not higher). The speed perception bias is one of the causes of travellers' discomfort sharing paths with electric-assisted vehicles, and if corrected (through time, exposure, or some intervention) it would have an effect on travellers' comfort equivalent to a blanket speed reduction of 2 km/hr in cycling facilities (i.e., countering much of the discomfort effect of increasing speeds shown in Figure 30).

The majority of travellers are comfortable sharing paths with all observed new mobility vehicles except sit-down electric scooters (moped-style), which are outliers in terms of comfort and speed (possibly related to their typical size and weight, in addition to speed). The emerging vehicles are generally less comfortable to share paths with than conventional bicycles, but they are still deemed comfortable on average, even by pedestrians. Vehicle speed and electric-assist are both significant contributing factors to discomfort, which combine to influence perceptions of sharing facilities with emerging electric-assist vehicles. Perceived comfort in sharing paths with a certain vehicle type is also inter-related with the characteristics of the perceiver (age, experience, travel habits) and their travel mode on the path. For example, having experienced a past incident with another traveller on a path (including minor, no-injury incidents) on average degrades comfort equivalent to how a person would feel if other vehicles were travelling 11 km/hr faster (all other things equal). This is a substantial degradation of comfort, and illustrates the importance of facility safety not just for immediate outcomes, but for future perceptions and likely behaviour. Beyond the examined covariates in the comfort model, data from the web survey open comments suggest that vehicle weight, size, and sound (either silent or noisy), and distrust in riders' control or balance also contributed to reported perceptions of comfort.

5.3 Proposed vehicle categories

The four clusters presented in this study identify vehicle types with similar operational (speed) and comfort characteristics, for use in policy and design. Cluster 4 consists of a single vehicle type, moped-style sit-down electric scooters, which emerged from the data as an outlier for both high speed and low comfort. Although not common on cycling facilities (63 observations), they were still more prevalent than electric skateboards, self-balancing unicycles, and self-balancing scooters (Segways and hoverboards) combined. Although sometimes sold and used as electric bicycles, our results that show that they are clearly distinct in both operation and effects on other travellers. This empirical finding is consistent with the perceptions of a wide range of industry stakeholders (Aono and Bigazzi 2019). Therefore, although many of the observed vehicles are illegal on paths either under the MVA or local bylaws, it only the sit-down electric scooters (among existing devices) that we identify as a problematic vehicle type which warrants future work to eliminate the use of in cycling facilities.

Presuming the exclusion of only Cluster 4 as a design vehicle, the other three clusters, 1) low-speed, 2) conventional bicycle, and 3) electric-assist, can be used as design classes for both operations and comfort. Figure 32 illustrates the effects on pedestrian comfort of new mobility vehicle penetration scenarios, similar to the illustration above for expected effects on speeds. The boxplots represent the distribution of individual pedestrian comfort levels, averaged across all other users on a multi-use path (on a scale of -10 "very uncomfortable" to +10 "very comfortable"). Pedestrian comfort decreases somewhat as the mode share of electric-assisted vehicles increases (i.e., travellers shift from Cluster 2 to Cluster 3), but the average and median pedestrian's comfort is still positive. Presented another way, Figure 33 shows that if the electric-assist mode (Cluster 3) share increases by a factor of 17 (from 5% to 85%), the percentage of pedestrians uncomfortable on a multi-use path increases from today's 33% to 44%. Note that as the findings above regarding speed bias showed, better public information or familiarity over time may modify the discomfort effects of Cluster 3 vehicles.

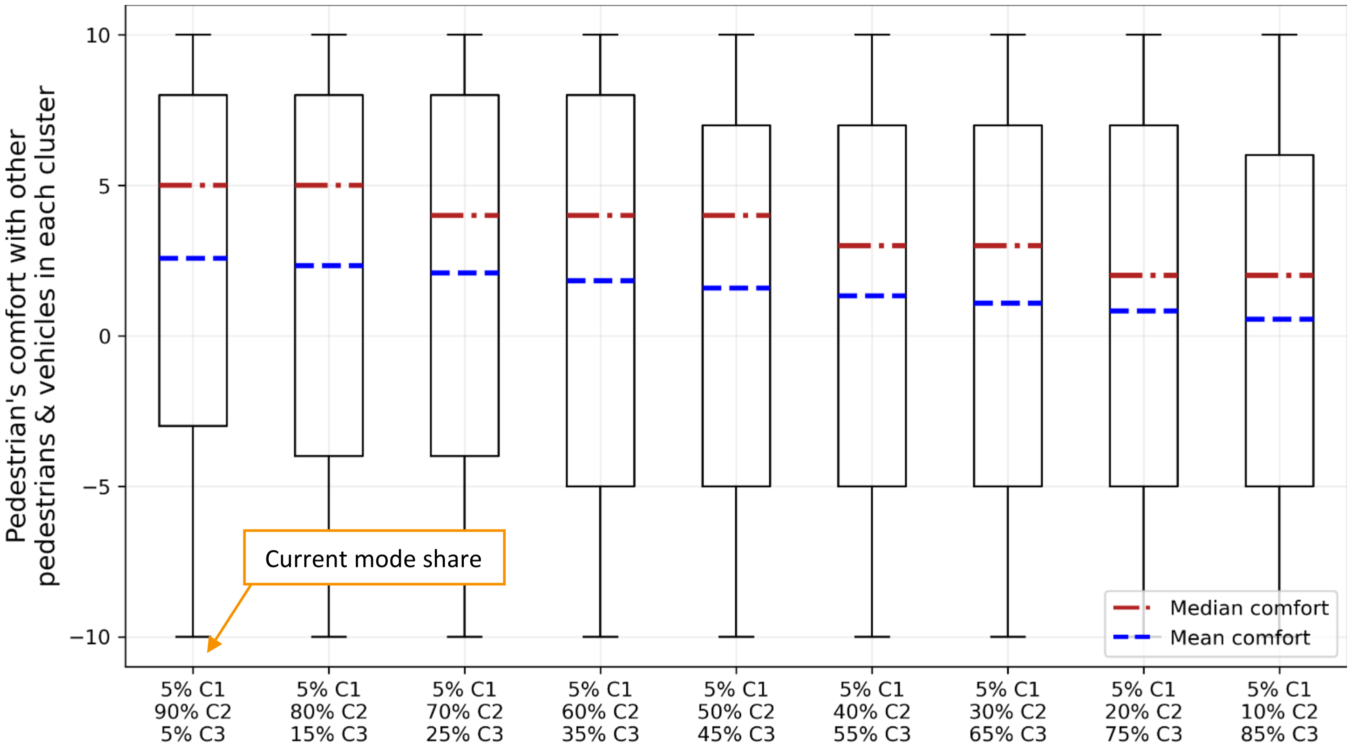


Figure 32. Pedestrians' comfort with others on a multi-use path with scenarios of electric-assist vehicle (Cluster 3) penetration

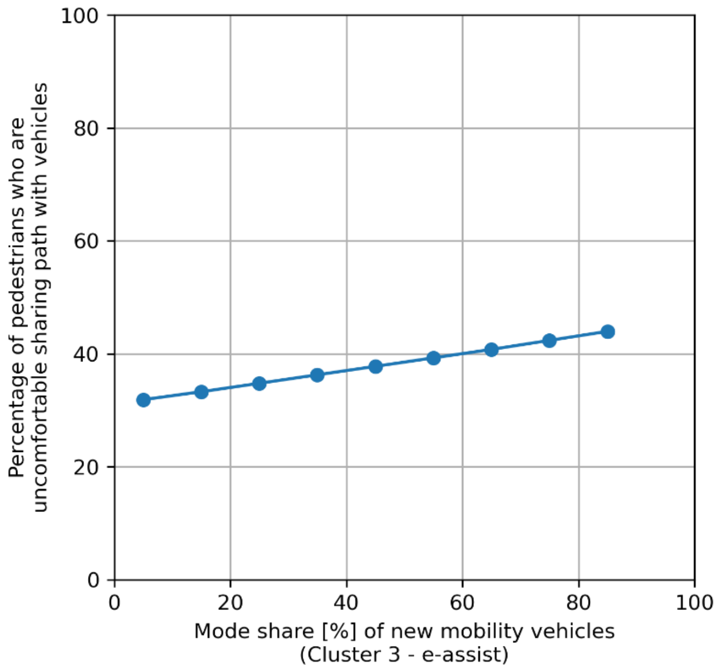


Figure 33. Percentage of pedestrians who are uncomfortable with others on a multi-use path with scenarios of electric-assist vehicle (Cluster 3) penetration

Already, pedestrian discomfort in sharing paths with conventional bicycles has led to design guidance to separate pedestrians from bicycles where volumes are sufficiently high. The same strategy can be used to offset the discomfort effects of electric-assist devices for pedestrians on multi-use paths, using the results in this study. For example, the current BCATDG guidance for separating pedestrians from other path users employs *total user volume* thresholds for suggesting separation (Table 6). But as shown in these results, different path user types have different and quantifiable effects on pedestrian comfort. Figure 34 shows the average pedestrian's comfort sharing a multi-use path with vehicles in each cluster. The impact on path user comfort of each additional Cluster 2 vehicle (conventional bicycle) is equivalent to 2.1 Cluster 1 vehicles (e.g., wheelchair). The impact of each additional Cluster 3 vehicle (electric-assist device) is equivalent to 1.3 Cluster 2 vehicles or 2.8 Cluster 1 vehicles. In other words, each additional electric-assist device has a comfort-equivalent effect of 1.3 additional conventional bicycles (30% more). Hence, if conventional bicycles (Cluster 2) are the reference path user, then the total comfort-equivalent user volume would be calculated:

$$Volume_{Eq2} = 0.5 \times Volume_{cluster\ 1} + 1.0 \times Volume_{cluster\ 2} + 1.3 \times Volume_{cluster\ 3}$$

Or using Cluster 1 as the reference level:

$$Volume_{Eq1} = 1.0 \times Volume_{cluster\ 1} + 2.1 \times Volume_{cluster\ 2} + 2.8 \times Volume_{cluster\ 3}$$

These comfort equivalents can be used to make volume adjustments for new mobility devices in multi-use path design thresholds for pedestrian segregation, as well as other comfort-based volume thresholds.

Table 6. Calculation guidance for separating pathway users (Ministry of Transportation and Infrastructure 2019)

User ratio for separation	Daily anticipated volume for various pathway width (users)		
	3 m	3.5 m	4 m
More than 20% of users are pedestrians and total user volumes are greater than 33 persons per peak hour	1000	1200	1400
Less than 20% of users are pedestrians and total user volume is greater than 50 persons per peak hour	1500	1750	2000

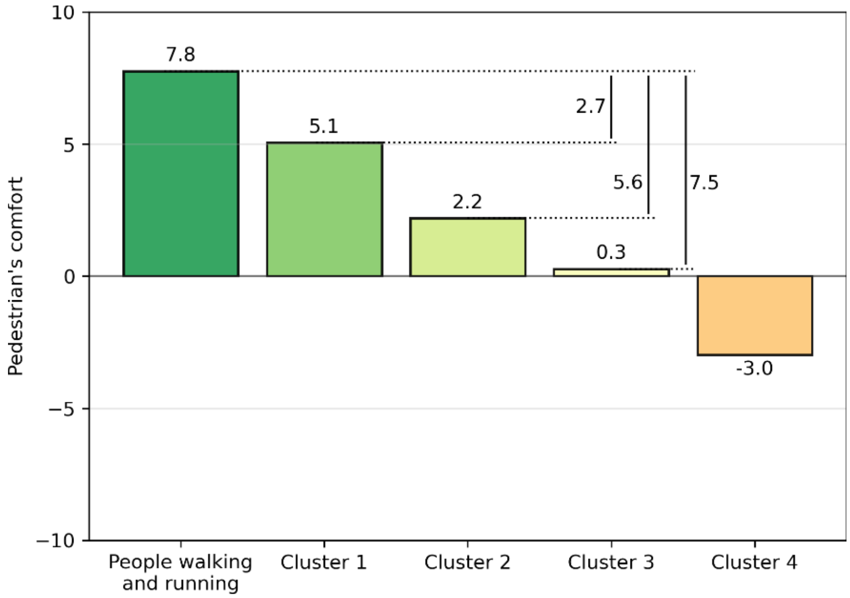


Figure 34. Average pedestrian comfort in sharing a multi-use path with vehicles from each Cluster

6 Research findings

1. Conventional bicycles are still the dominant vehicle on off-street paths, with a mode share of more than 90%; a wide range of new mobility devices are present in cycling facilities, but their mode share is currently extremely low (far less than perceived by the public).

2. On average, electric-assist increases bicycle, skateboard, and kick scooter speeds by 4, 10, and 14 km/hr (21%, 83%, and 156%), respectively, over human-powered speeds (more on up-hills). This effect tends to homogenize average speeds around 20-22 km/hr, which may provide a potential safety benefit due to reduced frequency of overtaking conflicts and reduced speed differences while overtaking.

3. Except for sit-down electric scooters (moped-style motorcycles), electric-assist vehicles on paths rarely exceed the 32 km/hr regulatory limit for motor assisted cycles (7% - much less than car speed violations). However, 44% of the observed electric kick scooter speeds would violate the 24 km/hr limit in the new Provincial electric kick scooter pilot project regulations.

4. Most travellers, including pedestrians, are comfortable sharing off-street paths with all the observed vehicle types except sit-down electric scooters.

5. Electric-assist in a vehicle reduces comfort for other path users equivalent to a 9 km/hr faster vehicle, all else (including speed) equal. Previous experience of an incident reduces traveller comfort equivalent to an 11 km/hr faster vehicle (all else equal).

6. The effect of electric-assist on speed is less than commonly perceived by the public; eliminating this perception bias would have the same effect on comfort as a 2 km/hr decrease in actual speeds.

7. We propose four speed- and comfort-aligned clusters of non-automobile vehicles using off-street paths for design and policy (Figure 3): 1) low-speed, 2) conventional bicycles, 3) electric-assist, and 4) moped-style scooters.

8. The negative impact on path user comfort of each additional Cluster 2 vehicle (conventional bicycle) is equivalent to 2.1 Cluster 1 vehicles (e.g., wheelchair); the negative impact of each additional Cluster 3 vehicle (electric-assist device) is equivalent to 1.3 Cluster 2 vehicles or 2.8 Cluster 1 vehicles. These comfort-equivalents can be used to make volume adjustments for new mobility devices in multi-use path design, such as thresholds for pedestrian segregation.

7 Conclusion and recommendations

1. The region is generally **ready to accommodate new mobility devices** in off-street paths without major effects on speeds and with only slight reductions in path user comfort (even with much higher mode shares of electric-assist vehicles).

2. Pedestrian discomfort justifies **reducing volume thresholds for separating pedestrians** from travellers using conventional bicycles or new mobility devices on multi-use paths and greenways.

3. We should work to **eliminate the use of (moped-style) sit-down electric scooters** on off-street paths and cycling facilities, which are clear speed and comfort outliers.

4. Other than for moped-style scooters, the current 32 km/hr regulatory limit on electric-assist cycle speeds **appears to be effective**, and further enforcement is not needed at this time. However, achieving lower speeds for other electric-assist devices (e.g., the 24 km/hr limit in the Provincial electric kick scooter pilot) may require additional vehicle-level speed control strategies. Monitoring of electric kick scooter speeds during the pilot program is recommended.

5. Active transportation design guidelines should be **updated to reflect real-world speeds**, particularly for electric-assist bicycles and devices. The 30 km/hr design speed for cycling facilities suggested in the BCATDG is appropriate, even for facilities with a large share of electric-assist new mobility devices (as currently used).

6. Further research is needed to include **other design aspects of new devices**, such as stopping distances and turning radii, in transportation design documents.

8 Limitations and future work

1. The current study provides baseline data regarding mode share over 4 consecutive seasons in Metro Vancouver. Future study is needed to examine the long-term trends in micromobility adoption and use.

2. It is unknown the way an evolving micromobility device market may affect vehicle use and path operations in the future. Electric-assist vehicles such as “speed pedelec” bicycles can have motor assistance as high as 50 km/hr (Zipper 2021). These, like many of the observed devices currently in use in Metro Vancouver, are illegal under the MVA. Future data collection is needed to update the findings of this study as the device market evolves.

3. To measure cruising speeds and control the number of external factors, the sampling locations in this study were limited to straight segments of off-street cycling facilities (physically separated from automobiles) distant from intersections with absolute grades not greater than 3%. Future study is needed to observe the effects of electric assistance around intersections, and compare network speeds for accessibility analysis. Further work is also needed to understand path user comfort during interactions at intersections, including with automobiles.

4. Incidents were investigated in this study, but the (fortunately) low number of crashes reported limited the strengths of the conclusions that could be drawn. Future work should continue to examine incident rates for different micromobility devices on paths, although the relative safety of off-street paths (compared to facilities shared with automobiles) will continue to impede statistical crash analysis.

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10 Appendix A: Sampling location selection

During phase 1 of data collection, 36 potential sampling locations were chosen through our local knowledge, studying of the municipal cycling maps, and inspection of Google Street view. In selection of potential sampling locations for the study, the following list of ten selection criteria was created. Each selection criterion was supported by a rationale for its creation in *italics*.

1. Sampling locations were selected from off-street facilities or facilities that were physically separated from automobile traffic *to ensure the vehicle speeds at sampling locations were not disturbed by automobile traffic.*
2. Sampling locations were selected at exactly at a pole or a tree adjacent to the path *to allow installation of a video camera and locking the speed and count measurement equipment to it.*
3. Sampling locations were selected at segments of the path that were straight within a 30 meters span on each side *to ensure that non-auto traffic speeds were not be affected by curves in the path and that the vehicles were maintaining a cruising speed. Furthermore, this allows homogeneity in geometry of sampling locations.*
4. Sampling locations were selected at segments of the path with no intersection within a 30-meter span on each side *to ensure the non-auto traffic speeds were not be disturbed by perpendicular traffic, and that the non-auto traffic was maintaining a cruising speed. This criterion further increases homogeneity in geometry of sampling locations.*
5. Sampling locations were selected from segments of the path with grade of equal to or less than 3 percent *to ensure non-auto vehicles cross the speed measurement equipment at a 90-degree angle without wobbling. Crossing the speed measurement equipment at an angle other than 90 degrees introduces errors in speed measurement.*
6. Sampling locations were selected from paths with surface material that were penetrable by nails (gravel, concrete, and brick surfaces were excluded) *to allow installations of speed measurement equipment on the ground.*
7. Half of the sampling locations were selected from the suburbs *to ensure representation from outside the City of Vancouver.*
8. The selected sampling locations were expected to have a minimum traffic of 6 non-auto vehicles per hour on a sunny day *to ensure the cost effectiveness of collecting data at that corridor.*
9. The selected sampling locations were expected to capture almost all of travellers on non-auto vehicles at the sampling location *to ensure the cost effectiveness of collecting data at that corridor.*
10. The selected sampling locations were expected to have parking at a walkable distance to allow us easily carry the data collection equipment from their vehicle to the site.

With the help of the selection criteria, 36 locations were chosen for site visits (Figure 35) to ensure they were right for the purposes of the study (Table 7 and Figure 36). After site visits, 12 locations were chosen as the final sampling locations for data collection in this study.

Figure 35. Site visit to 22nd Street, North Vancouver for determining the final list of sampling locations

Table 7. All sampling locations studied for sampling location selection in Metro Vancouver

Number	Location	Municipality	Phase 1	Inclusion as Sampling Location?
1	Highland Park Line Trail	Burnaby	✓	Included
2	22nd Street Station	New Westminster		Included
3	Esplanade West	North Vancouver	✓	Included
4	Railway Greenway	Richmond		Included
5	Wesbrook Mall	UEL		Included
6	Thunderbird Park	UEL		Included
7	York Ave and Cypress St	Vancouver	✓	Included
8	Central Valley Greenway at Tech Center	Vancouver	✓	Included
9	Richards St and Nelson St	Vancouver	✓	Included
10	Arbutus Greenway and King Edward Ave	Vancouver	✓	Included
11	Point Grey Rd and Alma St	Vancouver	✓	Included
12	Spirit Trail	West Vancouver		Included
13	Still Creek Ave and Douglas Rd	Burnaby		Excluded - Proximity to intersection
14	Hornby St and Drake St	Vancouver		Excluded - Proximity to intersection
15	Cambie St and Kent Ave	Vancouver	✓	Excluded - Proximity to intersection
16	No 3 Rd and Lansdowne Rd	Richmond		Excluded - Proximity to high traffic road
17	Cornwall Ave and Yew St	Vancouver		Excluded - No pole at location
18	King Albert Ave and Gatensbury St	Coquitlam	✓	Excluded - Low volume
19	Lougheed Hwy and Sherling Ave	Port Coquitlam	✓	Excluded - Low volume
20	Lansdowne Rd and Cedarbridge Way	Richmond	✓	Excluded - Low volume
21	Steveston Park	Richmond		Excluded - Low volume
22	10th Ave and Oak St	Vancouver	✓	Excluded - High grade & proximity to intersection
23	Burrard Bridge	Vancouver		Excluded - High grade
24	Stanely Park at Tennis Courts	Vancouver		Excluded - High grade
25	Charleson Dog Park	Vancouver	✓	Excluded - Horizontal curvature
26	Point Grey Rd and MacDonald St	Vancouver	✓	Excluded - Overrepresentation of Vancouver
27	Ontario St and 50th Ave	Vancouver	✓	Excluded - Overrepresentation of Vancouver
28	Arbutus Greenway Burrard St	Vancouver	✓	Excluded - Overrepresentation of Vancouver
29	Beach Ave at Alexandra Park	Vancouver		Excluded - Overrepresentation of Vancouver
30	1st Ave and Main St	Vancouver		Excluded - Overrepresentation of Vancouver
31	Central Valley Greenway	New Westminster		Excluded - Low volume
32	Hume Park	New Westminster		Excluded - Gravel path
33	23rd St and Lonsdale Ave	North Vancouver	✓	Excluded - Low volume
34	Chancellor Blvd	UEL	✓	Excluded - Due to abundance of data
35	Stanely Park	Vancouver	✓	Excluded - Overrepresentation of Vancouver
36	Coopers Park	Vancouver		Excluded - Overrepresentation of Vancouver

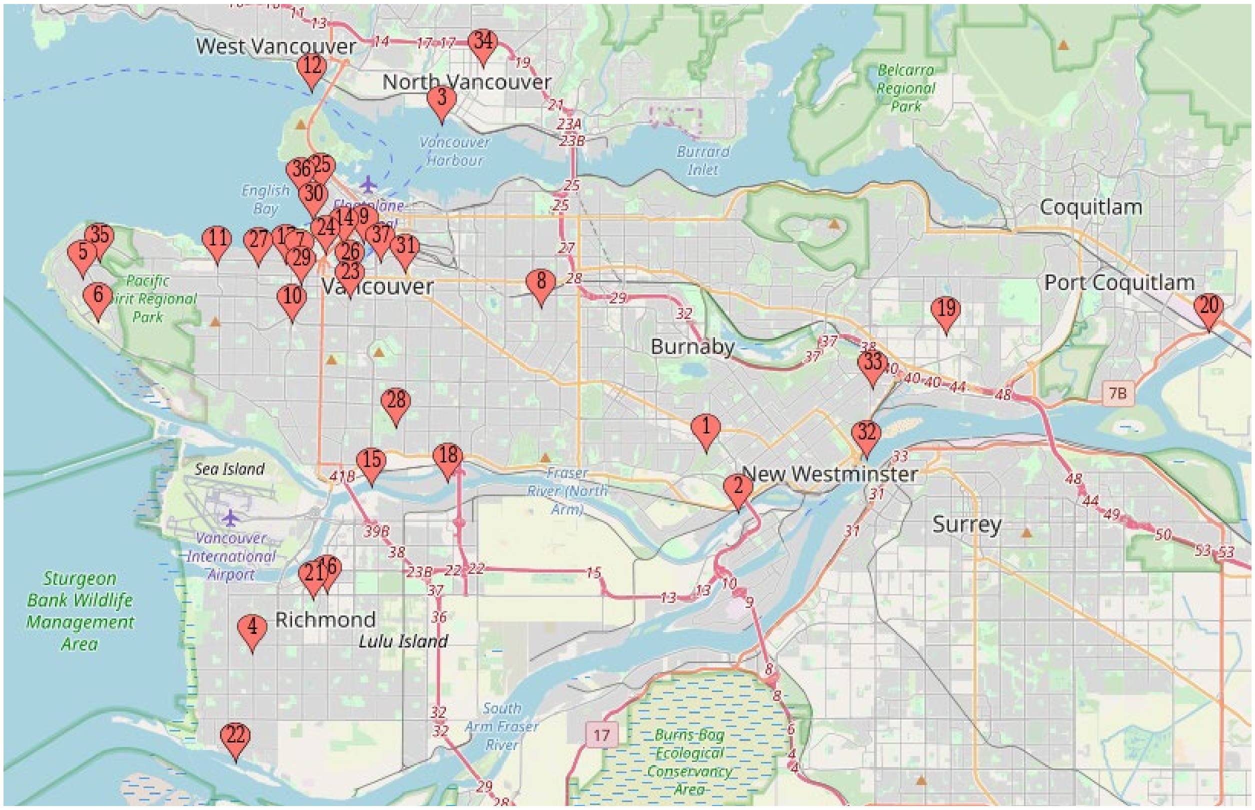


Figure 36. Map of the 36 locations selected for site visits based on the municipal maps and Google Street View

11 Appendix B: Data collection schedule

Data collection period was planned to cover 5 seasons (summer 2019 through summer 2020); however, the last season was cancelled due to the COVID-19 pandemic. In each season, data were collected at every sampling location on one weekend and one weekday. The hours of data collection in each weekday and weekend covered the respective traffic volume peaks based on trip data from Vancouver Mobi bikeshare (Figure 37). On weekdays data were collected typically from 8 am to 6 pm and on weekend typically from noon to 4 pm. Based on our estimates, this amount of data collection would have led to approximately 20,000 observations which would result in 50 observations from a vehicle with 0.5% mode share.

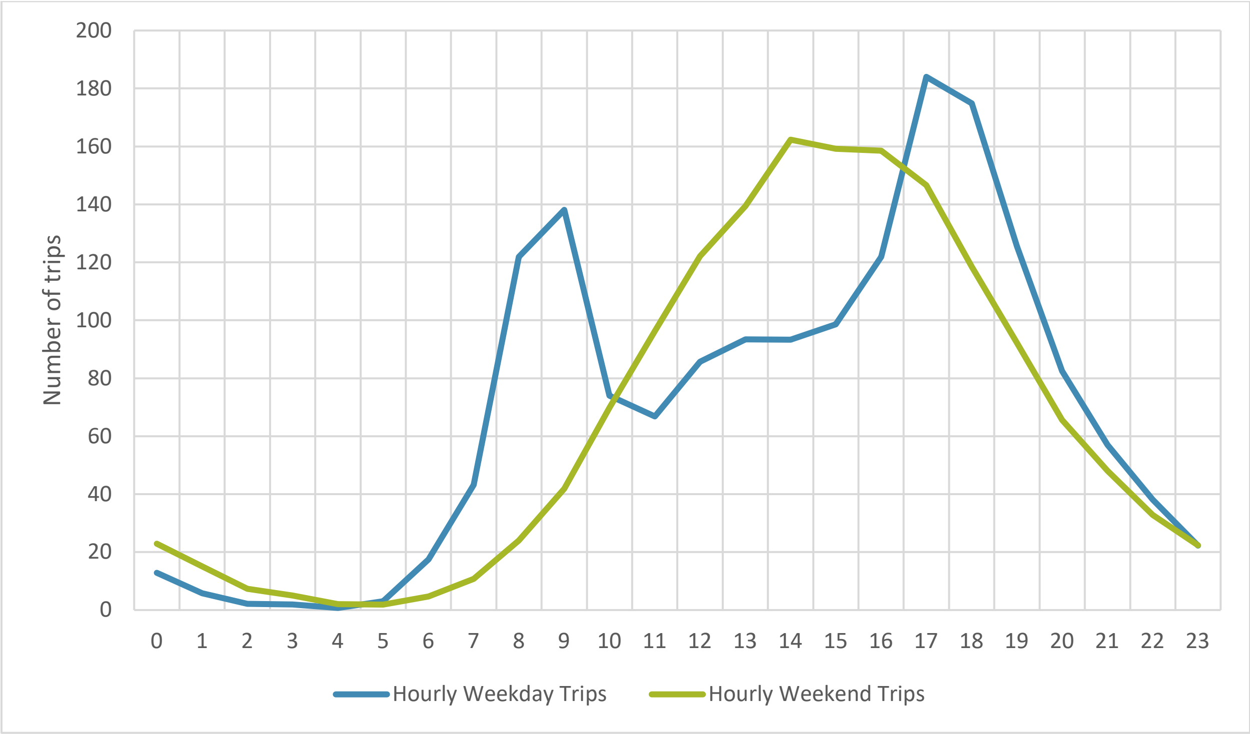


Figure 37. Average hourly trips by Mobi bikes in Vancouver in 2019

The exact days of count, classification, and speed data collection were from August 2019 to April 2020 on days illustrated in the calendar in Figure 38. The numbers on each day in the calendar show the number of hours data were collected at all locations visited on that day. From February 2020, we started collecting data at 2 locations per day, therefore, the number of hours of data collection nearly doubled from similar days in previous months. Data collection days were determined with consideration of the minimum requirements of 1 weekday and 1 weekend day per location per season, weather, and availability of student researchers and affordable transportation options to the sampling locations.

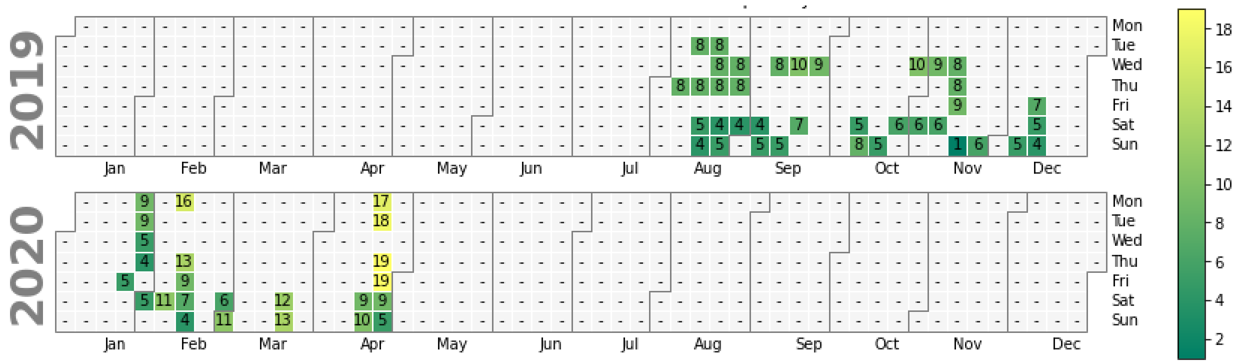


Figure 38. Days and number of hours of classified count and speed data collection

12 Appendix C: Decision matrix for selection of classified count and speed data collection methods

Various types of technology that could be used for collecting classified count and speed data were studied in multiple dimensions such as accuracy, legality, cost, etc. and the results were categorized in Table 8. In each dimension cells were color coded as green, yellow, and red which stand for suitable, neutral, and not suitable, respectively. After careful considerations of all the dimensions, RidePod BT5926 (pneumatic tubes) was chosen to collect count and speed data. The pneumatic tubes were coupled with a camera to manually classify the vehicles that were counted by the tubes. Similarly, to select the appropriate camera for this study, various brands and models were studied in multiple dimensions such as resolution, frame rate, price, etc. and the results were presented in Table 9. Each cell in Table 9 is color coded as green, yellow, and red which stand for suitable, neutral, and not suitable, respectively. Finally, GoPro Hero 5 was chosen to record vehicles that cross the pneumatic tubes for manual classification. Figure 39 shows the instruments used for classified count and speed data collection.

Table 8. Pros and cons of various types of count and speed data collection technologies

	Types of Technology	# of Equipment Needed	Counting	Classification	Speed	Requirement for location	Other Purchases	Software/ Computer Code	Occlusion?	Confidence based on past studies	Speed Accuracy	Count accuracy	Required labour hours	Obtrusive?	Legal/ Ethical Issues	Ease of Installation	Battery Life	Highest Image Resolution	Relative Cost
Manual Speed Calculation	COUNTcam2 Traffic Recorder	1	Manual	Manual	Manual	A Pole	N/A	Adobe Premiere Pro, R Studio	No	Yes	Highly Accurate	Highly Accurate	High	Low	OK	Easy	50 hr	640* 480	Medium $1620 CAD
	Two Camcorders (GoPro 5 Black)	2	Manual	Manual	Manual	Yes/No	Tripod, SD card	Adobe Premiere Pro, R Studio	No	Yes	Highly Accurate	Highly Accurate	High	Low	Ok	Easy	150 min power bank	1920* 1080	Low 0 CAD
	Infrared break-beam sensors w/ a camcorder (GoPro 5 Black)	8	Manual	Manual	Manual	Yes/No	Camera, Tripod	Adobe Premiere Pro, R Studio	Yes	Yes	Accurate	Accurate	High	High	Ok	Medium	150 min power bank	1920* 1080	Low 0 CAD

		Types of Technology	# of Equipment Needed	Counting	Classification	Speed	Requirement for location	Other Purchases	Software/ Computer Code	Occlusion?	Confidence based on past studies	Speed Accuracy	Count accuracy	Required labour hours	Obtrusive?	Legal/ Ethical Issues	Ease of Installation	Battery Life	Highest Image Resolution	Relative Cost
Automated Speed Calculation	Computer Tracking	One Camcorder (GoPro 5 Black)	1	Auto	Manual	Auto	Yes/No	Tripod	Computer Vision Tracking System	Yes	No	N/A	90%	Low	Low	Ok	Easy	150 min power bank	1920* 1080	Low 0 CAD
		Miovision Scout	1	Auto	Manual	Auto	A Pole	N/A	Miovision DataLink	Yes	N/A	Require more info from user manual	Require more info from user manual	Low	Low	Restricted	Easy	72 hr	720* 480	Medium ~$3000
		Drone & Camera	1	Auto	Manual	Auto	No	Camera, Tripod	DataFromSky Viewer	Yes	N/A	N/A	N/A	Low	Me	Res	Me	N/A	N/A	N/A
	Radar	Black CAT Radar Cycle Detection	1	Auto	Manual	Auto	Yes/No	Camera, Tripod	VDA -Pro R2	Yes	N/A	plus/minus 1.34m/s	90%	Low	Low	Ok	Easy	Various	N/A	Medium
		Viacount2 (Designed for auto vehicles)	1	Auto	Manual	Auto	A Pole	Camera, Tripod	Manufacturer's software	Yes	Yes	Require more info from user manual	Require more info from user manual	Low	Low	Ok	Easy	2 weeks	N/A	Medium
		Armadillo Tracker (Designed for auto vehicles)	1	Auto	Manual	Auto	A Pole	Camera, Tripod	Manufacturer's software	Yes	Yes	plus/minus 0.28m/s	97%	Low	Low	Ok	Easy	2 weeks	N/A	Medium $3915
	Pneumatic	RidePod BT5926	2	Auto	Manual	Auto	A Pole	Camera, Tripod	MetroCount Traffic Executive software V5 (Free)	Yes	Yes	Require more info from user manual	Require more info from user manual	Low	Medium	Ok	Medium	2-year battery life	N/A	Low 0 CAD
	Pneuma	Eco-Counter/Mobile MULTI	2	Auto	Manual	Auto	No	Camera, Tripod	Eco-Visio 5	Yes	Yes	Require more info from user manual	Require more info from user manual	Low	Low	Ok	Medium	2-year battery life	N/A	High
	Laser	TruCAM II Speed Enforcement Laser with Video	2	Manual	Manual	Auto	No	Accessories	TruCAM II Field Printing Software --- tPrint	No	N/A	plus/minus 0.56m/s	Highly Accurate	Medium	Medium	Ok	Easy	8-10 hr	2592* 1944	High ~ $5500*2

Table 9. Pros and cons of various types of cameras for manual classification of vehicles

Brand	Model	Focal length (mm)	Horizontal FOV (Degree)	Typical Battery Life (min)	Other Power Supply?	Price (CAD)	Water Resistance	Highest Resolution	Frame Rate
Canon	Vixia R800	32.5	58	85	N/A	259	No	1920*1080	60/30/24
	Vixia HF W10	40.5	49	130	N/A	419	Yes	1920*1080	60
	Vixia HF W11	40.5	49	130	N/A	539	Yes	1920*1080	60
	HF R70	32.5	58	85	N/A	426	No	1920*1080	60/30/24
	HF R80	32.5	58	85	N/A	458	No	1920*1080	60/30/24
	HF R82	32.5	58	85	N/A	525	No	1920*1080	60/30/24
	HF G21	26.8	70	95	N/A	1079	No	1920*1080	60/30/24
Panasonic	HC-V180	28	65.5	60	VBT380 (120min)	329	No	1920*1080	60/30
	HC-V380k	28	65.5	70	VBT380 (120min)	402	No	1920*1080	60/30
	HCV770 HD	29.5	63	50	VBT380 (120min)	699	No	1920*1080	60/30
	HC-VX981K	30.8	62	50	N/A	780	No	3840 x 2160	60/30/24
	HCV800 HD	28.9	64	50	N/A	899	No	1920 x 1080	60/30/24
	HC-VX1 4k	28.9	64	50	N/A	1099	No	3840 x 2160	60/30/24
	HC-WXF1 4k	28.9	64	50	N/A	1399	No	3840 x 2160	60/30/24
Sony	HDR-CX405	26.8	70	55	N/A	249	No	1920*1080	60/30
	HDR-CX440	26.8	70	55	N/A	335	No	1920*1080	60/30
	HDR-CX455	26.8	70	75	NP-FV100A (325min)	449	No	1920*1080	60/30
	HDR-CX675	26.8	70	75	NP-FV100A (310min)	679	No	1920*1080	60/30/24
	FDR AX33 4k	26.8	70	75	NP-FV100A (150min)	899	No	3840 x 2160	60/30/24
	FDR AX53 4k	26.8	70	75	NP-FV100A (150min)	1099	No	3840 x 2160	60/30/24
	FDR-AX100 4k	29	64	65	NP-FV100A (135min)	1699	No	3840 x 2160	60/30/24
GoPro	HERO 5 Black	14	104	150	Power bank	0	Yes	3860*2140	24 - 240
CountingCars	COUNTCam2	<10	170	50 hours	External battery booster pack (150hrs)	1620	Yes	640*480	10

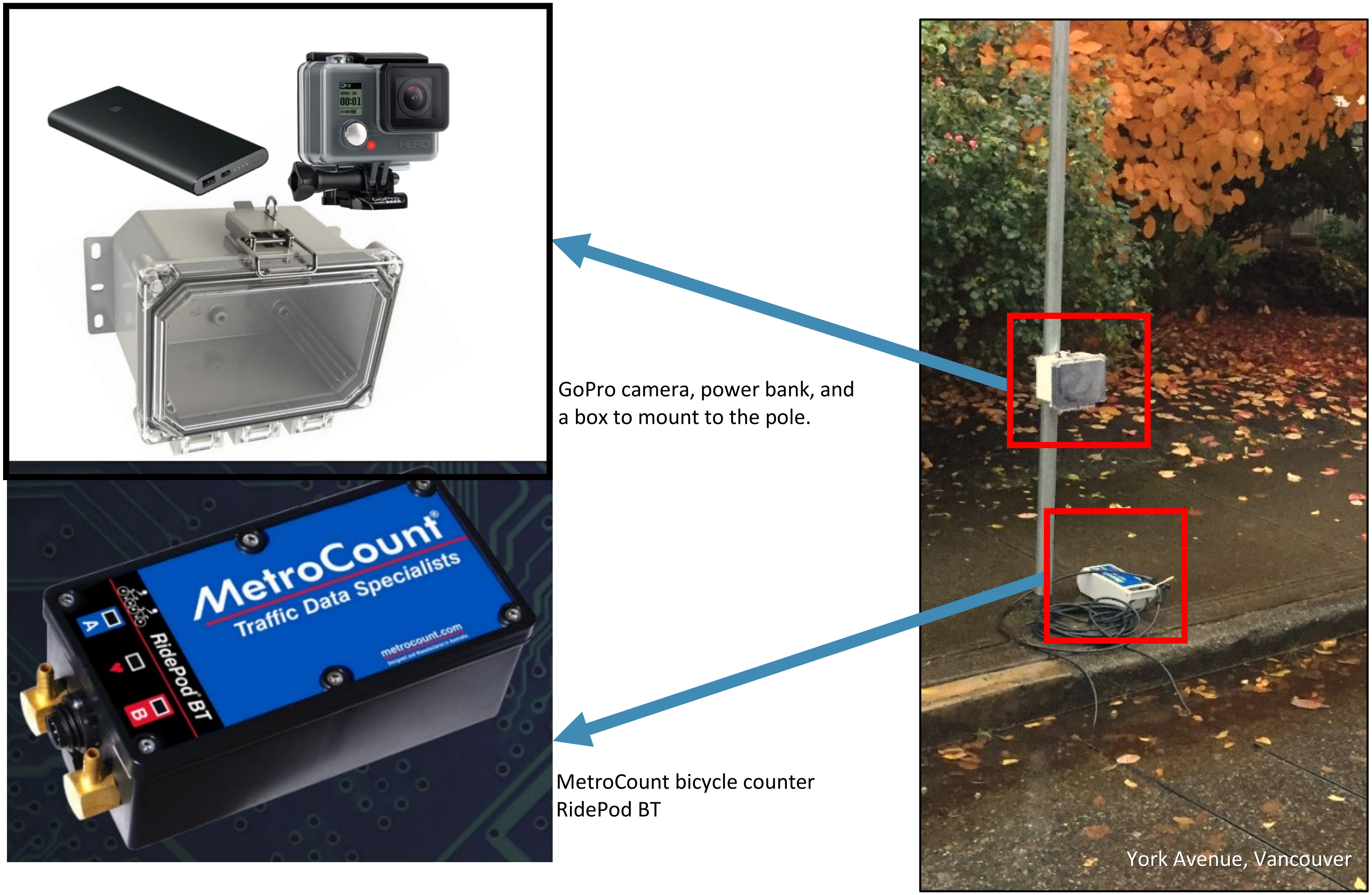


Figure 39. Classified count and speed data collection instruments

13 Appendix D: Post-evaluation of classified count and speed data collection instruments

13.1 Accuracy of count and speed measurements

The RidePod BT5926 was tested for its accuracy in detecting (counting) the vehicles that cross its tubes prior to data collection. Results of the test indicated 100% accuracy in detecting vehicles crossing the tubes. RidePod also detected pedestrians (adults and kids) stepping on the tubes or kicking the tubes. The speed of bicycles from pneumatic tubes were compared against speed calculated from video data (as ground truth) to investigate the accuracy of speed measurement with RidePod. Speeds calculated from video recordings are prone to uncertainties themselves and the intensity of the uncertainty is related to the error in measuring of distance (Δx), and the accuracy of measurement of time (Δt). The former is the precision of the ruler (ε_x) used for measuring the distance, and the latter is the frame rate of the camera (ε_t) used for recording videos. The error in measurement of speed relative to speed as calculated using Equation 1.

Equation 1. Error in speed measurement relative to speed

$$u_v = \frac{\varepsilon_v}{v} = \pm\sqrt{(\frac{\varepsilon_x}{\Delta x})^2 + (\frac{\varepsilon_t}{\Delta t})^2}$$

Figure 40 show the relative uncertainty in calculation of speed from video given distance and camera frame rate. The highest frame rate on the selected camera for data collection (GoPro Hero 5), 120 fps, was used for this test to achieve the lowest levels of uncertainty. A distance of 5 meters was marked with two pieces of duct tape with the pneumatic tubes in the center (Figure 41) to ensure the lowest relative uncertainty is achieved as well as closest measurement to the instantaneous speed measurement made by the pneumatic tubes.

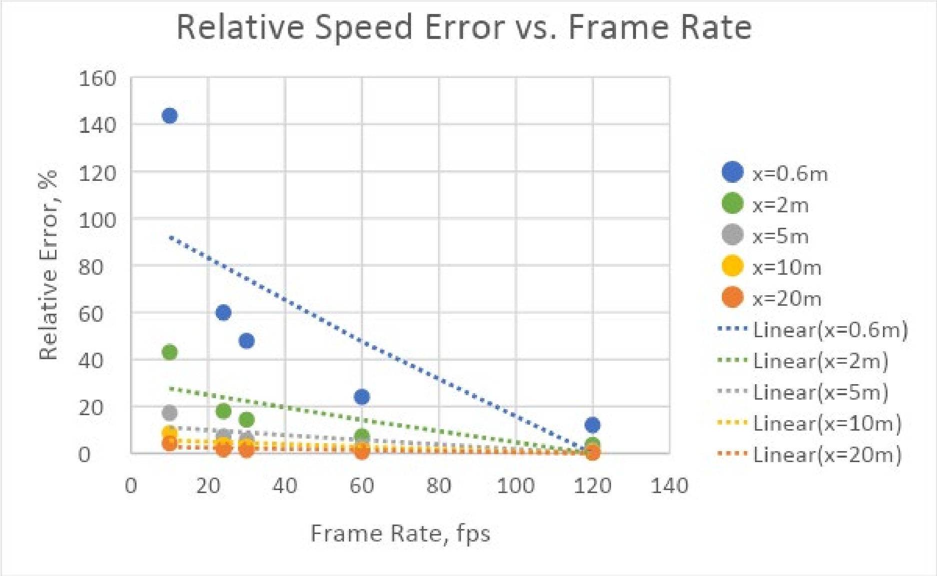


Figure 40. Relative uncertainty in calculation of speed from video given distance and camera frame rate

Figure 41. The set-up of testing the accuracy of pneumatic tube's speed measurements against ground truth (speed from video recordings)

34 speed measurements were done with speeds varying from 10 km/hr to 30 km/hr. The results in Table 10 show that speed difference from pneumatic tubes and the ground truth were consistently less than 1 km/hr (less than 5% error). This amount of deviance from ground truth was acceptable for this study.

Table 10. Comparison of pneumatic tube's speed measurements against ground truth (speed from video recordings)

Observation number	Ground truth speed (km/hr)	MetroCount speed (km/hr)	Δ Speed	Error %
1	14.03	14.22	0.19	1.38
2	13.85	14.23	0.38	2.77
3	12.71	12.72	0.01	0.11
4	13.67	13.72	0.05	0.36
5	13.17	13.77	0.60	4.55
6	14.03	14.25	0.22	1.60
7	19.64	19.65	0.01	0.07
8	15.21	15.45	0.24	1.57
9	19.64	20.00	0.36	1.85
10	13.67	14.20	0.53	3.87
11	10.80	10.87	0.07	0.65
12	15.65	16.22	0.57	3.63
13	19.64	19.60	-0.04	-0.19
14	15.65	16.07	0.42	2.67
15	19.64	19.40	-0.24	-1.20
16	15.88	16.23	0.35	2.19
17	18.31	18.20	-0.11	-0.57
18	12.00	12.38	0.38	3.17
19	15.88	16.10	0.22	1.37
20	18.95	19.35	0.40	2.13
21	23.48	23.73	0.25	1.07
22	17.14	17.73	0.59	3.43
23	19.64	19.71	0.07	0.37
24	17.14	17.76	0.62	3.60
25	18.31	18.83	0.52	2.87
26	15.43	15.32	-0.11	-0.70
27	19.29	19.10	-0.19	-0.96
28	16.88	16.86	-0.02	-0.09
29	11.49	11.32	-0.17	-1.47
30	15.88	16.73	0.85	5.34
31	15.88	16.05	0.17	1.06
32	14.59	15.04	0.45	3.05
33	29.19	29.12	-0.07	-0.24
34	12.56	12.90	0.34	2.72

13.2 Obtrusive test of pneumatic tubes

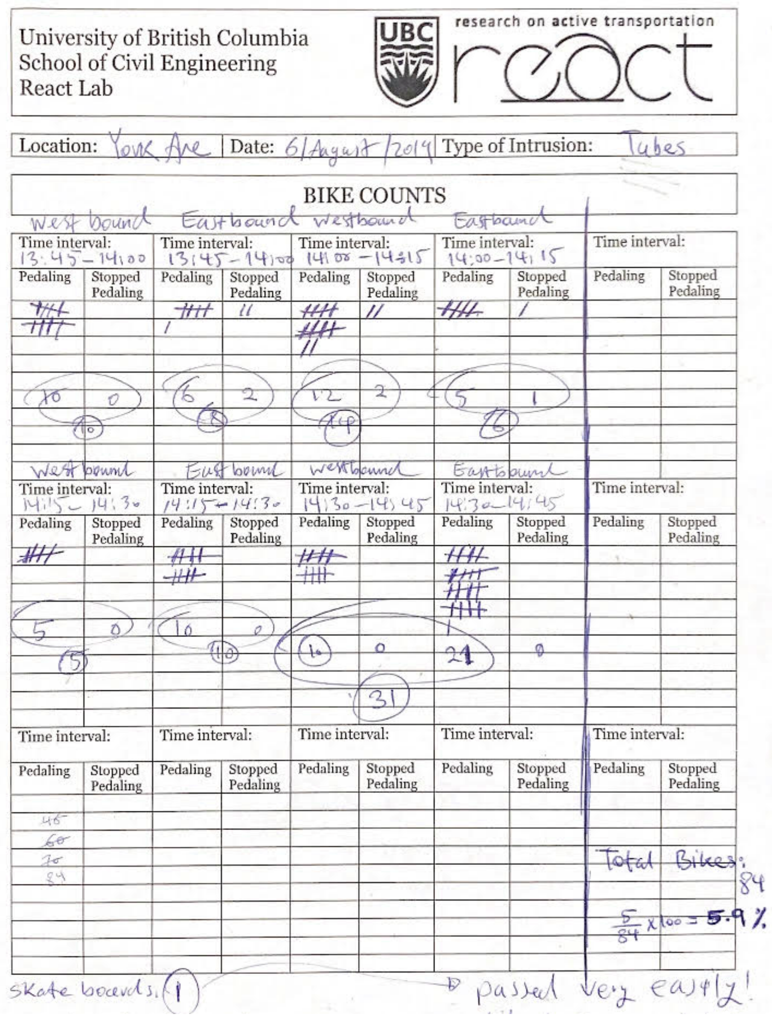
Cycling behavior (changing speed) in the vicinity of the speed measurement setup (pneumatic tubes) was observed in a flat cycle lane. The pneumatic tubes might have the potential to act as an intrusion in the cyclist's commute and force them consciously or unconsciously to reduce speed; therefore, the effects of pneumatic tubes were investigated to ensure cruising speed of cyclists were observed. The York Avenue cycle lane between Cypress and Maple Street was chosen for this test due to its relatively high volume of cyclists and zero grade. In this test, stopping pedaling, was taken as a proxy measure for slowing down (distraction by the tubes):

- No intrusion, which acts as out control data;
- Pneumatic tubes placed 40 centimeters from each other;
- And silver colored duct tape placed 5 meters from each other with pneumatic tubes in between.

The percentage of cyclists who were not pedaling in the 10-meter span before reaching the setup were extracted in a 1-hour timeframe for three types of intrusion (see Figure 42). The results presented in Table 11 show that tubes were not intrusive to cyclists' commute and cyclists either do not see the tubes or do not slow down when they do. In the first scenario, of the 74 bicycles that passed the study location, 5.4 percent were not pedaling in the 10-meter span before the study area. In the second scenario, we saw the same pattern as the first scenario. Of the 84 cyclists, only 5 did not pedal (5.9 percent). However, this figure soured to 9.3 percent in the third scenario. Nine out of 97 cyclists were not pedaling in the 10-meter span before the study location. We believe this was due to the prevalence of using tubes by the municipality for extracting bicycle counts in the city which makes cyclists used to riding over them. Additionally, 5 skateboards were also observed during the experiments who crossed the tubes with no visible reduction in speed or discomfort.

Table 11. Percentage of cyclist distracted by each type of data collection instrument

Scenario	**Percentage of cyclist who were not pedaling in the 10-meter span before reaching**
No intrusion (control)	5.4% out of 74 cyclists
Pneumatic tubes placed 40 cm apart	5.9% out of 84 cyclists
And silver colored duct tape placed 5 m apart with pneumatic tubes in between.	9.3% out of 97 cyclists



University of British Columbia
School of Civil Engineering
React Lab

UBC research on active transportation react

Location: York Ave	Date: 6/August/2019	Type of Intrusion: Tubes

BIKE COUNTS

Westbound Time interval: 13:45–14:00		Eastbound Time interval: 13:45–14:00		Westbound Time interval: 14:00–14:15		Eastbound Time interval: 14:00–14:15		Time interval:	
Pedaling	Stopped Pedaling	Pedaling	Stopped Pedaling	Pedaling	Stopped Pedaling	Pedaling	Stopped Pedaling	Pedaling	Stopped Pedaling
10	0	6	2	12	2	5	1		
10		8		14		6			

Westbound Time interval: 14:15–14:30		Eastbound Time interval: 14:15–14:30		Westbound Time interval: 14:30–14:45		Eastbound Time interval: 14:30–14:45		Time interval:	
Pedaling	Stopped Pedaling	Pedaling	Stopped Pedaling	Pedaling	Stopped Pedaling	Pedaling	Stopped Pedaling	Pedaling	Stopped Pedaling
5	0	10	0	10	0	21	0		
5		10		31					

Time interval:		Time interval:		Time interval:		Time interval:		Time interval:	
Pedaling	Stopped Pedaling	Pedaling	Stopped Pedaling	Pedaling	Stopped Pedaling	Pedaling	Stopped Pedaling	Pedaling	Stopped Pedaling
45									
60									
70								Total Bikes: 84	
84									
								$\frac{5}{84} \times 100 = 5.9\%$	

Skate boards: 1 → passed very easily!

Figure 42. Results sheet from the intrusion test on pneumatic tubes on York Avenue on August 6th, 2019

13.3 Visual test of cameras after sunset

Video recording quality after sunset was experimented to ensure that enough light can be captured by the selected camera (GoPro Hero 5) to conduct manual classification of the observed vehicles. Knowing that video recordings without external light source were not useful, the effects of three types of street lights on the quality of videos were investigated. Figure 43 shows the quality of video recordings under each of these three street lights. The test demonstrated that classification of vehicles was not possible under this light; therefore, data collection was not conducted later than 6 pm.

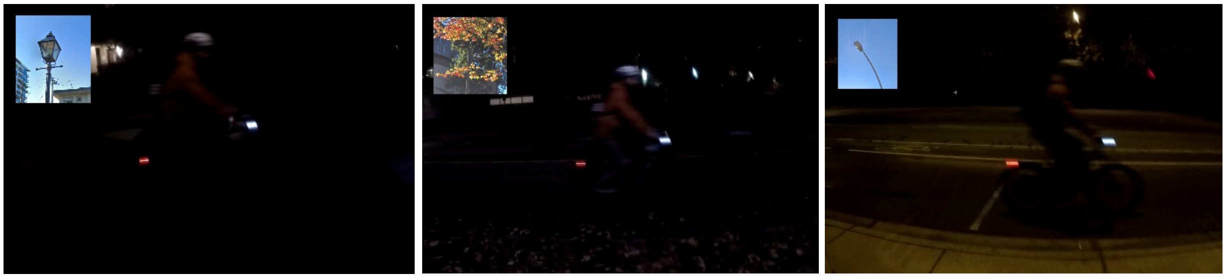


Figure 43. Video recording quality under three different street light

14 Appendix E: Web survey data collection

14.1 Survey distribution

Due to the limitations in close physical contact caused by the pandemic, an online intercept survey was developed to collect data on the nature of interactions among users of non-auto road facilities. The advertisement for the survey was done with the help of twelve 42*36-inch sandwich boards. A sandwich board with two survey advertisement posters on either side was placed at each of the 12 sampling locations in this project. The sandwich boards were locked to a pole next to the non-auto road facilities. Participants could take the survey on the spot with their smartphones using the link or the QR code on the posters, or take a card from the cardholder to take the survey later. Figure 44 shows the days survey was active and the number of responses recorded on each day. Close to the end of October, 2020, when the number of daily survey responses were dwindling, the survey was deactivated and the survey advertisements were collected from the sampling locations.

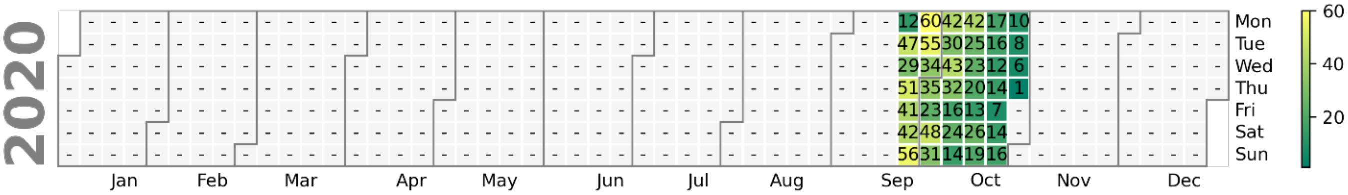


Figure 44. Days the survey was active with total recorded survey responses per day

14.2 Survey responses

Figure 45 presents the distribution of 1054 processed and filtered survey responses at sampling locations and Table 12 reports the percentage of survey respondents in each socio-demographic category (income, education, gender, and age) at all sampling locations and broken down at each sampling location.

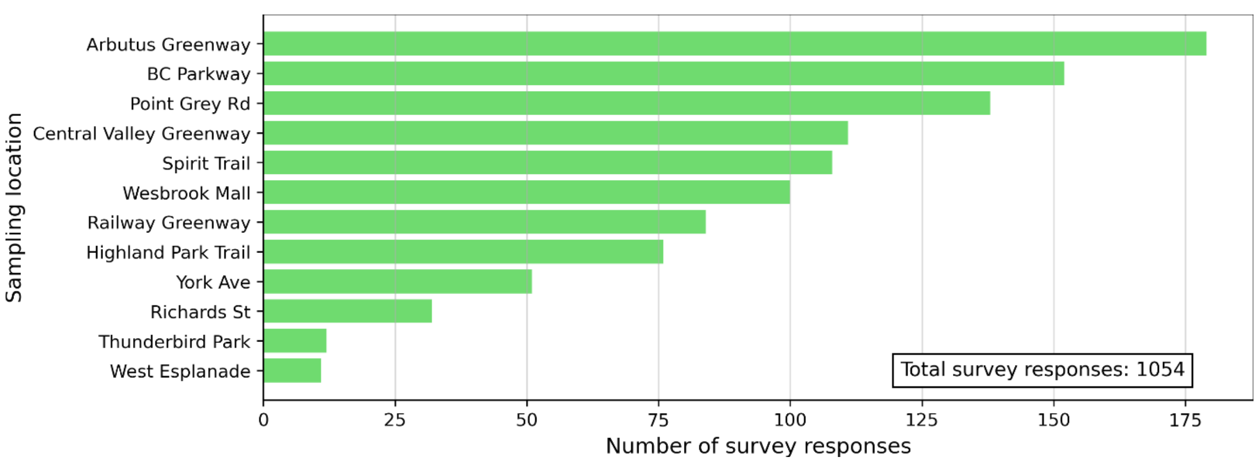


Figure 45. Number of survey responses at sampling locations where the survey was advertised

Table 12. Percentage of the survey respondents in each socio-demographic category at all sampling locations and broken down at each

		Lower Mainland	all sampling locations	Sampling Locations (See Figure 6)											
				1	2	3	4	5	6	7	8	9	10	11	12
Household Income	$150,000 and above	16.1	20.9	22.6	27.3	26.7	22.5	20.0	21.5	10.9	37.2	20.0	13.5	14.8	17.3
	$100,000 to $149,999	18.0	18.7	16.0	9.1	18.5	22.5	15.0	22.1	21.8	16.0	10.0	21.6	18.1	16.0
	$75,000 to $99,999	14.1	12.7	8.5	18.2	8.2	12.5	21.7	12.8	15.5	9.6	5.0	17.6	16.8	8.6
	$50,000 to $74,999	17.4	11.8	4.7	0.0	11.0	22.5	10.0	13.4	15.5	10.6	0.0	14.9	12.8	12.3
	$25,000 to $49,999	19.3	7.1	12.3	9.1	4.8	5.0	8.3	5.2	10.0	3.2	10.0	8.1	8.7	4.9
	under $24,999	15.2	5.8	3.8	0.0	3.4	2.5	8.3	5.2	6.4	7.4	35.0	5.4	3.4	8.6
	Prefer not to answer	-	23.1	32.1	36.4	27.4	12.5	16.7	19.8	20.0	16.0	20.0	18.9	25.5	32.1
Highest Level of Education	Graduate degree	12.1	31.7	30.8	27.3	39.3	37.5	38.3	36.2	32.7	44.7	30.0	20.3	21.5	17.1
	Bachelor's degree	23.2	37.2	33.6	18.2	37.9	30.0	36.7	44.3	31.8	31.9	30.0	45.9	32.9	45.1
	College/University certificate or diploma	31.0	18.5	21.5	27.3	13.8	27.5	15.0	14.4	21.8	7.4	10.0	18.9	28.2	20.7
	Completed high school/equivalency	25.2	5.9	3.7	0.0	2.8	5.0	6.7	3.4	5.5	8.5	25.0	10.8	6.7	7.3
	Some high school or less	8.6	2.7	2.8	0.0	2.8	0.0	1.7	0.6	2.7	5.3	5.0	1.4	5.4	2.4
	Prefer not to answer	-	4.0	7.5	27.3	3.4	0.0	1.7	1.1	5.5	2.1	0.0	2.7	5.4	7.3
Gender	Female	48.9	47.4	56.1	27.3	38.4	45.0	35.0	48.9	54.5	57.4	65.0	45.2	37.6	56.1
	Male	51.1	49.0	42.1	63.6	55.5	50.0	63.3	49.4	40.0	39.4	35.0	49.3	59.1	40.2
	X	-	3.8	1.9	9.1	6.9	5.0	1.7	1.7	5.4	3.2	0.0	5.5	3.4	3.6
Age	<16	15.1	0.8	1.9	0.0	0.7	0.0	1.6	0.6	0.9	1.1	0.0	0.0	1.3	0.0
	16-19	5.8	1.7	0.0	0.0	1.4	0.0	0.0	0.6	0.9	3.2	10.0	1.4	4.0	2.4
	20-29	13.8	13.5	11.2	18.2	6.8	22.5	14.8	13.8	17.1	19.1	50.0	13.5	8.7	9.8
	30-39	14.1	19.9	5.6	9.1	18.5	30.0	23.0	19.5	18.9	22.3	10.0	40.5	26.2	7.3
	40-49	14.2	17.1	11.2	0.0	14.4	25.0	24.6	14.9	23.4	23.4	10.0	13.5	16.1	18.3
	50-59	14.9	21.2	25.2	9.1	24.0	12.5	14.8	20.1	20.7	23.4	20.0	21.6	22.1	19.5
	60-69	11.7	14.2	20.6	45.5	22.6	10.0	14.8	14.4	12.6	2.1	0.0	1.4	14.1	19.5
	70-79	6.5	8.4	14.0	9.1	8.9	0.0	1.6	12.6	3.6	4.3	0.0	6.8	5.4	20.7
	80+	4.1	1.3	6.5	0.0	0.0	0.0	1.6	2.3	0.0	0.0	0.0	0.0	0.0	1.2
	Prefer not to answer	-	2.1	3.7	9.1	2.7	0.0	3.3	1.1	1.8	1.1	0.0	1.4	2.0	1.2

Socio demographics (age, gender, income, and education) and travel habits of the survey respondents are presented in Figure 46, Figure 47, and Figure 48. Moreover, survey respondents declared their comfort in taking risks (also known as risk tolerance or risk-taking ability; opposite of risk aversion) with an average value of 2 from -10 to 10. The distribution of the responded values is reported in Figure 49.

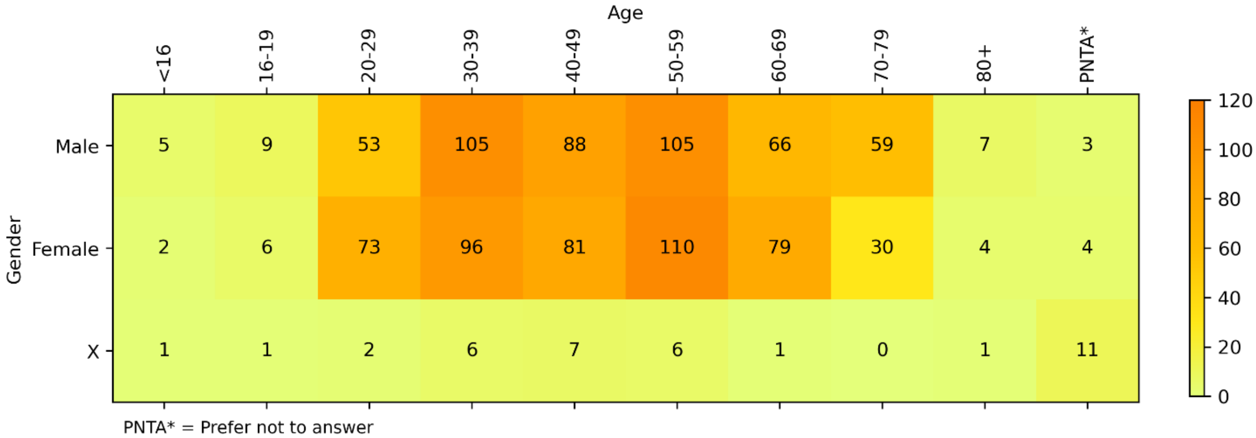


Figure 46. Number of survey respondents in each age and gender category. Gender X represents those who did not identify as male or female, or preferred not to declare their gender identity.

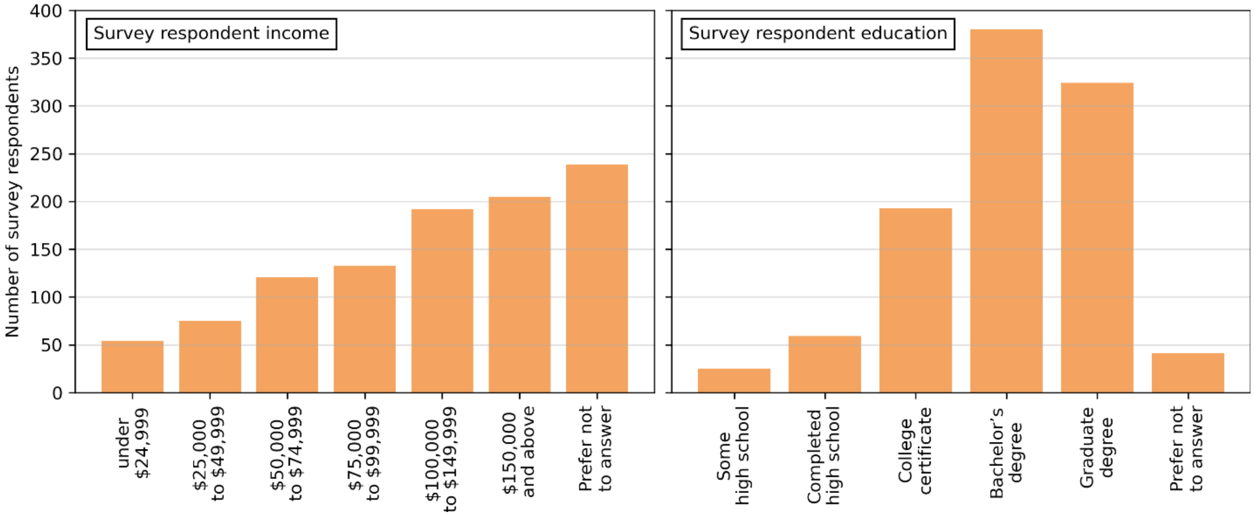


Figure 47. Number of survey respondents in each income and education category

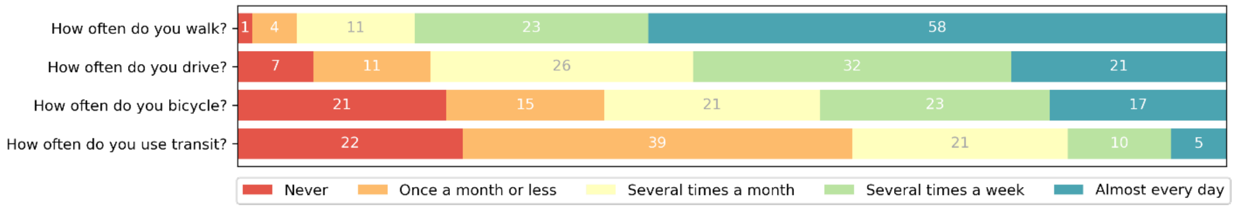


Figure 48. Travel habits of survey respondents

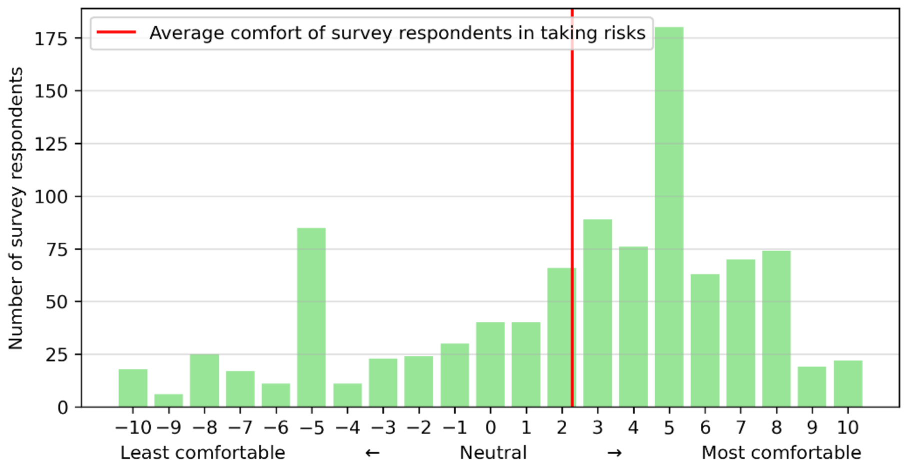


Figure 49. Survey respondents' self-declared comfort in taking risks (also known as risk tolerance, or risk-taking ability; opposite of risk aversion)

14.3 Survey questions

The list of questions asked in the online intercept survey regarding the nature of interactions among users of non-auto road facilities were as follows:

1. Consent form

Travel Experiences on Multi-Use Paths in Metro Vancouver

Thank you for considering participation in this study. This study is conducted by Dr. Alex Bigazzi and his research team from the Department of Civil Engineering at the University of British Columbia, with support from TransLink.

This study seeks to better understand travel on paths in general, and make recommendations for future design guidance. It is not part of a redesign process for any specific location.

We are investigating travel experiences on specific paths in Metro Vancouver. Therefore, please only proceed if you came across a sign on the side of a path recruiting for the survey. You will be asked to answer basic questions about yourself, your travel habits, and your interactions with other users of that specific path.

This survey should take no longer than 7 minutes to complete. Participation is voluntary, and you can withdraw at any time. Your responses will remain confidential, and any identifying information will be removed before the results are presented.

You can choose to enter a draw for 1 of 10 gift cards of $25 each by entering your email address on the next page. Your email address will not be shared or used for any other purpose. Everyone who takes the survey and enters their email address will be considered in the prize draw (even those who withdraw or do not answer every question).

If you have any questions about this study, please contact Dr. Alex Bigazzi, Associate Professor at the UBC Department of Civil Engineering, at alex.bigazzi@ubc.ca or 604-822-4426. If you have accessibility needs to take the survey, please email amirhhm@mail.ubc.ca. If you have any concerns or complaints about your rights as a research participant and/or your experiences while participating in this study, contact the Research Participant Complaint Line in the UBC Office of Research Ethics at 604-822-8598 or email RSIL@ors.ubc.ca or call toll free at 1-877-822-8598 (ethics ID: H19-02066).

Click on "I agree" below to indicate your consent to participate in this survey and proceed.

- I agree
- I disagree

2. Prize draw

Do you want to enter the draw for a gift card and/or hear about the results of the study?

- ○ I want to enter the draw for a gift card
- ○ I want to hear about the results of this study
- ○ I do not want to enter the draw for a gift card or hear about the results

Please enter your email address.
(Your email will not be shared or used for any other purposes)
----

3. Please answer the following questions about the path you were travelling on when you came across the sign recruiting for this survey.

At which location on the following map did you come across the sign recruiting for this survey? (Figure 6 shown here)

Were you travelling on the sidewalk or the path?

- ○ Sidewalk
- ○ Path

How often have you travelled on this path in the last year?

- ○ Never
- ○ Once a month or less
- ○ Several times a month
- ○ Several times a week
- ○ Almost every day

4. Please answer the following questions related to how you were travelling when you came across the sign recruiting for this survey.

How were you travelling when you came across this survey?
[The respondents choose their mode of transportation from a list of photos (see Appendix H: Diagram of observed vehicles*)]*

What is the make of your vehicle?

What is the model of your vehicle?

How often do you use your vehicle?

- ○ Once a month or less
- ○ Several times a month
- ○ Several times a week
- ○ Almost every day

5. **Please answer the following questions about how comfortable you are in sharing this path with others. The questions refer to the path, and not the sidewalk (if one exists at your location). Please note that "comfort" does NOT include your attitude or behaviour about COVID-19 (coronavirus) or its exposure, but rather the general quality of your travel experience in the presence of other users on the path.**

How *comfortable* are you sharing this path with people walking/running?
Very Uncomfortable Very Comfortable ▪ I don't know

How *comfortable* are you sharing this path with conventional bicycles?
Very Uncomfortable Very Comfortable ▪ I don't know

How *comfortable* are you sharing this path with electric bicycles?
Very Uncomfortable Very Comfortable ▪ I don't know

[These comfort questions were repeated for conventional tandem bicycles, electric tandem bicycles, conventional recumbent bicycles, electric recumbent bicycles, conventional tricycles, electric tricycles, conventional recumbent tricycles, electric recumbent tricycles, conventional skateboards, electric skateboards, roller/in-line skates, conventional kick scooters, electric kick scooters, sit-down electric scooters, self-balancing sit-down scooters, self-balancing stand-up scooters, conventional wheelchairs, electric wheelchairs, mobility scooters, conventional unicycles, self-balancing stand-up unicycles, and self-balancing sit-down unicycles.
The survey respondents were presented with 8 questions regarding a subset of the vehicles named above due to concerns regarding the length of the survey and attrition rate. Questions regarding comfort sharing the path with people walking and running, conventional bicycles, and electric bicycles were always asked however, the other 5 questions were randomly selected from categories of bicycles and tricycles, skateboards and skates, scooters, unicycles, and mobility devices.]

Please provide comments if you wish to clarify your rating, or describe any confusion/difficulty you had while rating.
----

6. **Please answer the following questions regarding the use of this path by different vehicles.**

What percent of the wheeled vehicles on this path do you think are conventional bicycles, electric bicycles, and other wheeled vehicles? (*The numbers must add up to 100*)
_______ Conventional bicycles
_______ Electric bicycles
_______ Other (e.g. tricycles, unicycles, wheelchairs, skateboards, etc.)

At what speed do you think **conventional bicycles** travel on this path?
0 10 20 30 40 50 km/hr

At what speed do you think **electric bicycles** travel on this path?
0 10 20 30 40 50 km/hr

Please provide comments if you wish to clarify your rating, or describe any confusion/difficulty you had while rating.
----

7. **Please answer the following questions about any incidents you may have experienced on this path in the past year**

While travelling on this path in the past year, have you had an incident where you fell to avoid contact, caused someone to fall, or made contact with another person or wheeled vehicle?

- No
- Yes, once
- Yes, more than once

Thinking of the most recent incident, please answer the following:
How were you travelling?

- Walking
- Bicycle
- Skate/Skateboard
- Scooter
- Tricycle
- Unicycle
- Mobility-assist vehicle (wheelchair)
- Other (please briefly describe)

How was the other person travelling?

- Walking
- Bicycle
- Skate/Skateboard
- Scooter
- Tricycle
- Unicycle
- Mobility-assist vehicle (wheelchair)
- Other (please briefly describe)

How serious was this incident for you?

- Very serious (overnight hospital stay)
- Serious (hospital visit, not overnight)
- Minor (scrapes and bruises)
- No injury (property damage only)
- No injury, no property damage

8. **Please answer the following questions about yourself**

How often do you use the following modes to travel?

Mode \ How often	Never	Once a month or less	Several times a month	Several times a week	Almost every day
Walk	■	■	■	■	■
Bicycle	■	■	■	■	■
Public transit (bus, Skytrain, etc.)	■	■	■	■	■
Automobile (driver or passenger)	■	■	■	■	■

How would you place yourself on the following scale regarding taking risks?

Very uncomfortable taking risks — Very comfortable taking risks

-10 -5 0 5 10

What is your age?

- <16
- 16-19
- 20-29
- 30-39
- 40-49
- 50-59
- 60-69
- 70-79
- 80+
- Prefer not to answer

What is your current gender identity? *(<u>Check all that apply</u>)*

- Male
- Female
- Transgender
- Not listed
- Other (*please briefly describe*) ___________
- Prefer not to answer

What is your ethnic origin? (*<u>Check all that apply</u>*)

- North American Aboriginal origins
- Other North American origins
- European origins
- Caribbean origins
- Other (*please briefly describe*) ___________
- Latin, Central and South American origins
- African origins
- Asian origins
- Oceania origins
- Prefer not to answer

What is the highest level of education you have completed?

- Some high school or less

- Completed high school/equivalency
- College/University certificate or diploma
- Bachelor’s degree
- Graduate degree (master’s degree or doctorate)
- Prefer not to answer

What is your gross annual household income? (In CAD)

- under $24,999
- $25,000 to $49,999
- $50,000 to $74,999
- $75,000 to $99,999
- $100,000 to $149,999
- $150,000 and above
- Prefer not to answer

15 Appendix F: Data processing and filtering

15.1 Classified count dataset

A total of 31,707 hits were registered on the pneumatic tubes before data cleaning (raw data before processing and filtering). Using the classification scheme “shared path +” in MetroCount Traffic Executive™ Software v5, that detects vehicles and pedestrians in shared facility, 3,396 hits were classified as non-vehicles i.e., pedestrians, noise, etc. and cleaned from the dataset (C1). A data cleaning process (C2) was undertaken to ensure from the remaining 28,311 vehicles, only vehicles that were classifiable were in the dataset. In the C2 process observations from the pneumatic tubes (hits) that 1) did not have video footage due to by battery drainage, researcher error, etc. or 2) had video footage and were not visible due to no/low visibility caused by low lighting, glare on the lens, blockage by pedestrians, etc. were removed. The total number of observations removed in C2 were 1,686 changing the total observations to 26,625.

After C2, every observation was manually studied for manual classification and an additional round of data cleaning (C3) thorough which observations that were not make by vehicles of interest were removed. In the C3 process hits on the pneumatic tubes made by pedestrian stepping, rolling a stroller, or rolling a walker on the tubes were removed. In addition, hits on the pneumatic tubes made by trailer of vehicles (three axle vehicles), and hits registered due to noise (not caused by any objects in the pneumatic tubes) were removed from the dataset. A total of 1,343 observations were removed from the dataset, changing the total observations to 25,282.

15.2 Speed profile dataset

The remaining 25,282 observations were cleaned in the last round of data cleaning (C4) to ensure no observations with erroneous speed observations existed in the dataset. In the C4 process, observations with speeds lower than 1 m/s (average pedestrian speed for design purposes proposed by (Knoblauch, Pietrucha, and Nitzburg 1996)), and higher than 32 km/hr (maximum legal speed of motor assisted cycles based in the British Columbia Motor Vehicle Act) were studied. The MetroCount device was highly prone to erroneous measurement of speed and incorrect detection of direction of travel for two or more vehicles crossing the tubes simultaneously (or pedestrians stepping on the tubes simultaneously with a vehicle); therefore, observations with wrong direction were also removed in the data cleaning process. Furthermore, observations in which vehicles jumped over the tubes (specially skateboards) were also removed from the dataset due to concerns over erroneous speed measurement.

15.3 Comfort rating dataset

The survey data also went through a two-step process of data cleaning, C1 and C2, though which 123 and 112 observations were removed, respectively. In the first step (C1), the incomplete survey responses with less than 45% progress were removed. The value 45% was chosen since it marks the beginning of the questions in the survey which intend to investigate the objective of the survey, perceptions of comfort and safety for non-auto travellers. In the second step (C2), complete survey responses with the following characteristics were removed from the survey dataset:

- Consent to use their data was not given
- By respondents who came across the survey at a location other than our sampling locations
- Duplicate responses

16 Appendix G: Vehicle classification method

16.1 Vehicle classification manual

16.1.1 Preparation of files

- *Read the 10 question to help understand the variables and their possible outcomes.*
- *Look through the vehicle photo bank to get familiarized with the types of vehicles that are potentially being used the cycling facilities.*
- *Open the excel file containing the vehicle observations data and enable Macros code from developer tab.*

16.1.2 Running the recorded videos

- *Press Ctrl+E while highlighting any cell in any row in the Macros Enabled Excel file to run the video segment corresponding with that row's timestamped crossing.*
- *Observe the vehicle and its objective features as accurately as possible (when in doubt, annotate "**Uncertain**" in Note column.*

16.1.3 Video coding

Based on our internet research on the types of vehicles (keywords such as micromobility, emerging transportation, personal transportation device, human-electric hybrid vehicles, etc.) we expected to see the following vehicles in the cycle lanes in Metro Vancouver (see Table 13).

Table 13. The list of vehicles expected to observe on Metro Vancouver's off-street paths based on online search

Tentative Category	Vehicle Name	Sources of power in vehicle		Was the vehicle observed during data collection?
		Human	Electric	
Bicycles	Conventional bicycles	✓	✓	✓
	Elliptical bicycle	✓	✓	X
	Recumbent bicycle	✓	✓	✓
	Tandem bicycle	✓	✓	✓
	Treadmill walking bicycle	X	✓	X
Tricycles	Conventional tricycle	✓	✓	✓
	Recumbent tricycle	✓	✓	✓
Unicycles	Conventional unicycle	✓	X	✓
	Self-balancing stand-up unicycle	X	✓	✓
	Self-balancing sit-down unicycle	X	✓	✓
Boards	Skateboard	✓	✓	✓
	Casterboard	✓	X	✓
Scooters	Push/Kick scooter	✓	✓	✓
	Self-balancing stand-up scooter	X	✓	✓
	Self-balancing sit-down scooter	X	✓	✓
Mobility Assist	Wheelchair	✓	✓	✓
	Mobility scooter	X	✓	✓
	Tandem mobility scooter	X	✓	X
	Walking trike	✓	X	X

Figure 50 illustrates the taxonomy of the above vehicles by answering the following questions, each answered by an integer (0,1,2,3 …):

1. Is the vehicle attached to the feet? (Yes: 1 and No: 0)
2. Does the vehicle have pedals?
3. How many seats does the vehicle have?
4. Does the vehicle have seatback?
5. How many wheels does the vehicle have?
6. How many axles does the vehicle have?
7. Does the vehicle have handles?
8. Is the vehicle motorized? Or does the vehicle have a visible battery?

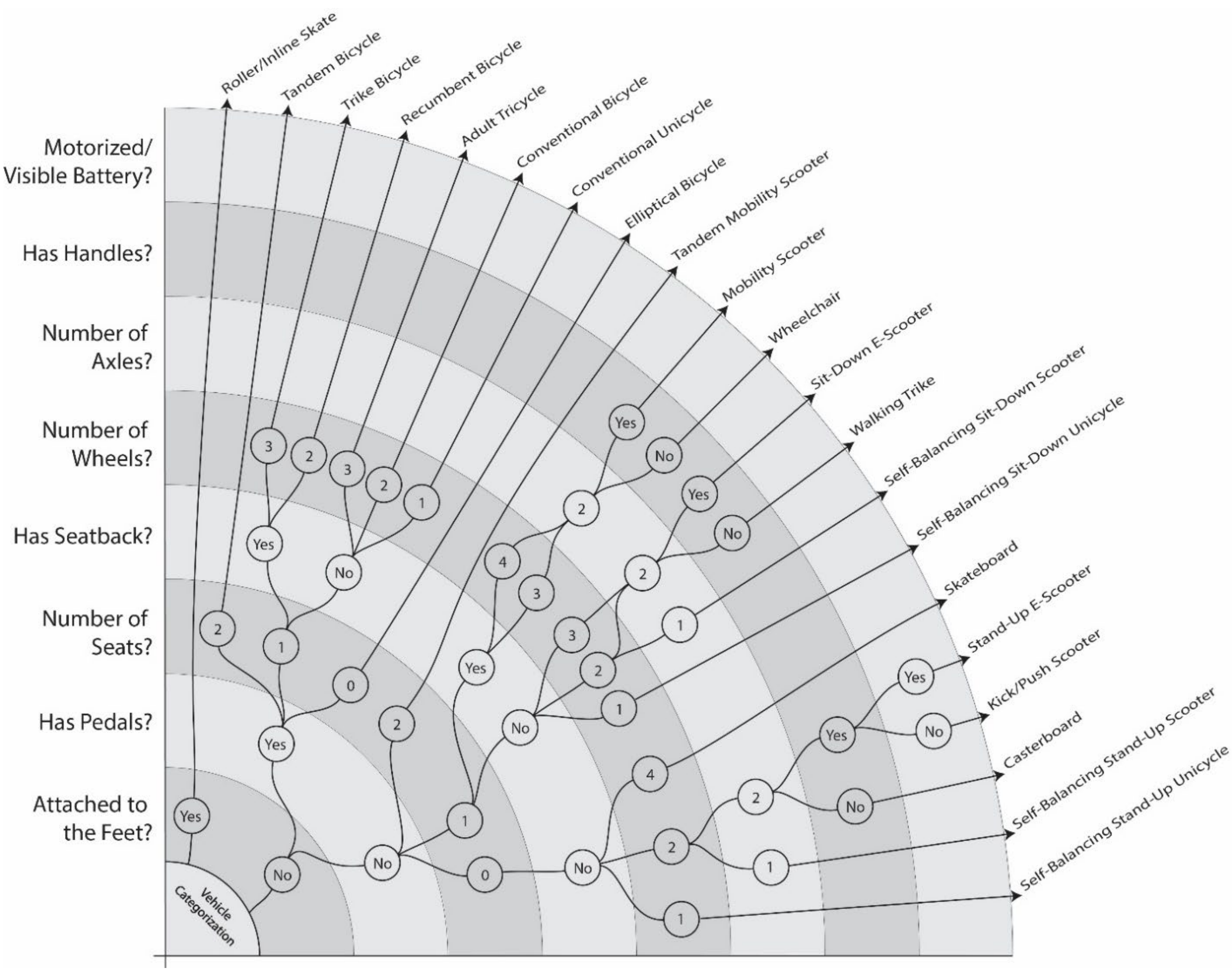


Figure 50. Taxonomy of personal mobility vehicles on cycling facilities

The visually identifiable objective features of the vehicles mentioned above (such as the number of wheels) is useful as a wide variety of vehicle types exists with often multiple names. The following manual was read by undergraduate and graduate students who helped with coding of vehicles:

- *If a vehicle has been recorded in the excel file but there is **nothing** in the video, annotate "**noise**" under Vehicle Type and move on to the next row.*

- *If the recorded vehicle in the excel file is a **pedestrian** in the video, annotate "**pedestrian**" under Vehicle Type and move on to the next row.*
- *If the observed vehicle is a **conventional bicycle**, the first **six** variables must be filled and the rest of the variables must be **ignored** (they can be filled later using an automated code)! The first variables are:*
    - *Vehicle Type*
    - *Visible Battery / Motorized?*
    - *Shared (i.e. bike-share program) Vehicle?*
    - *Has Trailer?*
    - *Handlebar type?*
    - *Number of Riders?*
- *If the observed vehicle is **not a conventional bicycle**, the **rest** of the variables **must** completed as well.*
    - *Attached to the Feet?*
    - *Has Pedals?*
    - *Number of Seats?*
    - *Has Seatback?*
    - *Number of Wheels?*
    - *Number of Axles?*
    - *Has Handles?*
    - *Flag*
    - *Note*

DOs during video coding:

- *Have the cheat sheet file open when video coding for quick access to necessary information on video coding.*
- *If the value for any of the variables above was **uncertain**, the **Flag** variable must be valued 1, otherwise 0.*
- *In case of coding a **conventional bicycle**, if the outcome of any variable is 0, leave the cell blank. This avoids entering 0 in most of the data fields.*
- *If the video shows **two vehicles** simultaneously crossing the pressure tubes in the same direction at the same speed, but the Excel file only shows one row of data, duplicate that observation under the same row to ensure we count both vehicles. State **"row added manually"** under **Note** variable.*
- *If the video shows a **vehicle(s)** crossing the pressure tubes, but the Excel file did not capture that crossing, duplicate the previous observation under the same row to ensure we count the uncaptured vehicle(s). State **"row added manually"** under **Note** variable. Delete Speed, Hits, Axle, Wheelbase, Headway, Gap, Vehicle, Hit_Corr (columns E-L).*
- *Only put 1 under **Visible Battery / Motorized** if you are 100% certain the vehicle is electric. If you are not 100% certain, **flag** it.*
- *If a vehicle and its trailer (bicycle and trailer: ooo) are recorded in the Excel file as two separate vehicles (first bicycle: oo and second trailer: o) consider the first record to be a vehicle with trailer. Ignore the second vehicle and only annotate **"trailer"** under **Vehicle Type** variable.*
- *If the video shows anything unusual (i.e. e-skateboard dodging tubes), annotate the anomaly under **Note** variable.*

- ***Flat handlebars with bar end extensions*** *should be coded as* ***"other"*** *under* ***Handlebar Type***

DON'Ts during video coding:

- ***Never*** *delete rows/columns – even if it is a pedestrian or the trailer of a bicycle or nothing (perhaps noise).*

Vehicle Types:

- *Cycle-oo: a vehicle with two axles (conventional bicycle, tricycle, scooter) – Also can be a conventional bicycle with a trailer on the back (but the trailer will be captured as another uni-axle vehicle)*
- *0: a uni-axle vehicle (unicycle, self-balancing scooter) – Also can be the trailer of a bicycle (in which case annotate* ***"trailer"*** *under Vehicle Type and* ***do not*** *video code that vehicle)*
- *Co-Cycle-oo: when a Cycle-oo is travelling next to another Cycle-oo at the same speed*
- *Other-oo: a vehicle similar to Cycle-oo but maybe at a higher speed or with a thicker wheel*

Things to Remember:

- *Wheel configuration is not always accurate! [ooo doesn't always mean three vehicles] (check point #4 in DOs section).*
- *Always check* ***speed*** *and* ***direction*** *of the recorded vehicles in the excel file to make sure you are looking at the correct vehicle in the videos.*
    - *Speed and direction must make sense according to the video – you will understand typical vehicle speeds (in km/hr) by observing just a couple of vehicles go by.*

16.2 Cohen's Kappa test

An interrater reliability test, Cohen's kappa, was conducted to see how similar can two different persons answer the 8 questions asked in Figure 50 for classifying the observed vehicles. The questions answered by the classification assistants were the following:

1. Is the vehicle attached to the feet?
2. Does the vehicle have pedals?
3. How many seats does the vehicle have?
4. Does the vehicle have seatback?
5. How many wheels does the vehicle have?
6. How many axles does the vehicle have?
7. Does the vehicle have handles?
8. Is the vehicle motorized? Or does the vehicle have a visible battery?

In addition, two more questions that were deemed useful for modelling but not used for classifying vehicles were answered by the classifying assistants during the manual classification of vehicles:

9. Is the vehicle a shared vehicle?
10. How many riders are on the vehicle?

Cohen's kappa measures the level of agreement between two raters in answering a question. Two classifying assistants separately looked at video footage of 150 vehicles and answered the above 10 questions. For each question, a value of Kappa was estimated between 0 and 1, with 0 showing no agreement and 1 showing absolute agreement. Table 14 show presents the subjective level of agreement suggested by (McHugh 2012) and Table 15 shows the value of Kappa estimated for each question. The classifying assistants showed an “almost perfect” agreement in answering questions 1 to 7; however, questions regarding electric-assist in vehicles, shared or private use of vehicles, and number of riders showed weak, none, moderate agreement between the classifying assistants. Investigation into the low levels of agreement in answering question 8, proved that there was a necessity in creating a bank of electric bicycle photos for classifying assistants to review and familiarize themselves with various types of electric vehicles to ensure electric vehicles were correctly coded. A handful of photos of electric bicycles are presented in Appendix I: Coding electric bicycles to emphasize the importance of appearance items of electric bicycles, such existence of a battery (in the frame, rear rack, etc.), existence of a motor (in the wheel hub, bottom bracket, etc.), size of the frame, etc. Furthermore, other aspects such as posture of the person on the bicycle and speed were also took into consideration for determining the existence of electric-assist in the bicycles. The low degree of agreement in answering question number 9 was due to a misunderstanding of the variable shared and was solved by creating a bank of photos of the three bike sharing services currently active in Metro Vancouver: HOPR, Mobi, Ucycle. Lastly, the low levels of agreement in answering the question number 10, was due to inclusion of pets on vehicles as a rider which was solved by deciding not to include pets and only include humans on a vehicle (child or adult) as riders.

Table 14. Interpretation of Cohen’s Kappa test results suggested by (McHugh 2012)

Cohen's Kappa test value	Level of agreement
0 – 0.20	None
0.21 – 0.39	Minimal
0.40 – 0.59	Weak
0.60 – 0.79	Moderate
0.80 – 0.90	Strong
0.90 – 1.00	Almost perfect

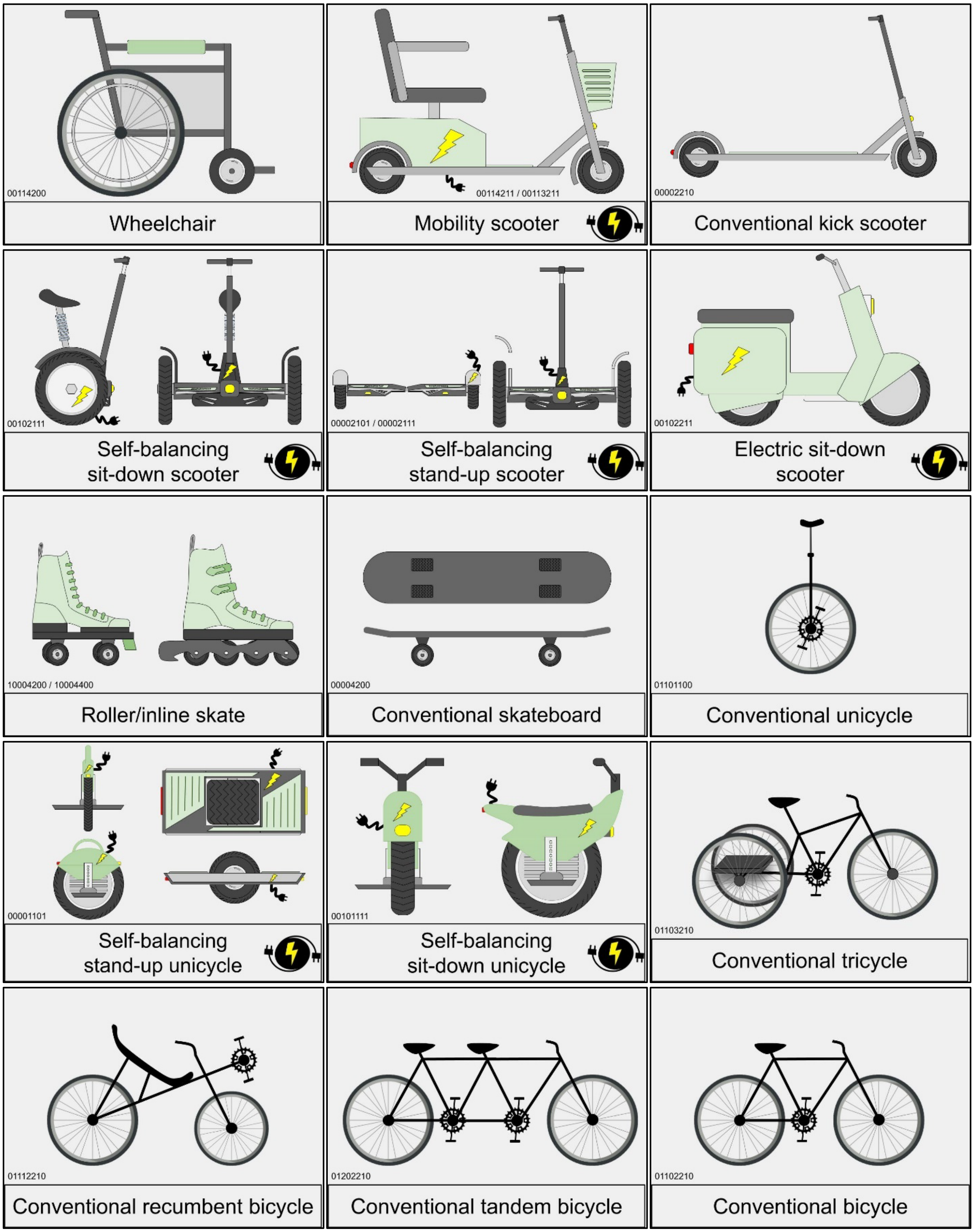
Table 15. Cohen’s Kappa test result in answering the 10 questions during manual classification of vehicles.

Number	Variable	Nobs	Cohen's Kappa Test Value
1	Is the vehicle attached to the feet?	150	1.00
2	Does the vehicle have pedals?	150	1.00
3	How many seats does the vehicle have?	150	1.00
4	Does the vehicle have seatback?	150	1.00
5	How many wheels does the vehicle have?	150	1.00
6	How many axles does the vehicle have?	150	1.00
7	Does the vehicle have handles?	150	1.00
8	Is the vehicle motorized? Or does the vehicle have a visible battery?	150	0.47
9	Is the vehicle a shared vehicle?	150	0.05
10	How many riders are on the vehicle?	150	0.66

The following manual was prepared for the classification assistants before starting the process of manually classifying the observed vehicles. After reading the data dictionary manual and familiarizing themselves with various types of vehicles from a bank of photos gathered from online sources, the classification assistants were tasked to complete the classification for a small sample of vehicles. Feedback was provided to their work to ensure classification is done correctly and consistently among classifying assistants.

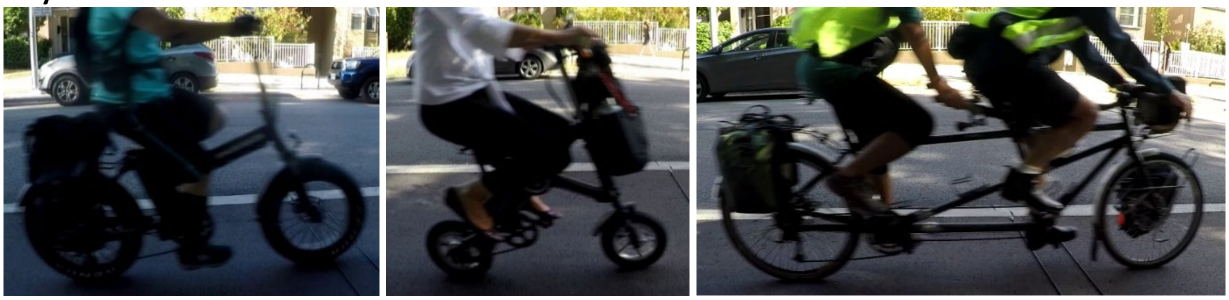
17 Appendix H: Diagram of observed vehicles

The following diagrams were created to represent vehicles observed at sampling locations along with a descriptive name and a code name based on the questions in Figure 50.



The following are sample photos of vehicles observed at the sampling locations categorized into 8 categories of bicycles, tricycles, recumbents, unicycles, unicycles, mobility scooters and wheelchairs, scooters, boards, and motorcycles. These images are for the purpose of demonstrating the video footage data and are not for the purpose of introducing clusters of vehicles.

Bicycles



Tricycles

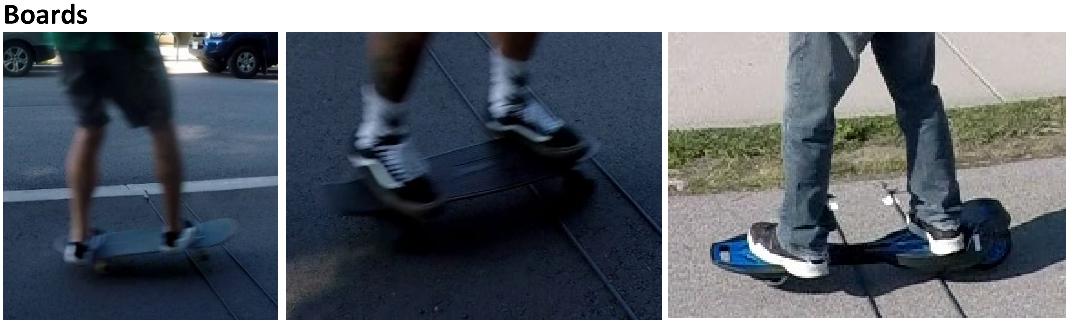
Recumbent Bicycles and Tricycles

Unicycles

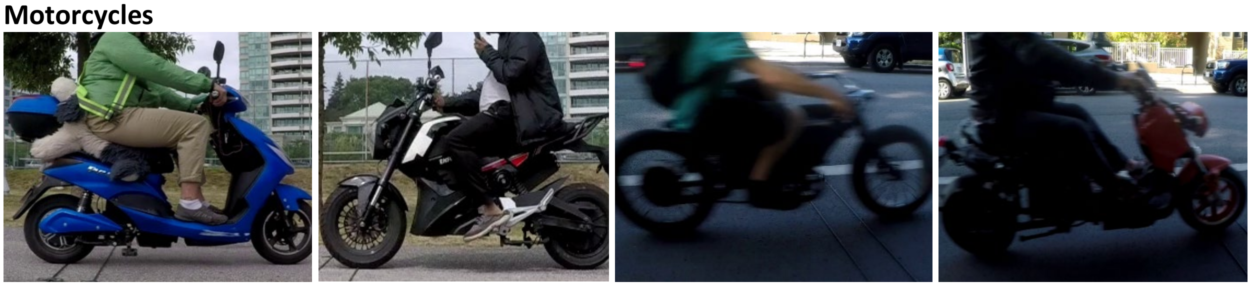
Mobility Scooters and Wheelchairs

Scooters

Boards



Motorcycles



18 Appendix I: Coding electric bicycles

A comprehensive online study of commercial electric bicycles was conducted to ensure electric bicycles were correctly identified from conventional bicycles during the classification of vehicles (see Figure 51). A photo bank of various electric bicycles was created to help familiarize classifying assistants with the subtle differences between electric and conventional bicycles.

Figure 51. Sample photos of various electric bicycles on online shops as reference for identifying electric bicycles from conventional bicycles in the manual vehicle coding process

Further investigation into the inter-rater reliability of classifying electric bicycles and conventional bicycles was conducted to ensure the 4.2% mode share of electric bicycles was accurate. Two classifying assistants classified 100 bicycles from 100 video snippets chosen randomly from the video footage data into electric or non-electric categories. Approximately, half of the bicycles were chosen among electric bicycles, an information not disclosed to the classifying assistants. Moreover, the video footage were chosen from various locations and lighting conditions. The results showed a 99% agreement between the two classifying assistants, further strengthening the our trust in their ability in distinguishing bicycles with electric-assist from those without.

A more in-depth look at the percentages of electric bicycles observed on each data collection day at each of the sampling locations (Figure 52) shows that variations from 0% to 20% exists in the mode share of electric bicycles.

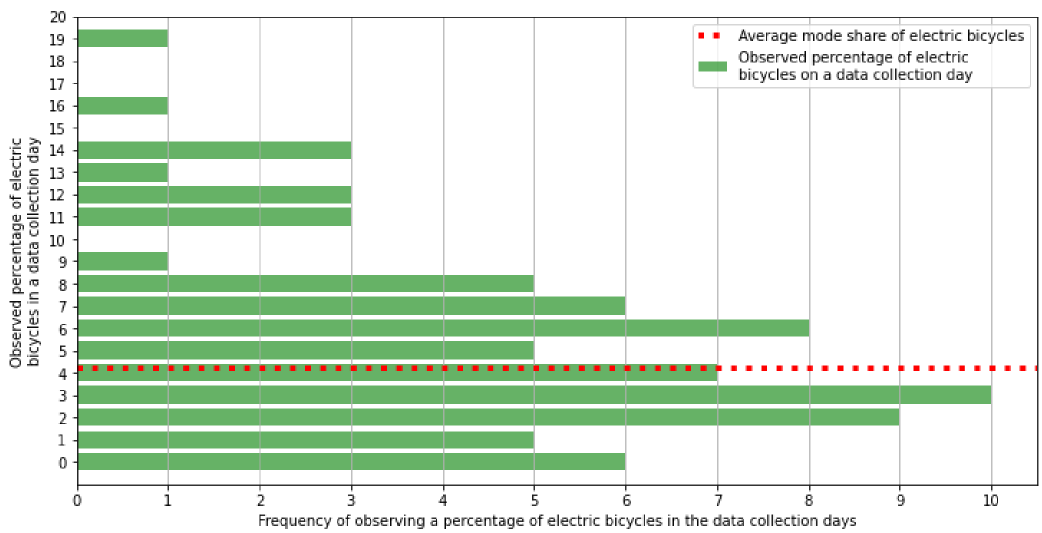


Figure 52. Frequency of each integer percentage points of electric bicycles observed on each data collection day at each of the sampling locations

19 Appendix J: Modelling

19.1 Speed modelling

A mixed-effect regression model was estimated to model the speed of bicycles, skateboards, and scooters using the data presented in Table 16. Bicycles in this model include conventional bicycles and electric bicycles, and does not include shared bicycles such as Mobibikes. Moreover, skateboard category includes conventional and electric skateboards, and scooters include conventional and electric stand-up push scooters. The pearson correlation matrix of the variables used in the model are presented in Figure 53 and the results of the estimated model are presented in Table 17.

Table 16. Descriptive statistics of the data used to create a speed model for bicycles, scooters, and skateboards

Variable	Count	Mean	Standard Deviation	Minimum	25% percentile	50% percentile	75% percentile	Maximum
Observed speed (km/hr)	24111	19.0	6.1	3.6	14.4	18.6	23.2	55.2
Bicycle (binary)	24111	0.98	0.12	0.0	1.0	1.0	1.0	1.0
Scooter (binary)	24111	0.0	0.1	0.0	0.0	0.0	0.0	1.0
Skateboard (binary)	24111	0.0	0.1	0.0	0.0	0.0	0.0	1.0
Uphill grade (binary)	24111	0.2	0.4	0.0	0.0	0.0	0.0	1.0
Electric-assist (binary)	24111	0.0	0.2	0.0	0.0	0.0	0.0	1.0
Number of riders	24111	1.0	0.1	1.0	1.0	1.0	1.0	3.0
Multi-use path (binary)	24111	0.6	0.5	0.0	0.0	1.0	1.0	1.0
Weekend (binary)	24111	0.4	0.5	0.0	0.0	0.0	1.0	1.0
COVID Lockdown (binary)	24111	0.3	0.5	0.0	0.0	0.0	1.0	1.0
Temperature (centigrade)	24111	15.4	4.7	0.8	12.5	15.9	18.0	25.7
Hourly precipitation (mm)	24111	0.1	0.4	0.0	0.0	0.0	0.0	4.8
Hourly traffic volume	24111	160	114	1	66	132	239	450

Table 17. Mixed-effect regression model of speed of bicycles, scooters, and skateboards

Variable	Coefficient Estimate	Standard Error	p-value
Intercept	24.275	0.867	<0.01
Scooter	-9.589	0.540	<0.01
Skateboard	-6.188	0.387	<0.01
Uphill grade	-3.710	0.108	<0.01
Electric-assist	2.864	0.172	<0.01
Electric-assist x Scooter	9.781	0.800	<0.01
Electric-assist x Skateboard	6.231	1.071	<0.01
Electric-assist x Uphill	2.086	0.406	<0.01
Number of riders	-2.821	0.292	<0.01
Multi-use path	-2.159	1.051	0.04
Weekend	-1.292	0.088	<0.01
COVID lockdown	-1.408	0.093	<0.01
Temperature	0.052	0.010	<0.01
Hourly rain	0.110	0.096	0.251
Traffic Volume	0.001	0.001	0.011
Location (Mixed-effects)	5.691	0.367	-
Number of observations		24,111	
Number of groups (Mixed-effects)		22	
Efron’s Pseudo R-Squared		0.33	

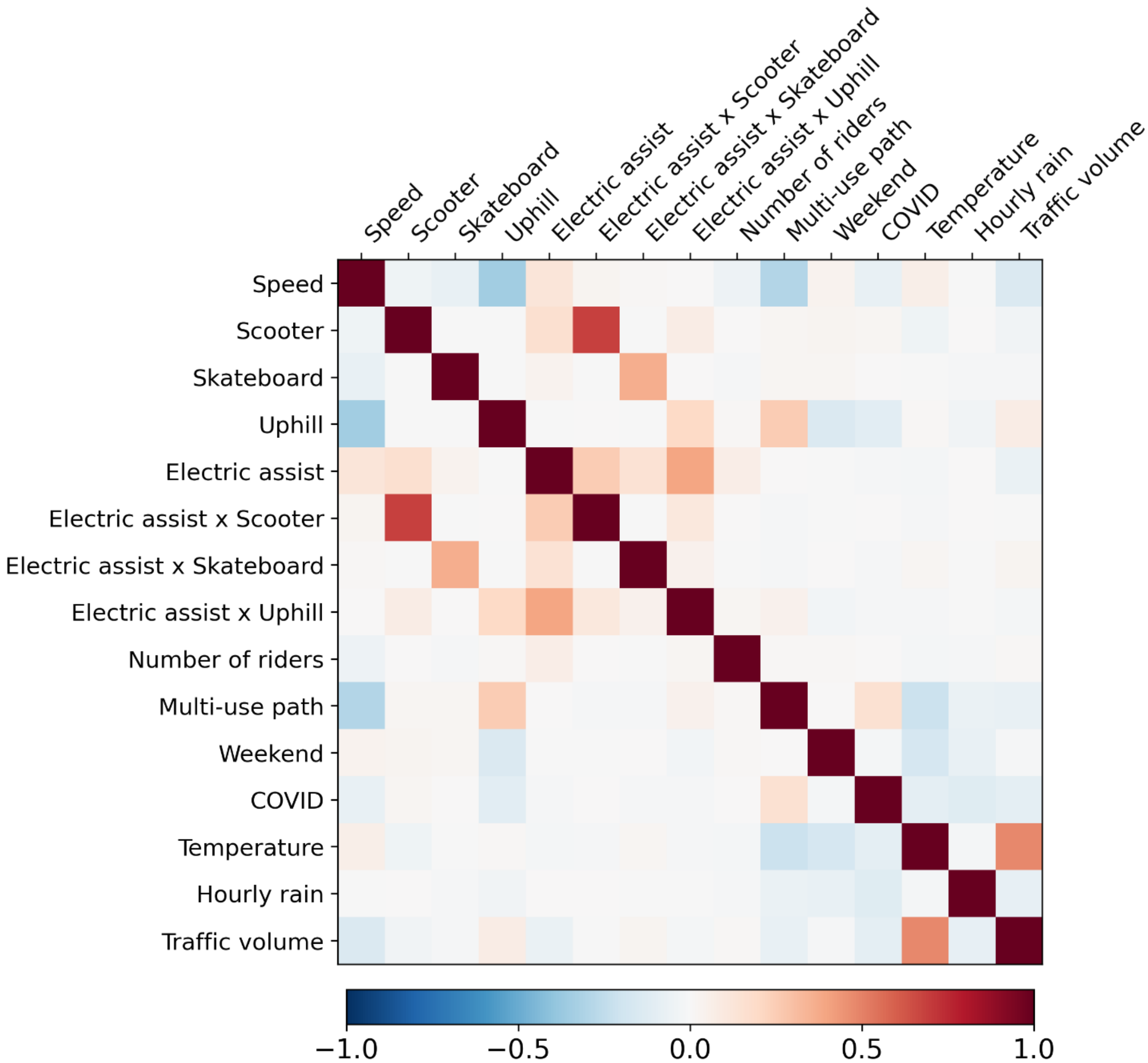


Figure 53. Correlation matrix of variables used on the mixed-effect regression model of speed of bicycles, scooters, and skateboards

19.2 Comfort modelling

A regression model was estimated to model the comfort rating of path users in sharing the path with 25 various types of vehicles using the data presented in Table 18. The regression model contained random effects of variable location with group size of 12 (12 sampling location) to capture the unobserved effects specific to each location and a nested random effects of variable survey respondents with group size of 739 to capture the unobserved effects specific to each survey respondent. The pearson correlation matrix of the variables used in the model are presented in Figure 54 and the results of the estimated model are presented in Table 19.

Table 18. Descriptive statistics of the data used to model comfort level of survey respondents sharing path with various users

Variable	Count	Mean	Standard Deviation	Minimum	25% percentile	50% percentile	75% percentile	Maximum
Male (binary)	5771	0.5	0.5	0.0	0.0	1.0	1.0	1.0
University degree (binary)	5771	0.7	0.4	0.0	0.0	1.0	1.0	1.0
Age (integer)	5771	46.9	15.5	10.5	34.5	44.5	54.5	84.5
Walk frequency*	5771	3.3	1.0	0.0	3.0	4.0	4.0	4.0
Bicycle frequency *	5771	2.2	1.4	0.0	1.0	2.0	3.0	4.0
Transit frequency *	5771	1.3	1.0	0.0	1.0	1.0	2.0	4.0
Car frequency *	5771	2.5	1.1	0.0	2.0	3.0	3.0	4.0
Active frequency **	5771	4.3	2.5	-3.0	3.0	4.0	6.0	11.0
Experienced incident (binary)	5771	0.1	0.3	0.0	0.0	0.0	0.0	1.0
Perceived speed of conventional bicycles (km/hr)	5771	19.3	6.5	0.0	15.0	20.0	22.0	50.0
Perceived speed of electric bicycles (km/hr)	5771	25.8	8.1	0.0	20.0	25.0	30.0	50.0
Comfort taking risk	5771	2.5	4.7	-10.0	0.0	4.0	6.0	10.0
alignment of modes (binary)	5771	0.2	0.4	0.0	0.0	0.0	0.0	1.0
Speed (km/hr)	5771	15.1	6.8	4.5	8.9	18.5	21.8	27.6
Number of wheels	5771	2.2	1.3	0.0	2.0	2.0	4.0	4.0
Number of seats	5771	0.7	0.5	0.0	0.0	1.0	1.0	2.0
Electric-assist (binary)	5771	0.5	0.5	0.0	0.0	0.0	1.0	1.0
Multi-use path (binary)	5771	0.8	0.4	0.0	1.0	1.0	1.0	1.0
Reported level of comfort with vehicles	5771	3.2	6.5	-10.0	-2.0	5.0	9.0	10.0

Walk frequency *: 0 = never, 1 = once a month, 2 = several times a month, 3 = several times a week, 4 = every day
Active frequency ** = Walk frequency + Bicycle frequency + Transit frequency - Car frequency

Table 19. Regression model of comfort of survey respondents sharing the path with various types of vehicles with nested random effects

Variable Type	Variables	Coefficient Estimate	Standard Error	p-value
Intercept	Intercept	6.168	1.086	<0.01
Perceiver variable	Male	0.443	0.288	0.125
	Age	-3.692	0.693	<0.01
	University degree	0.283	0.323	0.381
	Experienced incident	-1.901	0.415	<0.01
	Comfort taking risks	1.161	0.612	0.058
	Perceived speed of electric bicycles	-4.555	0.901	<0.01
	Active frequency	3.050	0.826	<0.01
Vehicle variable	Alignment of modes	3.387	0.161	<0.01
	Electric-assist	-1.473	0.150	<0.01
	Observed speed of vehicle	-4.012	0.250	<0.01
Built environment variable	Multi-use path	0.771	0.770	0.336
Mixed-effects	Mixed-effects	Standard Deviation		
	Location	3.404		
	Respondent (nested in location)	1.016		
	Total Number of observations	5712		
	Number of location groups	12		
	Number of respondent groups	739		

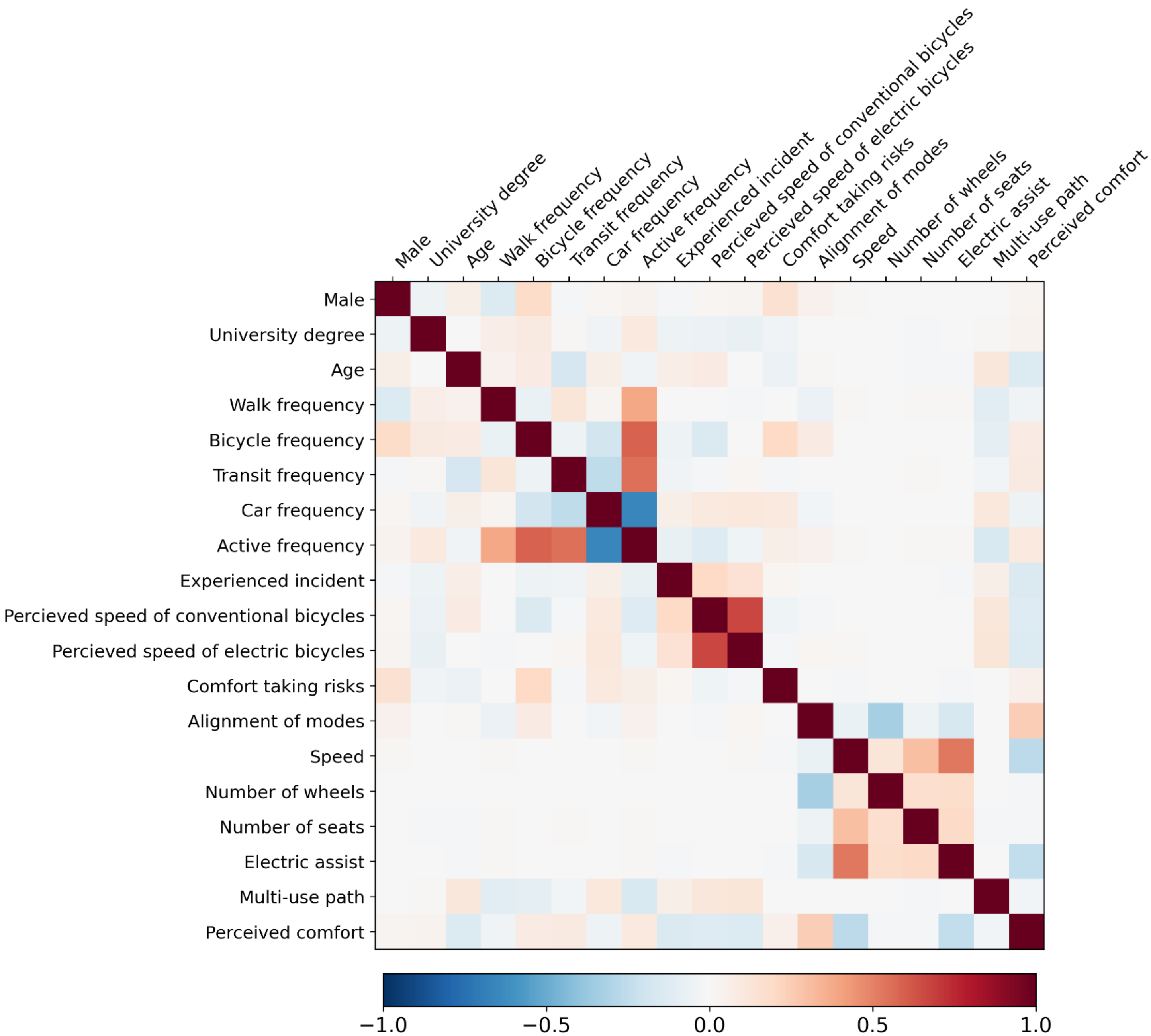


Figure 54. Correlation matrix of variables used on the mixed-effect regression model of speed of bicycles, scooters, and skateboards

20 Appendix K: Policy review

The search for municipal, regional, and federal documents was recent to August 1st, 2020.

20.1 Specific policies

20.1.1 Federal: The Motor Vehicle Act and the Motor Vehicle Safety Act

The following vehicles were regulated in the Motor Vehicle Act and the Motor Vehicle Safety Act:

Low-Speed Vehicle: Although low-speed vehicles exist on the spectrum from pedestrian to auto forms of transportation, they are not what we would classify as emerging transportation vehicles. Low speed vehicles according to the chart titled “Canada Motor Vehicle Safety Standards” under SCHEDULE III (Subsections 4(1) and 5(2)) require a Vehicle Identification Number, seatbelt assemblies, glazing materials, and Mirrors and Rear Visibility Systems. Examples of low-speed vehicles involve tractors.

Motor-Tricycle: Motor-tricycles are motor powered and not human powered or human-electric hybrid vehicles and therefore are not considered an emerging transportation vehicle as examples in this report.

Power-Assisted Bicycle: Power assisted bicycles also known as e-bikes require electric motors, pedals, and are limited by their motor’s power.

Minibike: Although the term ‘Minibike’ does not appear in the MVA and is explicitly repealed in the MVSR, they are nonetheless outlawed on public roads in British Columbia. ICBC states that “The reason that these vehicles aren't generally allowed on public roads is because they don't meet minimum height specifications for headlamps, tail lamps, stop lamps, and turn signals. They're also difficult for other motorists to see.” Furthermore, ICBC says these vehicles are classified by Transport Canada as “restricted use motorcycles that are permitted to be imported as competition vehicles for closed-course racing only.” Though ICBC does not provide an explicit link to Transport Canada’s ruling on motor bikes, minibikes are somewhat consistent with an example provided by Transport Canada on non-regulated vehicles which includes “competition vehicles designed only for closed course competitions, with the necessary labels.” Non-regulated vehicles are exempt from having to comply with the Motor Vehicle Safety Act but subject to importing restrictions overseen by Canada Border Services Agency entry requirements. Since minibikes appear to be non-regulated vehicles, ICBC has instead imposed operating restrictions on them which are summarized in the body of the report.

Moped: Electric or gas-powered vehicle without pedals. Mopeds’ speeds are limited to 70km/h on level ground.

Motor Driven Cycle: In the Motor Assisted Cycle Regulations, e-bikes are regulated according to the specification of their motors, wheels, motor shut-off requirements, brake performance, drive system and equipment securement, electric terminals, and absence of generators.

Other Devices: For vehicles other than those mentioned above, most micro mobility devices fall under Division 24 — Vehicles of Unusual Size, Weight or Operating Characteristics. Section 24.01 of the Motor Vehicle Act Regulations identify a further 8 vehicle categories of which the eighth is “a miniature motor vehicle”. A miniature motor vehicle is defined as (a) a motorized go-cart, skateboard or similar wheeled toy vehicle, or (b) a motorcycle that has a wheel rim diameter of less than 250 mm, a wheelbase of less than 1 016 mm when measured from the centre of one axle to the centre of the other axle, or a seat height, when the vehicle is unladen, of less than 650 mm.

When looking at human electric hybrid vehicles other than e-bikes, most categories would fall under 24.01 (a) although some electrified bicycles may fall under 24.01 (b) according to their dimensions. To further clarify, line 119 of the motor vehicle act sates: "cycle means a device having any number of wheels that is propelled by human power and on which a person may ride and includes a motor assisted cycle, but does not include a skateboard, roller skates or in-line roller skates." In both cases however, miniature motor vehicles according to section 24.02 are not to be used on a highway unless on a parade route, or unless the vehicle has been registered and licenses under the motor Vehicle Act or Commercial Transport Act and obtained an owner's certificate under the Insurance (vehicle) Act. Subsection (1) of Section 24.02 of the motor vehicle act regulations is reproduced below with the latter subsections detailing exclusions omitted for brevity:
24.02 (1): A person must not use or operate any of the following motor vehicles on a highway except as otherwise authorized by this Division:

- an air cushion vehicle
- a golf cart
- a neighbourhood zero emission vehicle (four-wheeled electric powered vehicles built to travel 40 km/h or less)
- a snow vehicle
- a snowmobile
- a utility vehicle
- a beverage cart
- a miniature motor vehicle.

It should be noted that although section 24.06 of the MVA allows the use of Neighborhood Zero Emission Vehicles (NZEV) in municipalities as well as unorganized areas of British Columbia, the emerging transportation options in this report are not the same as Neighborhood Zero Emission Vehicles.

20.1.2 Regional and Municipal

A summary of operating restrictions imposed by Insurance Corporation of British Columbia can be found in Table 20 below with vehicle class images from ICBC's websites in Figure 3 on the following page.

ICBC provides a handy guide to help road users distinguish between the vehicle-classes that they regulate. They provide images for eight vehicle classes and have a more detailed comparison of motor assisted cycles and mopeds/scooters which they dub "limited speed motorcycles." ICBC has also adopted the minimum age requirement for electric bicycle riders to be 16 years old as per section 182.1 of the Motor Vehicle Act and has not raised the minimum age requirement nor imposed requirements on motorized scooters/skateboards or pocket bikes and mini motorcycles. Note that ICBC has no explicit policy on rollerblades, unicycles, or recumbent bicycles.

As depicted in Figure 55, ICBC also provides visitors to its website a side-by-side comparison of motor assisted cycles (e-bikes) and limited speed motorcycles (mopeds) to simplify distinction between the two.

Table 20. Operating restrictions imposed by Insurance Corporation of British Columbia (Insurance Corporation of British Columbia 2020)

Vehicle Class	Allowed	Driver's License	Registration	Insurance	Speed limit on level ground
Electric Bikes 	Yes	Not Required	Not required	Not required	32 km/h
Mopeds and Scooters 	Yes	Class 5 or 7	Required	Required	70km/h
Motorized wheelchairs 	Yes	Not Required	Not required	Not required	N/A
Motorized scooters and skateboards 	Only on private property without public vehicle access or trails as allowed by municipal bylaw	Not Required	Not required	Required (if in a parade)	N/A
Pocket bikes & mini motorcycles 	Only on parade routes	Not Required	Not required	Required	N/A

	Motor Assisted Cycles	Limited Speed Motorcycles
		
Description	Combine bicycle pedal power with electric motor assistance. To qualify, must be a Motor Assisted Cycle as defined in the Motor Vehicle Act and meet Motor Assisted Cycle Regulation criteria.	Are low-powered motorcycles (that is, mopeds and scooters). LSMs rely on motor power and are generally not equipped with bicycle-style pedals. To qualify, must be a Limited Speed Motorcycle as defined in the Motor Vehicle Act Regulations.
Power	Electric motor or motors (power output not exceeding 500 watts in total) and bicycle-style pedals.	Gas engine 50 cc or less *or* electric motor less than 1,500 watts.
Maximum speed	32 km/h on level ground.	70 km/h on level ground.
Vehicle registration, licensing and insurance	None required. (Insurance may be available under a homeowner's policy.)	An LSM must be registered, licensed and insured as a motor vehicle.
Driver	No driver's licence is needed. You must be at least 16 years old.	You must have a driver's licence; however, you can not operate on a learner's licence other than a Class 6 or 8 motorcycle learner's licence.
Helmet	Must wear a bike helmet.	Must wear a motorcycle helmet.
Rules of the road	Subject to the same rights and duties as the driver of a motor vehicle, such as obeying all traffic lights and control devices. As well, bicycle safety rules should be followed. See Section 183 of the Motor Vehicle Act: Rights and duties of operator of cycle.	Subject to the same rights and duties of a motor vehicle, such as obeying all traffic lights and control devices. In some areas, highway use is restricted. For details, please contact your local police.
Manufacturer's label	As a condition of initial sale, all commercially manufactured MACs must have a label stating that the vehicle is a "power-assisted bicycle."	As a condition of initial sale, all commercially manufactured LSMs must bear a permanently affixed compliance label. On this, or on another separate label, a statement must appear that the use of the vehicle may be restricted by provincial authorities to certain roads.

Figure 55. Distinguishing electric bicycles from sit-down electric scooters and their respective rules by (Insurance Corporation of British Columbia 2022)

20.1.3 Municipalities of Metro Vancouver

Among the 21 municipalities, Electoral Area A, and Tsawwassen First Nation, in Metro Vancouver, only City of Vancouver, District of West Vancouver, and City of North Vancouver have adopted a formal regulation on emerging mobility vehicles beyond the regulations imposed by the province-wide Motor Vehicle Act. The City of Vancouver provides the most detailed guidance on various devices by providing a table summarizing vehicle types and where they may or may not be used within the municipality (see Figure 56). The City of Vancouver bans 4 device types whereas the District of West Vancouver, and City of North Vancouver have adopted bylaws outlawing only skateboarding and rollerblading in some or all parts of their municipalities. All three of these municipalities impose additional device specific operating restrictions, but at various granularities. In the City of Vancouver, electric skateboards, Segway, and hoverboards (self-balancing stand-up scooters) are banned. Electric bicycles are also banned from operating on the Seawall and park paths.

Vehicle	Roads	Sidewalks	Seawall and park paths	Protected bike lanes
Bikes	✓	✗	✓[1]	✓
Electric-assisted bikes	✓	✗	✗	✓
Electric kick scooters	✓[2]	✗	✗	✓
Skateboards, push scooters, rollerblades, and skates	✓[2]	✗	✓	✓
Motorized skateboards or scooters	✗	✗	✗	✗
Segways	✗	✗	✗	✗
Hoverboards	✗	✗	✗	✗
Motorized wheelchairs	✗	✓	✓	✗
Motorbikes and limited-speed motorcycles	✓	✗	✗	✗

Notes

1. Where signs permit
2. Local streets only

Figure 56. City of Vancouver operating restrictions table (City of Vancouver 2022a)

In the District of West Vancouver, and City of North Vancouver bylaws have been adopted outlawing skateboarding and rollerblading in some or all parts of their municipalities. In the District of West Vancouver longboarding is banned altogether (District of West Vancouver 2020) with the following statements on the District's website "Longboarding rules are laid out in the Traffic and Parking Bylaw. It states that longboarding or skateboarding on any West Vancouver roads is not allowed." However, a closer inspection of their bylaws reveals that it is only on highways that they are banned, and that boards and inline skates may be used on local roadways provided the user is abiding by the rules of the road, wearing a helmet unless exempt by religious headwear, and is riding in daylight hours (District of West Vancouver 2004). There exists however an ambiguous language whereby the city provides exceptions for where skateboards may be used as "designated for such use by the Engineer"(District of West Vancouver 2004). The City of North Vancouver, while adopting the same highway guidelines on longboards and rollerblades, highlights 14 streets and plazas where no boarding/blading is allowed on either roads or sidewalks (The Corporation of the City of North Vancouver 2021). Additionally, instead of warranting use as designated by an engineer, the City of North Vancouver use language such as a skateboard may be used on a local roadway as close to the side of the road using the term "as is practicable" instead of as "designated for such use by the Engineer" (The Corporation of the City of North Vancouver 2021).

Beyond these examples, other Metro Vancouver municipalities lack bespoke regulations such as those adopted by the City of Vancouver, District of West Vancouver, and city of North Vancouver, despite most municipalities mirroring the regulations in the motor vehicle act in their own bylaws (City of Port Coquitlam 2013; Burrad Commons 2019; City of Richmond 2007; City of Burnaby 2021; Township of Langley 2015; City of Surrey 2012; Township of Langley 2009; City of North Vancouver 2008; Township of Langley, n.d.; City of Langley 2014; City of Port Moody, n.d.; Stantec 2016; City of New Westminster 2015; District of North Vancouver 2012; The Corporation of Delta 2015; City of Pitt Meadows 2012; District of North Vancouver 2009; City of Port Moody 2017; City of Coquitlam 2017; 2012; City of Maple Ridge 2014; District of West Vancouver 2010; City of Vancouver 2012; City of Pitt Meadows 2014; Bowen Island Municipality 2018; The District of North Vancouver, n.d.; City of Surrey, n.d.; Tsawwassen First Nation 2013; 2009; City of Vancouver 2018; Village of Belcarra 2011; Village of Lions Bay 2010; City of Surrey, n.d.; City of White Rock 2014).

20.1.4 British Columbia Active Transportation Design Guide

A document, British Columbia Active Transportation Design Guide (BCATDG), was created by Ministry of Transportation and Infrastructure (2019) which contains suggestions for designing infrastructure based on best practices for planning entities encompassing various scopes. This document is not a design code; therefore, it does not include any design restrictions. BCATDG states "The Design Guide addresses all human-powered modes of transportation, focusing primarily on walking, cycling, and *rolling*." *Rolling* includes emerging modes of transportation such as small, one-person electric focused on in this report. Furthermore, the Design Guide considers winter-based active modes (such as skiing, skating, kick sledding, and snowshoeing), water-based active modes (such as paddling, kayaking, and canoeing), and horseback riding….", that are not focused on in this report. To the authors knowledge, no vehicle class-based design restrictions with a legal backing exist to this date in British Columbia and this Design Guide limits engagement with emerging technologies to discussions. A separate government webpage is dedicated to tracking changes on the design guide and states that the BCATDG may be subject to "major revision" such as "new or revised guidelines, errata corrections and may incorporate previously issued Technical Bulletins" (Ministry of Transportation and Infrastructure n.d.).

In the BCATDG, emerging transportation vehicle (micro mobility devices) riders are grouped together as "Skateboarding, in-line skating, and small, one-person electric vehicles." where "Small, One-Person Electric Vehicles" refers to human-electric hybrid vehicles. The report design guide correctly points out that "Small, One-Person Electric Vehicles" are "[…] not permitted on public roadways or sidewalks in British Columbia." Given the restriction on non-bicycle electric mobility vehicles, the report does not issue further guidance on designing specifically for these vehicles and thereby there are no class-based design restrictions either. The BCATDG reports the typical active transportation user speeds as presented in Figure 57; however, does not seem to be based on empirical data and our results in the body of the report suggest the speed values are biased towards higher speeds for new mobility vehicles. Beyond this, non-bicycle new mobility devices are seldom mentioned in the report other than being highlighted as an area of future work.

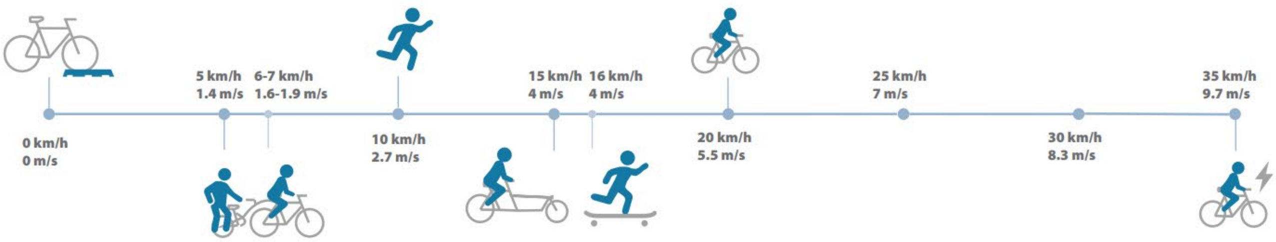


Figure 57. Typical speeds of active transportation users reported in British Columbia Active Transportation Design Guide (Ministry of Transportation and Infrastructure 2019)

20.2 Broader policies

20.2.1 Federal

Transport Canada and Transportation Association of Canada (TAC) do not have any explicit policy goals related to new mobility. Transport Canada oversees a portfolio of 55 organizations and is focused more on macroscopic transportation policy which includes marine and aviation transportation as well. Among the 55 organizations, the Canadian Transportation Agency is most closely related to provincial and regional transportation; however, they also focus primarily on air, rail, and marine transportation. Transportation Association of Canada (TAC) on the other hand is a non-profit organization focusing on the technicalities of road, highway, and urban transportation infrastructure. As a result, TAC has an Active Transportation Integrated Committee which reports to the mobility council. The mobility council in TAC is committed to "[…] integrated, multimodal mobility for people and goods." In terms of concrete actions TAC has a 2020 technical conference which has a presentation scheduled on *Emerging Issues in Urban Transportation: Examining the Public Interest in New Mobility.* Beyond this conference, a portfolio of past projects or current initiatives related to new mobility could not be found on their website.

20.2.2 Provincial

At the provincial level the CleanBC's "Move. Commute. Connect." strategy has led to the creation two grants and one design document and has initiated reviews of ICBC policies regarding new mobility. The first grant, Active Transportation Network Planning Grant, is made available to communities with populations under 25,000 or communities with active transportation plans that are either older than 5 years or nonexistent. The second grant, Active Transportation Infrastructure Grant, subsidizes the construction of active transportation infrastructure with a progressive scheme that provides up to 80% for smaller communities and/or indigenous communities and up to 50% for communities with populations over 25,000. Interestingly, the grant covers winter and water focused modes of active transportation such as skiing and kayaking in addition to traditional and *emerging* modes such as walking, cycling, and rolling. The grant is also open to evaluating other emerging modes of active transportation not listed on their website. The design document, British Columbia Active Transportation Design Guide, was put forth in 2019 by the Ministry of Transportation and Infrastructure with support from three commercials partners: Urban Systems, Universal Access Design, and P.K Consulting. The document is self-described as "[…] a living document that will be updated to reflect evolving best practices and feedback from B.C. communities." It is an expansive, albeit high level guide, with a near complete survey of active transportation design topics; however, it is not a design code. In terms of policy, the CleanBC's "Move. Commute. Connect." strategy is committed to reviewing ICBC policies and the Motor Vehicle Act in preparation for updating the texts to provision for new and emerging modes of active transportation. Currently ICBC interprets many new mobility devices as motor vehicles according to the *Motor Vehicle Act* and thus deems them unsafe.

20.2.3 Regional

At the regional level, TransLink's New Mobility Lab funds and conducts research on emerging technologies and trends, and has worked with Metro Vancouver to jointly put forth *Shared Micromobility Guidelines* for Metro Vancouver (TransLink 2019). These guidelines aim to lay the groundwork for municipalities and TransLink to develop issue-specific actions relating to micromobility challenges, particularly for shared-vehicle services. The document gives recommendations on best practices based on stakeholder consultations on the following six areas:

- Data and data sharing,
- Payments and price structures,
- System planning and design,
- Right of way management,
- System operations, and
- Permit structure and conditions.

The guidelines further outline five areas of opportunities with multiple recommendations for each:

- A Legislative Framework for Micromobility to provide consistency across municipalities and standardize procedures,
- Uniform Data Standards to facilitate compliance costs and non-compliance enforcement,
- Interoperability to improve customer experience and enable seamless integrated travel across municipalities,
- Build Transportation System Resilience and Sustainability by increasing transportation options, and
- Performance-based Permit Conditions to provide flexible permit conditions to operators.

21 Appendix L: Public information

We were often approached by the cycling facility path users during the installation/removal of the classified count and speed data collection instruments. The following handout was created to answer some question regarding the project.

THE UNIVERSITY OF BRITISH COLUMBIA

Department of Civil Engineering
2002–6250 Applied Science Lane
Vancouver, B.C. Canada V6T 1Z4

Human-electric hybrid vehicles: Implications of new non-auto mobility options for street design and policy in the Vancouver region

Thank you for your interest in this study!

In recent years, Vancouver has seen the emergence of new low-power vehicles (e.g., electric bicycles and scooters) and services (e.g., bikeshare) for non-auto personal travel. While creating opportunities, these new mobility services present new challenges to urban transport systems. There is already competition for space and access among road users, which can spill over into conflicts. It is crucial now to capture the potential benefits of more diverse travel options, while mitigating the risks of a wider variety of vehicles and services operating within constrained city street spaces?

That is why we are seeking to understand how new non-auto vehicles and services will impact road user interactions. We are performing data collection at various locations throughout Greater Vancouver to address the objectives of this study:

1. Determine mode shares of bicycles, scooters, skateboards, etc., with and without e-assist, on off-street facilities around the region, and
2. Determine representative speed distributions for each vehicle type.

We will be using pneumatic tubes for count and speed measurements (such as commonly used on city streets), and video recordings to manually classify vehicles. The video images will only be used to investigate vehicle characteristics, and only the UBC research team will have access to the video data. The research team is aware of the potential privacy risks, and takes data security seriously. The study methods have been reviewed and approved by the Behavioral Research Ethics Board at UBC.

For further information about this study please do not hesitate to contact Dr. Alex Bigazzi, UBC Department of Civil Engineering, at alex.bigazzi@ubc.ca or 604-822-4426. If you have any concerns or complaints about this study, you may contact the UBC Office of Research Services at 604-822-8581 or e-mail ors@ors.ubc.ca.

For more information on our lab's research projects, visit: http://reactlab.civil.ubc.ca/

research on active transportation
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