Does one bicycle facility type fit all? Evaluating the stated usage of different types of bicycle facilities among cyclists in Quebec City, Canada

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ABSTRACT

For cities wishing to foster a strong culture of cycling, developing a network of safe and efficient bicycle infrastructure is paramount, yet not a straightforward task. Once transport professionals have selected the optimal location for a new bicycle facility, determining the optimal facility type is imperative to ensure that new infrastructure encourages cycling trips and increases the safety of cyclists. The present study presents a nuanced approach to evaluating cyclists' usage of various types of bicycle facilities. To achieve this goal, we employed survey data of cyclists in Quebec City, Canada, to study how many cyclists reported using a particular bicycle facility in the survey against their reasonable access to those reported facilities. To account for different preferences, behaviour and motivations among cyclists, we segmented our study sample into six types of cyclists. Finally, regression modeling is employed to predict the stated usage of three facility types present in the study area (recreational path, bi-directional protected lane and painted lane), while controlling for access to this path, cyclist type, and personal and neighbourhood characteristics. Results indicate that if a cyclist has access to each facility type on their commute, they are most likely to use a recreational path on their commute, followed by a painted bicycle lane. Respondents with access to a bi-directional lane are no more likely to report using this facility than respondents without access. Overall, this study is intended to encourage a dialogue between cyclists and transport practitioners to uncover the factors contributing to effective bicycle infrastructure.

Keywords: Bicycle facilities, active transportation, bicycle planning, cyclist segmentation, bicycle facility preference.

INTRODUCTION

Should I cycle to work today or not? Although one can answer this question by simply saying yes or no, reasons explaining mobility behaviour are way more convoluted. Recent studies have identified a bundle of factors explaining why an individual is willing to cycle, among which the presence of bicycle parking at destination, access to bicycle facilities, travel distance, perceived and real safety, physical and social environment, weather conditions and attitudes were found as major determinants (*1-7*).

Bicycle facilities with greater separation from motorized traffic are recognized to be preferred by a large number of cyclists (*4; 8; 9*). As the construction of physically separated bicycle lanes generally requires higher capital investments than other facility types, it is essential to ensure that the best design is implemented to deliver a return on investment, in terms of encouraging cycling trips and increasing the safety of cyclists. Several municipalities measure the performance of a new facility by comparing the number of cyclists using a street before and after the construction of a facility or with estimated usage levels. However, these measures do not consider the behaviour of cyclists, and choices they make regarding the use of a particular bicycle facility. Evaluating the choice of cyclists to use various bicycle facilities would provide planners and policy makers with a nuanced perspective of how cyclists perceive different facility types. Accordingly, this study presents a new method of evaluating bicycle facility usage in Quebec City, Canada. Using a survey conducted by the Transportation Research at McGill group in 2015, we evaluate what facilities cyclists have reasonable access to during their commute to work or school and compare this to which facility types each cyclist reported using, in order to measure which facility types are not well used by cyclists. Furthermore, we take this method one step further by segmenting cyclists according to their behaviour, attitudes, and preferences, in order to better understand whether certain groups of cyclists with similar characteristics are more or less willing to cycle on different paths.

This paper is divided in four sections. We will first explore the existing literature on cyclists' segmentation techniques and on the preferences of cyclists towards different bicycle facilities. This will be followed by an analysis section, where we begin by describing the data employed in this paper, which is followed by a detailed overview of the methods used in our analysis, and we then present the findings of our study. Finally, we provide recommendations and highlight the implications of our results.

LITERATURE REVIEW

Segmentation approaches

Cyclists are not a homogenous group of individuals (*10-13*), rather studies have revealed that among cyclists, unique groups are distinguishable according to their cycling facility preferences, motivations, experience, habits, etc. (*10; 14*). Segmentation techniques are commonly employed to acknowledge the fact that policies will not impact all groups of users (for example public transit users) or individuals (in this case cyclists) in the same way. Performing a cyclist segmentation can help practitioners to uncover groups of cyclists with similar behavioural and attitudinal patterns. After identifying distinct groups of cyclists in a region, practitioners can design strategies that suit the motivations, needs, and desires of these different groups, thereby increasing their probability of success and ensuring that limited resources are effectively targeted (*15*).

There are two main segmentation approaches that are commonly applied by both cycling researchers and practitioners. The first approach is to determine *a priori* the number and types of cyclists before analyzing a dataset, to thereafter make cyclists fit into these pre-defined categories. Geller's well-known and widely used typology was created in this fashion (*13*). Geller's four types of cyclists include: *No Way No How, Interested but Concerned, Enthused and Confident, and Strong and Fearless.* This segmentation approach includes both non-cyclists and cyclists, which can be somewhat confusing. Dill and McNeil (*11); (12*) examined the suitability of Geller's segmentation, a first time, at the Portland regional scale, and a second time, at nation-wide levels in U.S. urban areas. The authors' conclusions tend to support the idea that *one unique cyclists' typology can fit all* urban contexts, despite acknowledging differences in cycling facility supplies and in the modal split between the studied areas. Generalizing one approach to all urban settings is likely not a guarantee of success, and in fact there may be other distinct groups of cyclists present in a region, as observed by Damant-Sirois, Grimsrud and El-Geneidy (*10)*.

The second segmentation approach commonly employed by researchers utilizes empirical techniques, such as factor analysis followed by a *K*-means clustering. Factor analysis is commonly used to derive factors of related data or questions and is particularly important when working with a large set of correlated questions. *K*-means cluster analysis is then employed to uncover how these factors relate to identify distinct groups of individuals. These techniques are commonly utilized when working with a large number of survey question (*16; 17*). Studies specific to cyclists that employed this technique include Gatersleben and Haddad (*18)* who found four types of cyclists in England: *Responsible Bicyclists*, *Lifestyle Bicyclists*, C*ommuter Bicyclists*, and *Hippie-Go-Lucky Bicyclists*. Eriksson, Friman and Gärling (*14)* used the 2009 City of Nanjing (China)'s Household survey to create six distinct types of commuter cyclists according to factors including their willingness to bicycle, need for fixed schedule, desire for comfort and environmental awareness. The results of this study included cycling facility improvements tailored to each type of cyclist, such as improving network connectivity, increasing the cycling network density, better integrating cycling facilities with land use were recommended. Finally, Damant-Sirois, Grimsrud and El-Geneidy (*10)* identified four groups of cyclists living in Montreal, Canada, according to factors such as stated cycling facility preference, motivation, and social encouragement: *Dedicated Cyclists*, *Path-using Cyclists*, *Fairweather Utilitarians,* and *Leisure Cyclists*.

Usage and preferences for bicycle facilities

There are different types of bicycle facilities as thoroughly defined in (*1; 4*). As it appears widely accepted that cycling facilities are a key component to encouraging cycling, many researchers have sought to uncover key knowledge regarding which type of cycling facility can best help cities achieve this goal. For example, many studies have evaluated the routes of cyclists to shed light on the proportion of cyclists who divert to use a bicycle facility (*19-23*).

In Vancouver, Canada, Winters et al. (*23)* observed the ratio of the distance of stated routes of cyclists to the shortest route distance. The authors observed modest detour levels (360 meters), and these detours according to cyclists were for example to avoid arterial roads and to use local roads, off-street paths and routes with bike facilities. Using a large-scale survey of cyclists in Montreal, Canada, Larsen and El-Geneidy (*21)* used distance decay functions to understand how far cyclists will travel to use different bicycle facilities, where it was evident that all cyclists will travel further distances to use off-street bicycle facilities compared to all other facility types, however this preference was more pronounced among infrequent cyclists. However, after considering which factors are most influential for a cyclist's route choice, they observed that the diversion distance to a nearby facility is best explained by the supply of nearby facilities and the distance traveled on a given facility. Thus, suggesting that widespread implementation of longer, continuous cycling facilities may ultimately attract more users. In Portland, Oregon, USA, Broach, Dill and Gliebe (8) used GPS units to observe the travel behaviour of frequent cyclists, finding that the following factors are important in the route choice of cyclists: distance, turn frequency, slope, traffic signals, and traffic volume. The authors constructed a route choice model to compare the selected route of each cyclist to many route alternatives, and the findings suggest that individuals cycling regularly preferred off-street separated bicycle paths and bicycle boulevards over stripped lanes and arterial bike lanes, as using these two facilities diminish traffic exposure. These findings differ from several stated preference surveys that found experienced cyclists preferred cycling without designated facilities (10; 24; 25). The authors also recognize the importance of the local context. The network of separate paths present in Portland is potentially more extensive and/or located to facilitate utilitarian trips compared to other contexts that may not link utility trip origins and destinations, therefore presenting the importance of practicing caution when comparing results of studies of this nature. More recently, Broach and Dill (*26)* found that the presence of off-street bicycle paths, bike boulevards or routes enabling cyclists to avoid motorized traffic influenced cyclists to use a particular route where these facilities are available. The authors accordingly recommend investments in cycling infrastructure with traffic separation or in low-traffic streets.

Preferences for cycling facilities also vary among cyclists based on gender and age. Aldred et al. (*27)* observed a greater gender balance on protected bicycle lanes in London, UK, and suggest that protected cycle infrastructure may help to 'normalize' the image of cycling, such as the case of bicycle sharing systems in London, UK (*28*). Similarly, in a systematic review of stated preference studies that evaluated infrastructure preferences by age and gender, Aldred et al. (*27)* found that women had stronger preferences for bicycle infrastructure with greater separation compared to men. As per age, more than half of the studies examined did not observe a preference among older adults towards separation from motor vehicles. No groups studied however stated a preference for cycling in motorized traffic. Conversely, revealed preference studies did not find significant differences in facility usage by gender (*8; 21*). However, revealed preference studies (for example observing route choice and facility usage counts) do not necessarily reflect the active choice or preference of that facility type over another, rather my reflect their best option to reach their destination (*27*). In reality, physical characteristics, design, location and conditions of bicycle facilities may be different according to specific urban settings (*4*), which can partly explain these contrasting findings.

It would appear from this brief overview of the literature on cyclist typologies and preferences for bicycle facilities, that carefully considering local context is imperative for effective bicycle planning. For this reason, designing the best facility is more complicated than selecting the desired level of separation from vehicle traffic. Rather, factors such as the length of the facility, proximity to destinations, changes in elevation, traffic signals and vehicle traffic all play a role in affecting how cyclists will perceive and utilize a bicycle facility. In this study, we present a method to examine what types of facilities bicyclists reported using, and how this compares to the approximated route from their home to work location. In other words, we want to focus on which facilities are nearby a cyclists' daily commuting route and determine their odds of using this facility. Furthermore, we evaluate how different groups of cyclists react to the presence of different facility types near their routes. The grouping of cyclists will be derived from a cycling survey conducted in Quebec City in 2015, to identify types of cyclists that have similar attitudinal and behavioural patterns.

DATA

This study employs data collected in the 2015 Quebec City Bicycling Travel Survey conducted by the Transportation Research at McGill group in collaboration with the City of Quebec. The data was collected through an online survey between August and October 2015. Invitations to participate were sent by email to Quebec City employees for testing the survey. Furthermore, the survey was advertised in local newspapers, and the following groups were invited to share the online survey: university student associations, the public transit agency serving Quebec City, local associations, post-secondary institutions, cyclist advocacy groups, and school boards. In addition an article in the local newspaper was written by a local journalist and encouraged participation in the survey. Also various social media groups announced the survey online on Facebook and Twitter.

A total of 1,823 full responses were collected, with the majority of respondents being utilitarian cyclists. For the purpose of this study, we excluded respondents that did not provide their home, workplace or school geographic locations (e.g. postal codes or a nearby intersection that was provided on a map). Additionally, we omitted respondents that cycled for recreation and grocery shopping purposes because we did not have access to the location of their destinations. Moreover, we did not consider respondents who cycled less than 1 km to reach their workplace or school. As a result, our sample consists of 877 home and work/school cycling trips.

Survey questions were designed to identify the needs, motivations and deterrents of cyclists and non-cyclists residing in Quebec City. The main survey questions of interest to this study were the importance of various factors in cyclists' decision to cycle and whether or not each respondent reported using each facility (recreational path, bi-directional path and painted lane). Each bicycle facility type included in the survey was accompanied by a picture to ensure that respondents associated the right facility type to each question. The main distinguishing differences in these facilities reside in their level of separation from traffic, where recreational paths are off-street trails found mainly in parks, bi-directional paths are physically separated from traffic by median, and painted lanes are recognizable by on-street painted road markings. The distribution of each of these facilities is presented in Figure 1, and characteristics of the bicycle facilities is presented in Table 1. Our study area has approximately 76 km of recreational paths, 65 km of bi-directional paths separated by a median, and 112 km of painted lanes. Note that other types of cycling facilities are present but are not being considered in the present research.

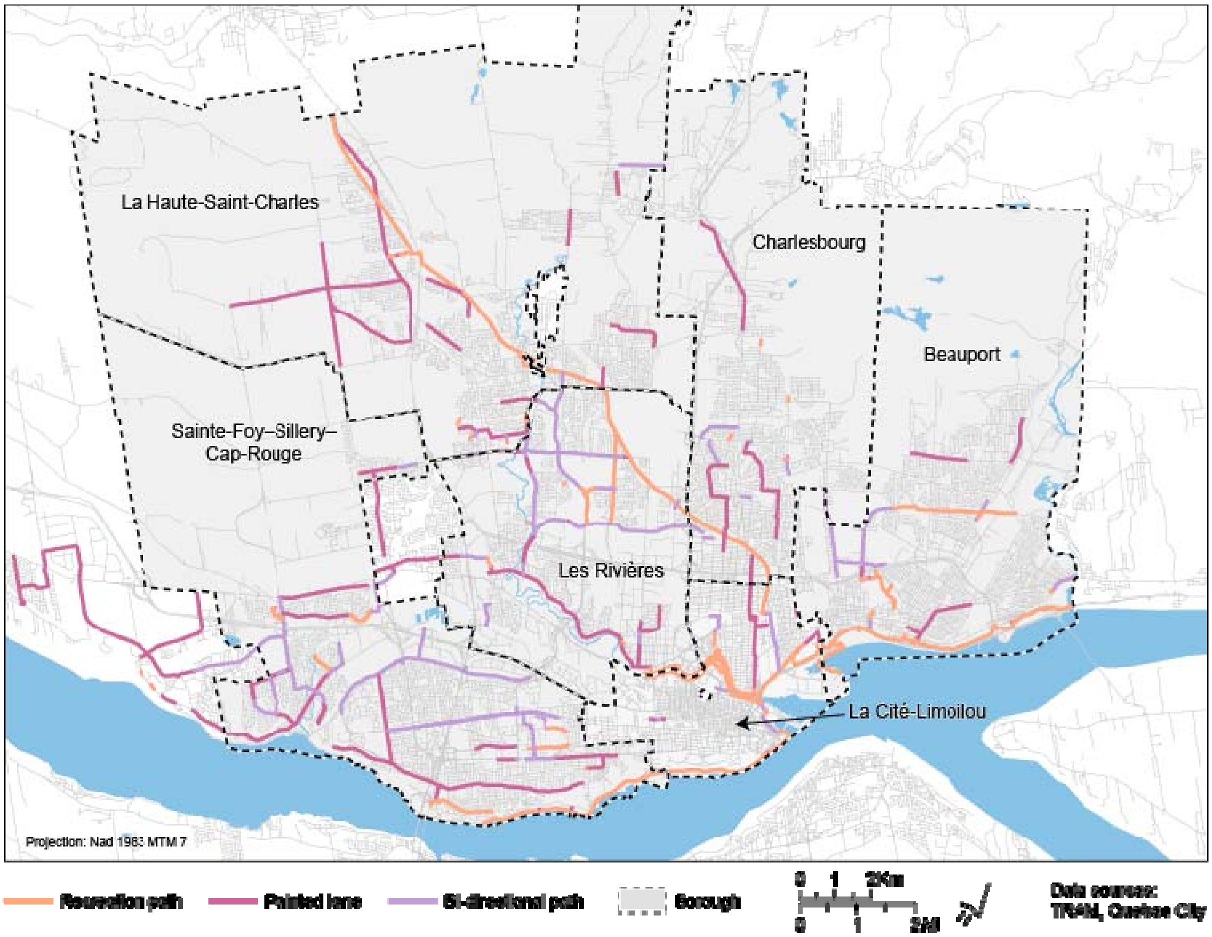

Figure 1 Location of recreational paths, bi-directional paths, and painted lanes in Quebec City, Canada.

Interestingly, slightly more than half of bi-directional paths are adjacent to arterial roads with a speed limit of 60 km/h. In a similar vein, 8% of painted lanes are located on major roads with a maximum speed limit of 80 km/h, whereas only 2.3% of bi-directional paths are located on these high-speed arterials. In terms of connectivity, painted lanes are intersected with the street grid by almost 2.5 times more than recreational paths and 1.7 times more than bi-directional paths. Furthermore, the density of retail, commercial and institutional uses, 500 metres on each side of bi-directional paths, is almost twice as high compared to painted lanes. Finally, unlike the two other types of facilities, bi-directional paths are mostly concentrated in two boroughs: Les Rivières and Sainte-Foy-Sillery-Cap-Rouge.

TABLE 1 Bicycle facility characteristics per borough

Bicycle Facilities Characteristics	Recreational path	Bi-directional path with median	Painted Lane (one way)
Total length (km)	**76.39**	**65.37**	**112.84**
Percentage of facilities adjacent/or located on streets with the following speed limit (%)			
50 km/h	-	45.8	48.74
60 km/h	-	51.9	43.24
80 km/h	-	2.3	7.97
Number of intersections divided by cycling facility length (km)	1.80	2.5	4.46
Retail, commercial and institutional activities density within a 500 meters buffer around each facility types	139 per km^2	158 per km^2	84 per km^2
Total length per borough† (km)			
Beauport	18.75	5.62	6.16
Charlesbourg	5.68	5.59	11.98
La Cité-Limoilou	15.90	4.38	4.40
La Haute-Saint-Charles	13.25	2.88	28.11
Les Rivières	10.32	16.59	15.40
Sainte-Foy–Sillery–Cap-Rouge	12.15	29.67	33.63
Outside City limits	0.34	0.64	13.15

† The location of each borough can be found in Figure 1

ANALYSIS

Our analysis consists of a three-step procedure (Figure 2). Each step of our analysis is conducted using the aforementioned sample of cyclists. First, we performed spatial analysis using ArcGIS to determine what types of bicycle facilities each respondent has reasonable access to diverge to use when commuting to work or school. Second, we carried out a factor analysis followed by a *K*-means cluster analysis to segment cyclists into distinct groups according to their motivations, childhood characteristics and cycling habits. Finally, three logistic regression models were constructed to predict the usage each the three types of bicycle facilities (recreational paths, bi-directional paths and painted lanes), while having reasonable access to these facility types.

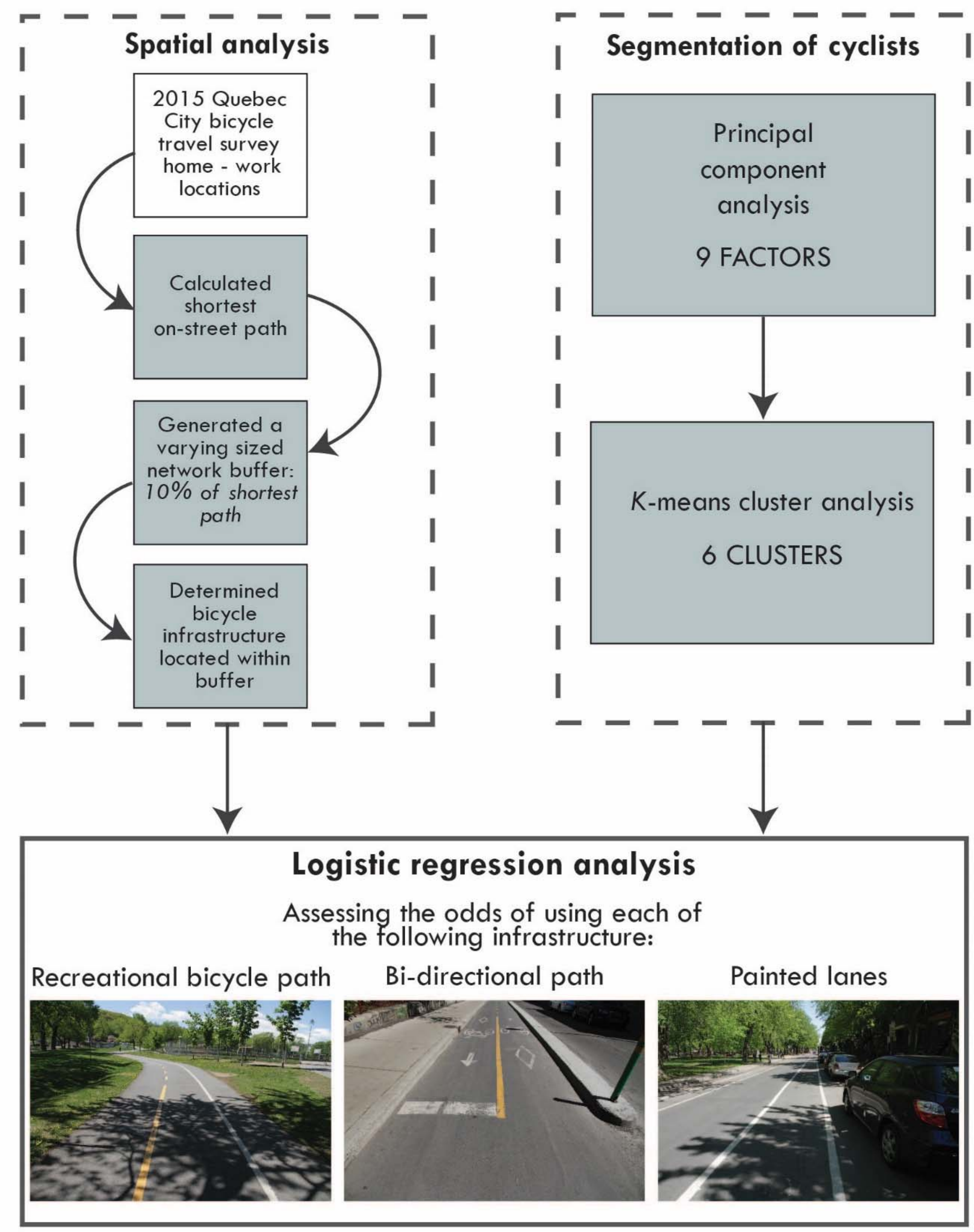

Figure 2 Analysis approach.

Spatial Analysis

The first step of our spatial analysis involved routing each cyclist home to work or school trip. Each respondent provided their home postal code, and the coordinates of their work or school location. Note that in Canada a postal code is a geographic area smaller than a census tract, which is comparable to the size of half a city block, thus enabling a finer scale analysis. Using this information, we modelled the shortest route from home (origin) to work or school (destination) using Network Analyst 'Closest Facility' Tool and a street network containing all segments potentially useable by cyclists. Only highways were thereby removed from the street network.

Next, we generated a network buffer around each route, to determine which types of bicycle facilities each respondent had access to, with the assumption that cyclists are willing to divert from their shortest path to use a preferred facility. Most previous research has aimed to understand whether cyclists are willing to travel farther than their shortest path to use a bicycle facility. Consistently the literature demonstrates that cyclists choose to deviate from the shortest path to use bicycle facilities (20; 29-31), however diversion distances have been found to be best explained by facility length and supply of nearby facilities (21) as well as by type of cyclist (10). In one study detour was calculated to measure how far a cyclist will travel from their shortest route to reach a bicycle facility, and found that of cyclists that use a bicycle facility on average these cyclists on average detour 12% or 695 meters (32). In our study we applied a conservative 10% diversion rate, assuming that cyclists are willing to detour a distance up to 10% of their route to use a preferred facility.

To generate the network buffer, we converted each respondent's route into a number of points equally distanced. In ArcGIS Network Analyst's Service Area, we computed a buffer following the street grid around all points, where sizes were set according to the route's diversion rate previously calculated. Finally, buffers around points forming one route were merged together to form a single buffer for each route. An example network buffer is presented in Figure 3. A varying sized network buffer was chosen for this method, assuming that the longer the respondents route, the more opportunities that an individual will have to divert away from their shortest path.

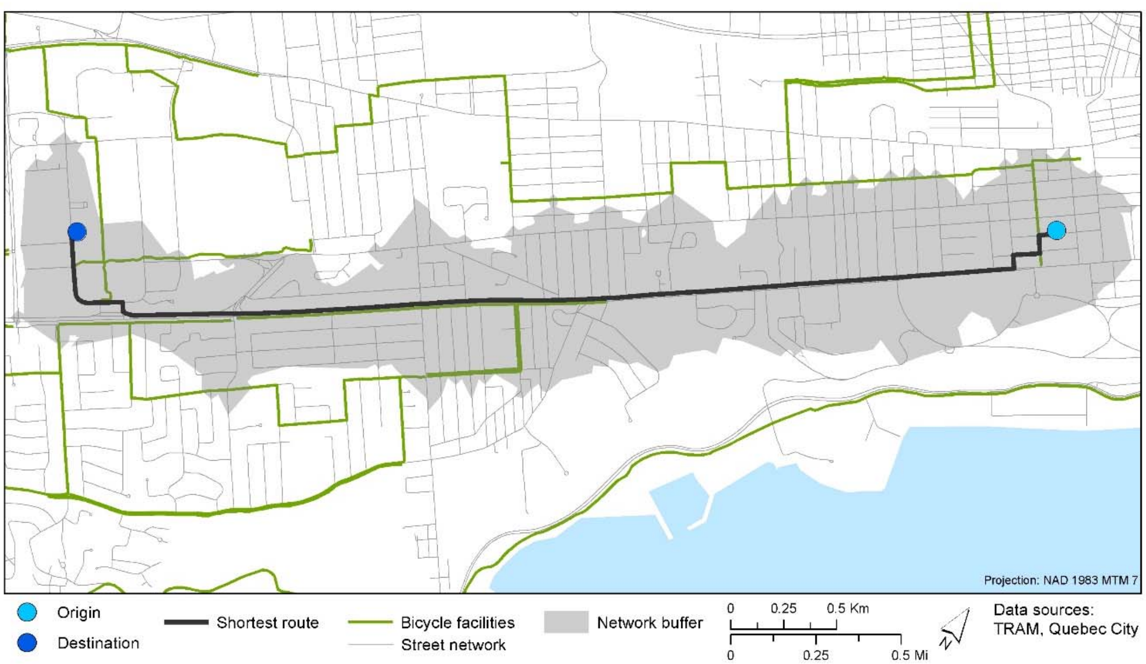

Figure 3 Example of a network buffer.

To identify the types of bicycle facilities that a cyclist has reasonable access to when commuting to work or school, we spatially joined the aforementioned buffer shapefile with the 2015 Bicycle Network shapefile. The results of this operation were also used to determine the length of each cycling facility present within each buffer. A cycling facility was considered present within a buffer if the segment length was greater than 25 meters. We determined the 25-meter threshold according to our study area bicycle network characteristics and by analyzing the spatial joint results. We thus ensured that a facility segment was long enough to be considered as a real potential option, in a cyclists' perspective, to divert from the shortest route to utilize it, by eliminating any residual facility segments spatially captured in the buffer by the spatial joint. We thereafter compare which facility type each respondent has reasonable access to and compare this to whether or not each respondent reported using those previously identified facilities.

Finally, we calculated the ratio of the supply of bicycle facilities within each route buffer relative to the total kilometers of streets present within each respondent's network buffer. To do so we summed the length of all bicycle facilities located within one buffer and divided this by the sum of the street length present within the same buffer. A higher ratio indicates a greater presence of bicycle facilities in that buffer, meaning that cyclist has many bicycle facilities available to use when commuting to work or school by bicycle.

Segmentation of cyclists

To segment our sample into distinct cyclist groups, we first conducted a factor analysis, namely a Principal Component Analysis (PCA), using the 2015 Bicycle Travel Survey. The data employed was derived from questions on satisfaction, motivation, and travel behaviour. Note that we did not include questions related to infrastructure preferences as previous segmentation studies have, for example (*10*). Our results will differ accordingly from previous studies, while differences are also expected to arise between different cities. A PCA statistically examines the variance and covariance among a chosen set of survey question responses, revealing the structure of a dataset, and allowing the formation of factors, which are a group of responses that correlate among each other (*17; 33*). The PCA was operationalized in SPSS using varimax rotation and eigenvalues greater than one, to obtain, in a systematic fashion, an optimal number of factors.

A total of 29 variables were grouped together to create 9 factors, which explained 59% of the variance of our selected data. TABLE 2 shows the results, where each variable is displayed with its respective loading. Note that a loading closer to 1 indicates a stronger relationship between a variable and its factor.

TABLE 2 Results from the Principal Component Analysis

Factors		Variables	Loading
1-	**Time efficiency**	*How important are these factors in your decision to cycle now?*	
		1.1 Flexibility for multiple trips	.850
		1.2 Flexibility of my departure time	.849
		1.3 It's the fastest way to get from A to B	.795
		1.4 Predictability of travel time	.774
2-	**Weather**	*I don't cycle when:*	
		2.1 There is ice or snow because of the danger of slipping	.815
		2.2 There is snow because of the additional effort	.807
		2.3 It's too cold	.573
		2.4 It's raining	.429
3-	**Cycling is enjoyable**	*How important are these factors in your decision to cycle now?*	
		3.1 Cycling is fun	.775
		3.2 It's part of my self-identity/culture	.762
		3.3 To what extent does cycling improve your quality life?	.618
4-	**Effort**	4.1 I don't cycle when the route I have to take is too steep	.752
		4.2 How important is a flat route in making a good bicycle route?	.705
		4.3 I don't cycle when I have to carry bags or heavy loads	.548
5-	**Experience**	5.1 As a child did you use a bicycle for getting around?	.710
		5.2 As a child did you use a bicycle for going to school?	.608
		5.3 Bicycles were seen as a common mode of transportation where I grew up	.514
		5.4 For how long have you been cycling regularly?	.488
		5.5 Did you start cycling as a child?	.449
6-	**Family encouragement**	6.1 To what extent your parent(s) or guardian(s) actively encouraged or discouraged you to cycle as a sport or recreational activity?	.904
		6.2 To what extent your parent(s) or guardian(s) actively encouraged or discouraged you to cycle as a way to reach destinations?	.881
7-	**Peer & institution encouragement**	7.1 How important are your classmates / coworkers cycle in your decision to cycle now?	.859
		7.2 How important are your employer / school encourages cycle in your decision to cycle now?	.851
8-	**Raised in the city**	8.1 Transit was seen as a common mode of transportation for most people where I grew up	.696
		8.2 I grew up in an urban environment	.686
		8.3 Driving a car was a normal and important part of becoming an adult	.607
9-	**Positive benefits associated with cycling**	*How important are these factors in your decision to cycle now?*	
		9.1 Health	.704
		9.2 Environment	.696
		9.3 Low cost of cycling	.524

In a second step, we conducted a *K*-means cluster analysis using the factors previously generated. This technique classified our sample into clusters or distinct groups of survey respondents, where the differences between each group are maximized, while at the same time favouring similarities within members of the same group (*10; 17*). The final number of cyclist types was determined in an iterative fashion by evaluating the outcomes of different grouping options ranging from three to seven clusters. Determining the final number of clusters was guided by the following four factors: (1) statistical output, (2) transferability to transport policy, (3) lessons from previous research, and (4) common sense and intuition (*34*).

Figure 4 presents our cyclist segmentation composed of the six following clusters: (1) *The Urban Cyclist*, (2) *The Benefit-Seeking Cyclist*, (3) *The Happy Cyclist*, (4) *The Picky-Efficiency Seeker*, (5) *The Childhood-Influenced Cyclist*, and (6) *The Indifferent Cyclist*. The colored bars represent the loading of each factor and indicate to what extent each cyclist perceived that factor either positively or negatively relative to other clusters. The types of cyclists were named according to their most salient characteristics, which are described in the following section.

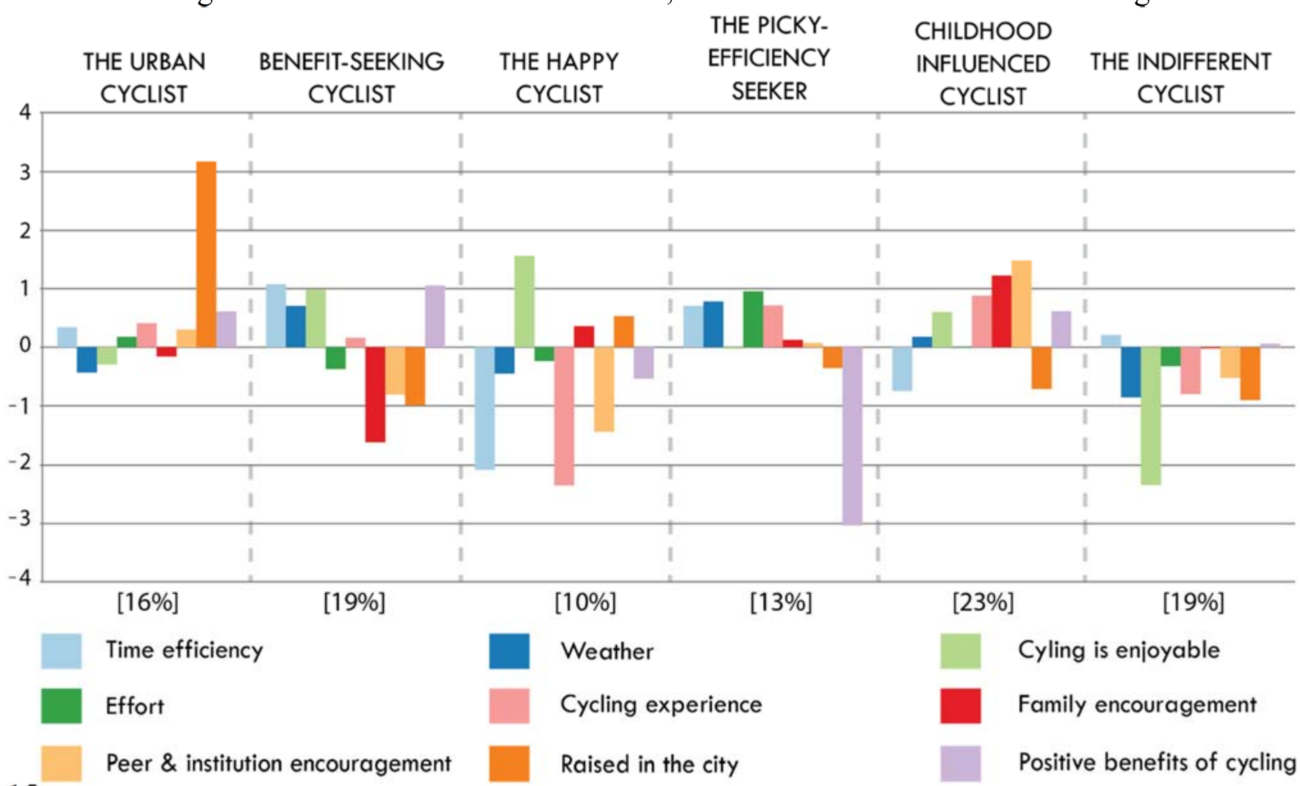

Figure 4 Cyclist segmentation derived from factor and cluster analysis.

The urban cyclist – *16% of the sample* – is characterized by the predominance of individuals (75%) growing up in an urban environment. On average, they cycle 6.8 km to reach their workplace or school location. The majority of *Urban Cyclists* (71%) perceived transit as a common mode of transport when growing up and 33% believed that driving a car was a normal and important part of becoming an adult. *Urban Cyclists* are also slightly more motivated by the positive benefits associated with cycling to work than most of the other groups of cyclists. Furthermore, poor weather conditions, such as ice, are less likely to negatively affect their decision to cycle. They are fairly neutral regarding the importance of peer and institutional encouragement as well as physical efforts required while cycling.

The benefit-seeking cyclist – *19% of the sample* – is foremost motivated by the benefits associated with cycling to work or school. The environmental and health benefits, as well as the low cost of cycling appear important to them. Their decision to cycle is also influenced by their perception of cycling as being time efficient. Similar to *Urban Cyclists*, they cycle on average 6.5 km to reach their workplace or school location. The *benefit-seeking cyclist* perceives cycling as enjoyable and seem rather unbothered by encumbrances and route steepness. However, they prefer not to cycle in poor weather conditions, especially when there is ice and snow. Finally, in their childhood, these cyclists were fairly discouraged by their parents or guardians from using a bicycle to reach a destination. Interestingly, 61% of this group grew up in a suburban environment.

The happy cyclist – *10% of the sample* – perceived cycling as an enjoyable mode of transport and as part of their self-identity. Their decision to cycle is positively influenced by the idea that cycling can improve their quality of life. Interestingly, *Happy cyclists* cycle on average 8.2 km to reach their destination, which corresponds to the greatest average commute distance of all groups. Nearly 84% of this group began to cycle as a child. However, in their childhood, only 30% used their bicycle to get around and 13% cycled to school. In fact, this group received moderate encouragement from their family or guardians to cycle for utilitarian and recreational purposes. Finally, they do not particularly value peer and institutional encouragement and they give the least importance to travel time predictability in their decision to cycle.

The picky-efficiency seekers – *13% of the sample* – cycle to work mainly for efficiency and practical reasons, and under certain conditions. In fact, time savings positively influence their decision to cycle, however, this group is most unlikely to cycle in poor weather conditions and when efforts required to reach their destination are perceived as too high. *Picky-efficiency seekers* are also the least motivated by the benefits of cycling. In addition, they are somewhat neutral towards the joy of cycling and encouragement. Finally, they cycle on average 6.1 km to reach their workplace or school location, and have been cycling regularly for the longest period of time among all groups. Nearly, 20% of this group grew up in an urban environment.

The childhood-influenced cyclists – *23% of the sample* – all cyclists in this group began to cycle as a child and were highly encouraged by family or guardians to cycle for recreational and utilitarian purposes. In their childhood, nearly 80% of *childhood-influenced cyclists* cycled to get around and slightly more than half of this group used their bicycle to get to school. Interestingly, 44% of this group perceived cycling as a common mode of transport when growing up and around 70% were raised in the suburbs. Overall, *childhood-influenced cyclists* perceived cycling as enjoyable. On average, they cycle 4.9 km to reach their workplace or school. Finally, the benefits of cycling are important in these individuals' decision to cycle. They are also neutral about efforts required to reach their destination and poor weather conditions.

The indifferent cyclists – *19% of the sample* – are neutral about cycling benefits and unbothered by factors that could potentially negatively affect their decision to cycle. On average, this group cycles 3.6 km to reach their destination, which is the shortest average commuting distance of all groups. In fact, *indifferent cyclists* are not discouraged by the efforts required to reach their destination and by poor weather conditions, and yet, they don't associate themselves as being part of the cycling culture. In a similar vein, this group is the least motivated by the idea that cycling is enjoyable. They are slightly motivated by time efficiency and are rather neutral towards the benefits of cycling. Finally, nearly 70% of this group grew up in a suburban environment, where cycling was not perceived as a common form of transport.

Next, we examined the six above-described types of cyclists according to their reported facility type usage and access to each facility type on their daily commute (Table 3). More than half of cyclists have reported using a recreational path and a painted lane when commuting to work or school, while solely a third of them have reported using a bi-directional path. Interestingly, nearly 57% have reasonable access to a bi-directional path, but did not report using it. This finding indicates that the majority of cyclists whose commuting route is in proximity to a bi-directional path decided not to cycle on this type of facility. This also suggests that there are possibly design-related factors pertaining to Quebec City bi-directional paths that deter cyclists from using them. In comparison, only a third of all cyclists who have reasonable access to recreational paths and painted lanes did not report using them.

Table 3 Percentage of types of cyclists by reported usage and facility access

Cyclist Types	Recreational			Bi-directional			Painted lanes		
	Reported usage (%)	Have access and not reported using it (%)	Do not have access and do not use it (%)	Reported usage (%)	Have access and not reporte d using it (%)	Do not have access and do not use it (%)	Reported usage (%)	Have access and not reported using it (%)	Do not have access and do not use it (%)
The urban cyclist (n=141)	50.4	30.5	19.1	29.1	53.9	17.0	61.7	23.4	14.9
Benefit-seeking cyclist (n=166)	51.2	30.1	18.7	25.3	59.6	15.1	59.6	25.9	14.5
The happy cyclist (n=91)	61.5	28.6	9.9	25.3	62.6	12.1	57.1	35.2	7.7
The picky-Efficiency Seeker (n=114)	43.0	35.1	21.9	27.2	44.7	28.1	64.0	20.2	15.8
Childhood Influenced cyclist (n=202)	57.4	31.7	10.9	30.7	57.4	11.9	54.5	37.1	8.4
The indifferent cyclist (n=163)	58.9	27.6	13.5	27.0	60.1	12.9	54.0	37.4	8.6
Total (n=877)	53.9	30.6	15.5	27.7	56.7	15.6	58.0	30.4	11.5

Logistic regression analysis

To predict the odds that each individual, previously classified in a cyclist type, uses a recreational path, bi-directional path, or painted lane, we constructed three binary logistic regression models, one for each facility type. For each model, the dependent variable was derived from the following question: "When you travel to work/school by bicycle, do you usually use the type of facility shown above?" The dependent variable employed is a dummy that equals one if a respondent reported using a facility type and zero if a respondent reported not using a facility type. Additionally, we controlled for trip, neighbourhood and personal characteristics.

Error! Reference source not found. presents the results of the three binary logistic regressions. Holding all other variables constant, **Model 1** shows that the likelihood of using a recreational path to commute to work or school is 3.49 times higher for a cyclist who has reasonable access to this facility type than those who have not. **Model 2** uncovers that the likelihood of using a bi-directional path is 1.42 times higher when cyclists have reasonable access to this facility type than those who do not. However, this finding is not statistically significant, therefore having reasonable access to a bi-directional bicycle path is not a predictor of whether or not an individual will use that facility. While we assumed that all cyclists could potentially divert from their shortest route up to 10% of their total trip distance, further analysis could be conducted to test different diversion rate options. In **Model 3**, the odds of using a painted lane are 1.72 times higher for cyclists who have reasonable access to this facility type, holding all other variables at their mean.

The results of these three models could be explained by the fact that cyclists commuting to work or school are more likely to be travelling during morning and evening peak hours, a period characterized by heavy motorized flow as mentioned by Broach, Dill and Gliebe (*8)*. While over half of bi-directional paths and painted lanes are adjacent to roads with a speed limit of 60 km/h and above, cyclists could be more willing to use recreational paths, when having access to them, as they are located further away from car traffic. In addition, cyclists using recreational paths to reach their destination cross fewer street intersections, which could eventually reduce their travel time. Future analysis could include cyclists' perception of bicycle facility safety and comfort.

Cycling Segmentation

Model 1 reveals that the odds of *Indifferent cyclists* using recreational paths when commuting to work is 2.13 times higher compared to *Picky-efficiency seekers,* all else equal. *Indifferent cyclists* are defined as being rather neutral and unbothered by factors that could affect their decision to cycle, such as poor weather conditions or positive benefits of cycling, while *Picky-efficiency seekers* are mainly cycling for efficiency reasons.

Model 2 indicates that there is no statistically significant difference in the odds of using a bi-directional path between *Picky-efficiency seekers* and all other types of cyclists. This is rather surprising giving the existing literature on how different types of cyclists have specific preferences in terms of bicycle facilities. Note that, across all cyclist types, between 45% and 63% of cyclists reported having access to a bi-directional path but are not using it to commute. Thereafter, the design and locations of bi-directional bicycle paths in Quebec City should be thoroughly examined to shed light on this finding.

In **Model 3**, the odds of *Childhood-influenced cyclists* using painted lanes are 47% lower compared to *Picky-efficiency seekers,* when keeping all other variables at their mean. Similarly, *Happy cyclists* and *Indifferent cyclists* are 41% and 39% less likely to use painted lanes compared to *Picky-efficiency seekers,* although this finding is statistically significant at the 90% level.

Overall, this study uncovers subtle differences in bicycle facility usage between our sample of cyclist types. As previous cyclist typologies (for example Damant-Sirois, Grimsrud and El-Geneidy (*10)*) included infrastructure preferences in their segmentation process, we cannot compare our results to previous studies that observe distinct infrastructure preferences among certain cyclists.

Table 4 Likelihood of using each bicycle facility

Variable	Odds Ratio					
	Mode 1 Recreational path		Model 2 Bi-directional path with median		Model 3 Painted lane	
Presence of infrastructure within route buffer†	3.49	***	1.42		1.72	**
Cyclist segmentation						
1. The urban cyclist†	1.26		1.05		0.84	
2. Benefit-seeking cyclist†	1.40		0.91		0.73	
3. The happy cyclist†	1.56		0.69		0.59	*
5.Childhood influenced cyclist†	1.45		0.98		0.53	**
6.The indifferent cyclist†	2.13	***	1.10		0.61	*
Ref : The picky efficiency seeker†	-		-		-	
Trip and neighbourhood characteristics						
Length of work/school commute (km)	1.08	***	1.10	***	1.05	**
Ratio of bicycle facilities to street length within route buffers	1.04	**	1.04	**	1.06	***
Perceived neighborhood as cycle-friendly in terms of infrastructure†	2.05	***	1.47	**	0.92	
Personal characteristics						
Age below 35 years old†	0.63	*	0.72		0.90	
Age between 35 to 54 years old†	0.74		0.68		1.05	
Ref Age 64 years and above	-		-		-	
Gender - Female†	0.92		0.57	***	0.89	

Dependent variable: Reported usage (1 = used and 0 = not used)
† Represents a binary dummy variable
* 90% significance level | ** 95% significance level | *** 99% significance level

Trip, neighbourhood and personal characteristics

Commuting trip distance positively influences the odds of cycling on all facility types. For every additional kilometer cycled, the odds of using recreational, bi-directional and painted lanes increase by 8%, 10%, and 5% respectively. This finding suggests that cyclists commuting longer distances to work are more likely to use an available bicycle facility on at least part of their route. With respect to the supply of bicycle facilities within a cyclists' buffer relative to total length of street, we observe that a larger ratio of bicycle facilities to street length is associated with a 4%

increase in odds of using a recreational path and bi-directional path with a median, and a 6% increase in the odds of using a painted lane. Our results also reveal that respondents who perceived their neighborhood as cycle-friendly in terms of bicycle infrastructure were more likely to have reported using a recreational path and a bi-directional path. However, no significant difference was observed for the usage of painted lanes. This suggests that if cycling infrastructure investments in a respondents' neighbourhood are perceived as unsatisfactory, cyclists are less likely to use that infrastructure, even if it is within a reasonable distance of their commuting route. Alternatively, this variable may capture the influence of self-selection, whereby individuals have chosen to live in a neighbourhood with access to these types of bicycle facilities and are therefore more likely to utilize them on their daily commute.

Finally, across all facility types, age is not statistically significant predictor of facility usage, with one exception. Cyclists under the age of 35 years were found to be 37% less likely to use a recreational path compared to cyclists above the age of 55. The lack of significance across age was unsurprising given previous literature that has found inconsistent findings for preferences for separated infrastructure across age groups (27). With respect to gender differences, women are 43% less likely to use a bi-directional path compared to men. However, no differences were observed for the other two facility types. This result may be related to the design of the bi-directional paths in Quebec City. This finding is very interesting and may indicate that the design of this facility type may invoke feelings of stress or safety concerns among cyclists. Female cyclists have previously been found to feel more unsafe than males under similar traffic conditions and have stated greater importance of safety concerns (including traffic speed and volume, signalized intersections etc.) relative to men (*35*), which may explain the lower usage of this facility type among women.

CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to present a nuanced methodology to assess how distinct types of cyclists are using or not using, three types of bicycle facilities: recreational paths, bi-directional paths, and painted bicycle lanes. Using the 2015 Quebec City Bicycle Survey, the first part of this analysis consisted of routing each respondents' commute trip and determining what bicycle facilities each respondent had access to along their route, assuming that cyclists are willing to divert from the shortest path to use a preferred cycling facility. We created personalized network buffers around the shortest route connecting each cyclist's home and work/school location, where the buffer size was created according to the distance of each respondents' commute. Accordingly, as a cyclist is travelling a greater distance, the area that is deemed reasonable to divert within is also wider and can potentially encompass more cycling facilities. Using these buffers, we identified which cycling facility types each respondent had access to, in order to discern who is or is not using bicycle facilities that are available to them.

To our knowledge, our study is the first to employ this personalized buffer method to account for cyclists' willingness to divert from their shortest route to reach a preferred cycling facility. We recommend to practitioners wishing to reproduce and adapt this method to try different diversion rates according to their city context; shorter diversion rates have been observed in cities or regions with a large supply of bicycle facilities (*21*). Future studies could also examine the impact of using different diversion rates on their results.

In the second part of the analysis, we segmented our sample into six distinct types of cyclists: *The Urban Cyclist, Benefit-Seeking Cyclist, The Happy Cyclist, The Picky-Efficiency Seeker, Childhood-Influenced Cyclist* and *The Indifferent Cyclist*. We derived our cyclist typology from factors such as their motivations, childhood characteristics, and sensitivity to peer and family encouragement. In the final phase of our analysis, we constructed three logistic regression models to determine the odds that a cyclist will use each facility type, controlling for whether or not that facility type was available to them on their commute to work or school. The models indicate that in Quebec City, if a cyclist has access to all three facility types on their commute, that same cyclist is most likely to use a recreational path, followed by a painted bicycle lane. Interestingly, we found that access to a bi-directional path on a respondents' commute trip was not a predictor of their reported usage of this facility type. In fact, the majority (57%) of cyclists in our sample have access to a bi-directional path on their commute trip and did not report using it while responding to the survey. As the data used in this study are a subset of all cyclists in Quebec City, it is difficult to prove or disprove if our study sample generally represents the cycling population of Quebec City in terms of their trip making decisions in the absence of comprehensive knowledge of the cyclist route choice in the region from other sources. Nonetheless, the results of this analysis are consistent with the literature and local experience. Furthermore, we must keep in mind that because a facility type in Quebec City is not well used, it does not necessarily mean that this facility is poorly perceived in our study area or elsewhere, and that it will not be desired in other urban contexts. In reality, the location of a bicycle facility may not effectively connect cyclists with their destinations, therefore diverting from their shortest route may not constitute an optimal option for some cyclists.

Modest differences were observed among the odds of using a bicycle facility type across our cyclist typology. In comparison, Misra and Watkins (*31)* observed that cyclist typology, derived from cyclist comfort level, did not predict a cyclist's decision to deviate from the shortest route to use a bicycle facility, however, the authors did not consider the type of bicycle facility in their analysis. In our study, with reference to the *Picky efficiency seekers* (highly motivated by time efficiency) all other types of cyclists were more likely to use recreational paths on their commute, while less likely to use painted lanes. This finding suggests that these cyclists are unlikely to deviate far from their shortest path, as a detour is typically required to use a recreational path, however knowledge of these cyclists' actual routes would allow us to confirm this. Knowledge of the types of cyclists in a region, including their motivations (i.e. time efficiency) and deterrents (i.e. cycling on high vehicle volume streets), should guide planners towards the optimal facility design in that region.

Irrespective of type, cyclists in our study sample have a strong preference for the use of off-street recreational paths, which is the facility type that offers the greatest separation from traffic in Quebec City. This is consistent with several studies that have observed cyclists' preferences for facilities with greater separation from traffic (*2; 4; 26*). However, this study raises questions regarding the influence of the bi-directional nature of these protected bicycle lanes, which is a common facility design in Quebec City and other cities including Montreal, Canada. While these facilities are physically separated from traffic, and therefore may offer greater protection to cyclists than, for example painted lanes, the bi-directional design of these lanes may be detrimental to how cyclists perceive their safety. In Montreal, Damant-Sirois, Grimsrud and El-Geneidy (*10)* observed that painted lanes running in the opposite direction of traffic are the least preferred cycling facilities present in the city. Accordingly, future studies should verify how cycling usage differs between physically separated bi-directional and uni-directional lanes in a city where both types are available. In another respect, 52% of bi-directional lanes in Quebec follow streets with motorized speeds limits of 60 km/h, which may explain the lower than expected usage of these facilities. In the future, we recommend monitoring intersections along bi-directional lanes to assess interactions between cyclists, vehicles and pedestrians.

Our results highlight the importance of thinking critically about what type of bicycle infrastructure is preferable to build according to a specific urban context and the typology of cyclists present in a region. While several studies have indicated that cyclists have a preference for physically separated bicycle facilities, expanding or improving incrementally an existing cycling network should be achieved by considering the network holistically, and not solely by deciding on the facility type or design to implement (*4*). As such, not only facility design but also characteristics of adjacent streets, and neighborhood characteristics should be considered when deciding which facility type is best suited (*4*). Moreover, given the diversity in cycling facility preferences, planners should engage in a dialogue with cyclists, both novice and more experienced cyclists, to collect information about safety and stress levels when using different facilities, with the goal of identifying optimal cycling facilities for future investments.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: Veillette, Grisé & El-Geneidy; data collection: Veillette, Grisé & El-Geneidy; analysis and interpretation of results: Veillette, Grisé & El-Geneidy; draft manuscript preparation Veillette, Grisé & El-Geneidy. All authors reviewed the results and approved the final version of the manuscript.

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