To cycle or not to cycle?

Planning tools and strategies to increase cycling in Quebec City, Canada

Supervised Research Project
Marie-Pier Veillette
April 2018

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Supervised Research Project

Submitted in partial fulfillment of the requirements of the degree of Master of Urban Planning

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April 2018

« To cycle or not to cycle ? »

Outils et stratégies d'aménagement pour augmenter les déplacements à vélo sur le territoire de la ville de Québec, Canada

RÉSUMÉ EXÉCUTIF

La présence de stationnements à vélo et d'infrastructures cyclables peut influencer les individus à utiliser leur vélo pour se rendre au travail ou à l'école. Néanmoins, aucune méthodologie n'a été développée pour identifier les endroits à prioriser pour l'ajout de nouveaux stationnements à vélo afin d'aider les villes à planifier une augmentation de l'usage du vélo comme moyen de transport utilitaire. De plus, aucune étude concernant la probabilité des cyclistes résidant à la ville de Québec d'utiliser certains types d'infrastructures cyclables n'a été à ce jour réalisée.

L'objectif de ce travail de recherche dirigé est d'aider les professionnels à planifier une augmentation des déplacements à vélo pour des motifs utilitaires en proposant des outils de planification, conçus avec des techniques d'analyse spatiale et statistique, visant **les stationnements à vélo** et **l'usage d'infrastructures cyclables**. Les résultats de ce travail peuvent guider les professionnels sur les stratégies optimales à adopter pour augmenter l'usage du vélo et ainsi maximiser les investissements publics dans les infrastructures de transport actif.

<u>Sommaire des outils développés</u>

Afin d'identifier les endroits à prioriser pour l'ajout de nouveaux stationnements, les outils suivants ont été développés :

1. **Deux indices** ont été créés pour identifier les besoins en stationnement à vélo de courte durée (support à vélo traditionnel) et de longue durée (casier sécurisé). Ces deux indices combinent plusieurs variables pondérées.
2. Le nombre **de places de stationnement** requis pour combler la demande en stationnement de courte et de longue durée a également été calculé.

Afin de prédire l'usage d'infrastructures cyclables, les analyses suivantes ont été réalisées :

1. Une **typologie des cyclistes utilitaires** a été créée en procédant à une analyse factorielle-typologique. Un total de six types de cyclistes a été défini.
2. Les **types d'infrastructures cyclables** auxquels les cyclistes ont **potentiellement accès** lorsqu'ils se déplacent vers leur destination ont été identifiés avec logiciel ArcGIS. Nous avons assumé que chaque cycliste est prêt à faire un détour, équivalent à 10% de la distance totale parcourue à vélo, afin d'utiliser une infrastructure cyclable particulière plutôt qu'une autre.
3. **Des modèles de régression logistique** ont été réalisés pour prédire la probabilité que chaque type de cyclistes utilise les pistes cyclables récréatives, bidirectionnelles séparées par une médiane et les bandes cyclables peintes au sol. L'accès potentiel des cyclistes aux trois types d'infrastructures cyclables a été inclus dans les modèles statistiques.

<u>Recommandations</u>

- La méthodologie développée pour planifier l'ajout de stationnements à vélo peut être utilisée par d'autres villes. Nous recommandons **d'adapter le nombre et le type de variables** formant les indices en fonction du contexte urbain et des objectifs fixés en matière de transport et d'urbanisme. De plus, il est conseillé de **revoir la pondération** des variables.
- Les professionnels peuvent **ajuster la demande pour les casiers sécurisés** en considérant la volonté des cyclistes à payer pour ce service.
- En ce qui a trait à l'usage des pistes cyclables, privilégier l'implantation d'infrastructures onéreuses de type bidirectionnel séparé par une médiane n'est pas nécessairement **l'option la plus optimale** à généraliser pour l'ensemble des villes.
- Nos résultats démontrent l'importance de planifier l'amélioration des réseaux cyclables en analysant **de manière critique** la préférence des cyclistes**: « One facility type does not fit all! »**

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EXECUTIVE SUMMARY

The provision of bicycle parking and the availability of cycling facilities can influence individuals' decision to cycle. Yet no method has been developed to help planners identify and prioritize locations to add new short-term (racks) and long-term (lockers) bicycle parking. Moreover, no study has assessed what type of cycling facility Quebec City should invest in, according to cyclists' stated preference and their likelihood to use different kinds of cycling facilities.

The goal of this supervised research project (SRP) is to help practitioners to plan for an increase in cycling usage by conducting spatial and statistical analysis in order to develop a **bicycle parking strategy** and **predict bicycle facility usage.** Findings from this SRP can support decision makers on the best-suited cycling strategies to adopt, thereby maximizing public investments.

Overview of tools employed

To identify and prioritize the locations of short-term and long-term bicycle parking:

1. **Two index** are created to assess parking demand; one for short-term parking (racks) and a second one for long-term parking (lockers). Both index are generated by combining and weighting various indicators.
2. The number of **parking spaces** required to meet the demand is also calculated

To predict facility usage:

1. A **utilitarian cyclist typology** is generated using a factor analysis followed by a *K*-means cluster analysis. We defined six types of cyclists.
2. **Reasonable access** to bicycle facility type is calculated using ArcGIS while assuming a cyclist diversion rate of 10%.
3. **Logistic regression models** are conducted to predict the odds of each cyclist type to use bi-directional, painted lane and recreational cycling facilities, while controlling for their access to these facilities.

Recommendations

- The **bicycle parking method** can be applied to other cities. Planners are recommended to tailor the **number and the type of indicators** utilized in both index according to their planning goals. **The weighting scheme** of each indicators can also be modified accordingly.
- Practitioners could also **adjust long-term parking (lockers) demand** by considering cyclists' willingness to pay for this service.
- With regards to **bicycle facility usage**, high capital investments in physically separated bi-directional bicycle paths may not be the most optimal facility to prioritize in all cities.
- It's important to think critically about infrastructure preferences: **One facility type does not fit all**!

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

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1. CHAPTER 1: 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 attitude were found as major determinants (Buehler & Dill, 2016; Handy & Xing, 2011; Heinen, Maat, & van Wee, 2011; Nkurunziza, Zuidgeest, & Van Maarseven, 2012; Pucher, Dill, & Handy, 2010; Wardman, Tight, & Page, 2007; Winters, Davidson, Kao, & Teschke, 2011). Cyclists are not, however, a homogenous group of individuals (Damant-Sirois, Grimsrud, & El-Geneidy, 2014; Dill & McNeil, 2013, 2016; Geller, 2006). Motivations to cycle and facility type preferences can differ from one cyclist to another (Broach, Dill, & Gliebe, 2012; Larsen & El-Geneidy, 2011; Li, Wang, Yang, & Ragland, 2013; Rietveld, 2000; Tilahun, Levinson, & Krizek, 2007). An array of strategies, planned comprehensively by practitioners, can therefore have the potential to generate an increase in bicycle usage and ownership (Dill, 2009; Dill & Carr, 2003; Handy & Xing, 2011; Nelson & Allen, 1997; Pucher et al., 2010).

Recently, the goal of increasing cycling levels has been integrated in several municipal transportation plans and policies (Buehler & Dill, 2016). Due to limited municipal budgets, achieving this goal has remained a challenge, but spatial and statistical tools can help municipalities to make the most of their resources and inform on strategies to adopt. **The goal of this supervised research project (SRP)** is to generate methodologies that can be used by practitioners to plan for an increase in cycling usage through applying a number of spatial and statistical analysis tools to Quebec City's urban context.

The City of Quebec, the second largest populated city in the province of Quebec, has enacted its first Bicycle Plan a decade ago and has since reaffirmed its desire to encourage a modal shift toward cycling through its 2011 Sustainable Mobility Plan and its 2016 Bicycle Vision (Ville de Québec, 2008; Ville de Québec, 2011, 2016). Accordingly, this SRP pursues **two objectives** that are anchored into Quebec City's planning goals and vision:

1- To develop a bicycle parking strategy to help planners identify optimal locations to install new bicycle parking.

2- To predict the use of different cycling facilities among distinct types of cyclists through employing various spatial and statistical techniques.

Our study uses the results of the Quebec City Bicycle Travel Survey designed and conducted in 2015 by the Transportation Research group at McGill (TRAM) in collaboration with Quebec City**. In chapter 2**, a multi-criteria and GIS-based methodology is developed to identify optimal locations to install new short-term and long-term bicycle parking. As defined in this chapter, short-term parking refers to traditional bicycle racks and long-term bicycle parking is defined as any type of bicycle storage with restricted access and provided for a fee. This chapter builds on Larsen, Patterson, and El-Geneidy (2013) to propose an easy-to-reproduce method to help plan for bicycle parking.

In chapter 3, six types of cyclists are defined to further assess their odds of using recreational, bi-directional, and painted lanes. To predict facility usage, cyclists' access to these facilities is also considered. These three aforementioned facility types are examined as they constitute the majority of Quebec City existing cycling network. Factor analysis followed by *K-means* cluster analysis are employed to segment cyclists into distinct groups. Logit modelling is conducted afterwards to predict the odds of using the three above-mentioned facility types among the identified groups of cyclists, while also considering cyclists' access to these facilities. The tools used in this chapter allow practitioners to understand what type of facilities are actually being used by cyclists when they have access to them.

While this SRP uses Quebec City as a case study, the tools and strategies employed in the present document can be tailored to other regions around the world. **Chapter 4** contains a set of recommendations from the tools employed in the two previous chapters and also highlights major lessons and policy issues. The methods employed in this SRP can support decision makers in prioritizing future cycling improvements and ensuring newly built cycling facilities are maximized in terms of uses; meaning existing and potential demand are met and facilities location and design are optimal.

2. CHAPTER 2: Park ‘n’ Roll: Identifying and prioritizing locations for new bicycle parking in Quebec City, Canada[1]

2.1 INTRODUCTION

A broad body of literature has explained the positive effects of the presence of bicycle infrastructure, such as bicycle lanes, parking, showers, and availability of bicycle-sharing system on cycling levels in a region (Dill & Carr, 2003; Pucher & Buehler, 2008; Pucher et al., 2010). In the Netherlands, Denmark and Germany, measures related to bicycle parking supply and security, as well as interventions aimed at better integrating cycling with other modes, have promoted cycling as a safe and convenient mode of transport, and thereby increased bicycle usage (Buehler & Pucher, 2011; Pucher & Buehler, 2008). Locating bicycle parking, however, has received little attention in the cycling literature. The aim of this study is to develop an easy-to-reproduce GIS-based method to identify and prioritize locations to add new short-term (bicycle racks) and long-term (bicycle lockers or indoor facilities) bicycle parking in Quebec City, Canada.

This paper seeks to answer three main research questions: 1) how can a region prioritize the installation of new short-term bicycle parking in order to meet the needs of existing and potential cyclists; 2) how can the same region locate

[1] This chapter was co-written with Emily Grisé and prof. Ahmed-El-Geneidy and presented at the 97th Transportation Research Board Annual Meeting in Washington, D.C. in January 2018. This chapter was accepted for publication in the Transportation Research Record Journal.

long-term bicycle parking; 3) what are the quantities of long-term and short-term bicycle parking spaces needed to accommodate existing and potential demand? We define short-term bicycle parking as any type of free-standing rack, similar to those presently provided by the city of Quebec and many North American cities, and long-term bicycle parking as any bike storage, locker or shed with restricted access and typically provided for a fee, similar to what is present at major public transport stations in European cities. Our study builds on a previous method developed by Larsen et al. (2013), who proposed the creation of a GIS-based prioritization index to identify high-priority grid cells to guide bicycle network improvements at a city-wide scale. The paper is divided in four sections. We will first provide an overview of the existing literature on bicycle parking, which will be followed by a brief description of our study area. The next section, the core of this paper, will be dedicated to describing our methodology and presenting our findings. Finally, we will discuss the implications and recommendations of our results.

2.2 LITTERATURE REVIEW

The presence of end-of-trip facilities, such as bicycle parking and showers, has been identified as an important factor in increasing bicycle modal share for utilitarian purposes (Buehler, 2012; Pucher & Buehler, 2008; Pucher, Buehler, & Seinen, 2011; Pucher et al., 2010; Wardman et al., 2007). However, the perceived risk of bicycle theft and vandalism can deter individuals from cycling (Rietveld, 2000; Rietveld & Daniel, 2004). van Lierop, Grimsrud, and El-Geneidy (2015) studied the locations of stolen bicycles and found that 50% of reported stolen bicycles were locked in a fly-parking fashion. Fly-parking is a concept that refers to locking a bicycle to any type of street furniture that is not proper bicycle parking (Gamman, Thorpe, & Willcocks, 2004; van Lierop et al., 2015). Accordingly, providing cyclists with a sufficient supply of bicycle parking at destinations, especially in areas where the bicycle mode share is increasing, has the potential to reduce bicycle theft and subsequently encourage bicycle usage (Rietveld & Daniel, 2004).

For optimal levels of security against bicycle theft, particularly for individuals parking their bike for long periods of time, demand and preference for bicycle parking that provides greater levels of security is rising. Long-term bicycle parking is typically referred to in the literature as a bicycle facility guarded by an individual or a facility which limits access through electronic keys (Gamman et al., 2004). Bicycle lockers have also been added to the list of long-term bicycle parking as they are usually present near destinations, such as train stations (Pucher et al., 2010). In Montreal, Canada, a Bicycle Theft Survey conducted in 2012 revealed that cyclists perceived bicycle lockers as more secure against theft compared to free-standing bicycle racks (van Lierop et al., 2015). The availability of long-term bicycle parking and showers at destinations was found to have a significant influence on bicycle usage (Hunt & Abraham, 2007). More specifically, Wardman et al. (2007) presented evidence that the availability of outdoor bicycle parking at work increased the share of trips to work by bicycle from 5.8% to 6.3%.

However, the combination of both indoor bicycle parking, described as more secure than outdoor, and showers at work would increase bicycle mode share from 5.8% to 7.1%.

The presence of bicycle parking near the public transit network can lead to a better-integrated transportation system (Pucher et al., 2010). In this respect, previous studies in the Netherlands have noted the key role of cycling as a means to access train stations, and thus highlighted the importance of providing bicycle spaces near stations (Martens, 2007; Rietveld, 2000). Van der Spek and Scheltema (2015) reported, among other examples, the case of Zutphen Station, in the Netherlands, where a “guarded” bicycle parking facility was built in 2006 in proximity to the train station, and increased the number of train users who cycle to the station from 41% in 2004 to 58% in 2009. Similarly, the availability of short-term and long-term bicycle parking near train stations increased cyclist’s satisfaction and bicycle usage for bike-and-ride purposes (Martens, 2007).

Krizek and Stonebraker (2010) identified key challenges related to the integration of bicycle and transit use, and evaluated five potential ways of integrating bicycle with transit. For example, the Final Mile Initiative, implemented by Boulder County, is a program that supplies bicycle lockers and bicycle loans along their regional bus routes. The authors mentioned that the program aims to limit the number of bicycles aboard buses in order to improve the bus service by reducing the dwell time (Krizek & Stonebraker, 2010).

Bachand-Marleau, Larsen, and El-Geneidy (2011) highlighted that bicycles on buses (BOB) are the most common way to integrate these two modes together in North-American cities. The authors found that 60% of respondents in their study preferred taking their bicycle aboard transit. This preference can potentially be explained by either the absence of secure bicycle parking at stations or by an actual need of bringing a bicycle aboard a transit vehicle for access to their bicycle upon egress from the transit service. Despite the potential benefit of bringing bicycles aboard transit vehicles, longer dwell time associated with passengers bringing bicycles aboard buses has led to programs aimed at limiting the number of bicycles aboard buses (Krizek & Stonebraker, 2010). While these two studies provide conflicting views on the integration of bicycles and transit use, better long-and short-term bicycle parking at transit stations would be beneficial for the integration of these two modes.

Although recent studies used a GIS-based approach to plan for new bicycle lanes and bike-sharing stations, no study has developed a methodology to specifically identify the optimal locations to install long-term and short-term bicycle parking (García-Palomares, Gutiérrez, & Latorre, 2012; Larsen et al., 2013; Rybarczyk & Wu, 2010). This study tries to fill this gap by using a multi-criteria GIS-based approach, which modifies and expands on a similar method developed by a previous study (Larsen et al., 2013).

2.3 STUDY AREA

The City of Quebec is the second largest populated urban center in the province of Quebec, Canada with 531,902 inhabitants in 2016 (Statistics Canada, 2017). The study area is divided into five boroughs, for a total area of approximately 454 km^2 (Statistics Canada, 2017). Similar to many North American cities, the construction of highways between 1960 and 1980 encouraged the localization of employment nodes and housing developments at the periphery of the inner city, which in turn contributed to the creation of a polycentric-structured city (Vincens, Vandersmissen, & Thériault, 2007). Nowadays, the presence of highways, in addition to railways, rivers and territory steepness, are major barriers to the existing bicycle network expansion and consolidation (Ville de Québec, 2016).

In 2016, the City announced its Bicycle Vision to encourage a modal shift toward cycling by specifically improving the safety and connectivity of the bicycle network (Ville de Québec, 2016). Nine kilometers of new bicycle paths and 60 more bicycle parking racks were added in 2016 (Ville de Québec, 2017). Presently, the City of Quebec has around 424 kilometers of bicycle network and 480 short-term bicycle parking (bicycle racks) of either 3, 5, and 7 spaces each, for a total of nearly 3,784 public bicycle parking spaces available for cyclists. The distribution of these parking spaces is presented in Figure 1.

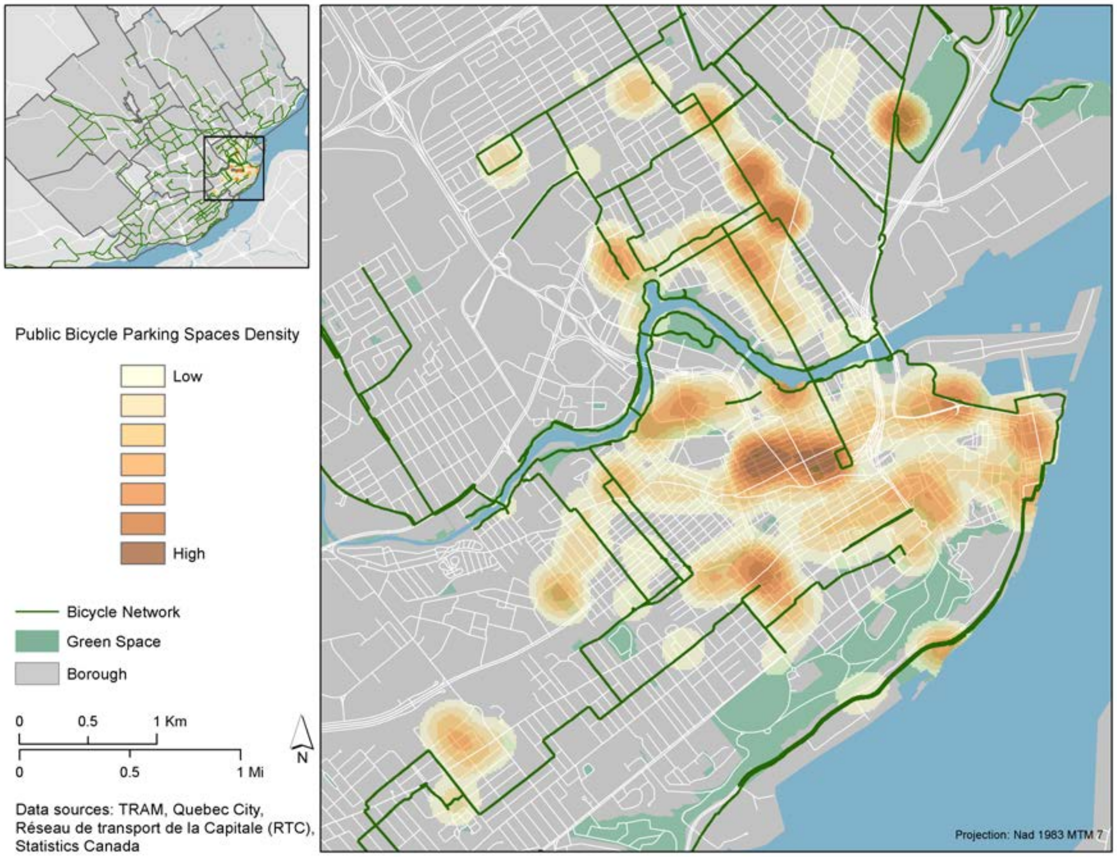

Figure 1: Location and density of municipal bicycle parking spaces in 2017

2.4 METHODOLOGY, DATA AND RESULTS

Our method consists of a multi-criteria approach to prioritize the location of new long-term and short-term bicycle parking. A flow chart illustrating the main steps of our analysis is displayed in Figure 2. Using data of the destinations of existing and potential cyclists, as well as the proximity of the bicycle network to high frequency bus stops, we developed a priority index for locations with the highest need for new bicycle parking. A second priority index is then developed that identifies where long-term bicycle parking is needed among the locations identified in the previous step. Finally, the number of recommended bicycle parking spaces for these locations is calculated, taking into account the current supply of bicycle parking. We generate two priority maps, one for long-term and one for short-term bicycle parking needs in the region. The data employed in our analysis will be described in further detail in the following section.

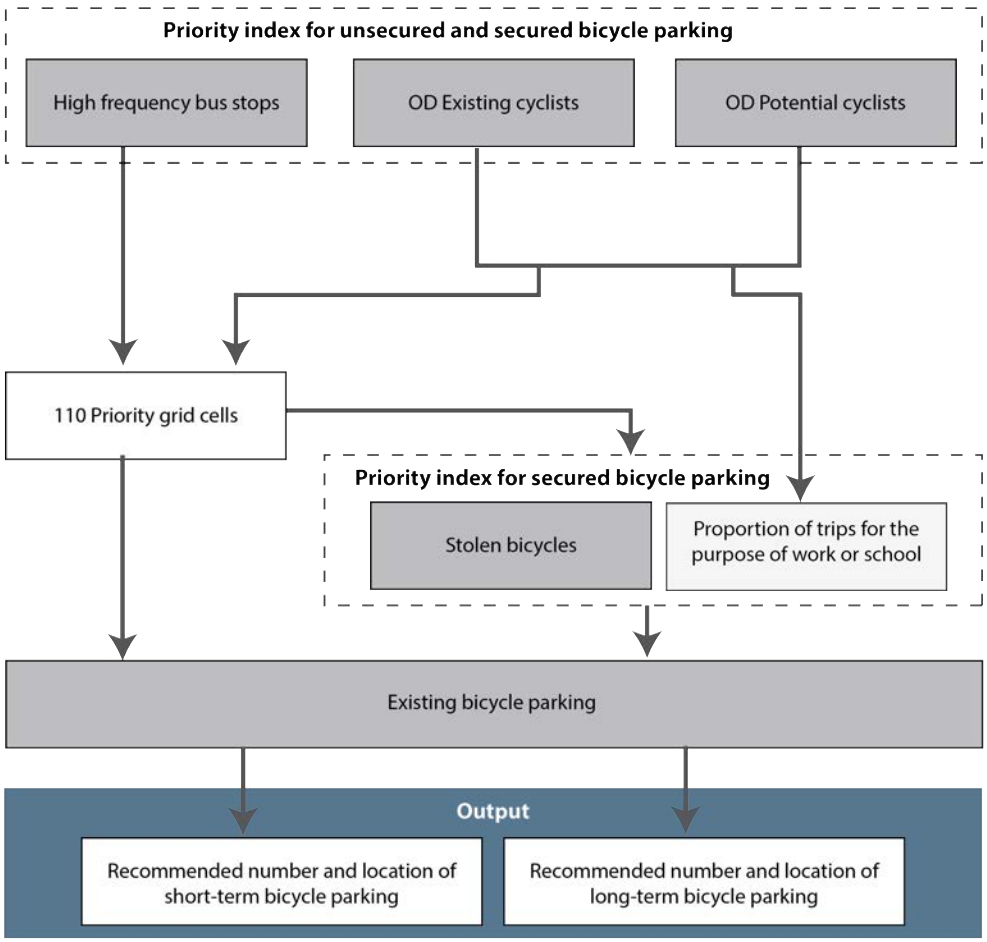

Figure 2: Flow chart of main steps in methodology

2.4.1 Data Sources

The first data source used in our analysis is the 2011 Quebec Origin-Destination Survey (OD), which collects information regarding trip purposes, modes, socio-demographic characteristics and the origin and destination of each trip from respondents. OD Survey data is collected every five years by phone and samples between 7 to 20 % of all households living in the city between September and December (Ministère des Transports du Québec, 2015). The second source of data used is the location of bus stops served by high-frequency bus routes called Metrobus. Metrobuses operate every 10 minutes during weekday peak hours. High frequency bus stops were used in this analysis, as Quebec City does not have a subway or light rail service. The data was extracted from the transit agency serving the City of Quebec's territory, called *Réseau de Transport de la Capitale* (RTC). The third and fourth data are the number of bicycle parking racks and spaces owned by the City of Quebec and the current bicycle network obtained from the City of Quebec. Our analysis only considered the number of public bicycle racks, since data on privately owned bicycle parking was unavailable. Due to data unavailability and because the City has a limited influence on the decision to add bicycle parking on university campuses, we excluded Laval University from our analysis, although it is a major cycling destination and requires its own specific analysis. The last data used in this analysis was the 2015 Bicycle Travel Survey conducted by the Transportation Research at McGill (TRAM) group. We extracted two questions from this survey. First, cyclists were asked if they had a bicycle stolen in the past, and if so, respondent ware asked to identify the location where it was stolen.

2.4.2 Prioritization Index for New Bicycle Parking

Using the fishnet tool in ArcGIS, the first step was to generate a grid that covered the extent of our study area, which was adapted from a previous study (Larsen et al., 2013). The selected size of each grid cell was 300 by 300 meters. This size was found optimal to aggregate multiple criteria, such as the proximity of the bicycle network and the destinations of existing and potential cyclists. The same grid cell size was employed by Larsen et al. (2013), however practitioners interested in reproducing our methodology can choose a grid cell size that corresponds to their own city structure. We removed all cells that had their centroid outside the boroughs of Quebec City and within Laval University Sainte-Foy campus, which resulted in a working grid composed of 5,185 cells.

To identify and prioritize the best locations to install new bicycle parking, the first step consisted of generating a prioritization index. The index is composed of three indicators: 1) the destinations of existing cyclists, 2) the destinations of potential cyclists, and 3) the proximity to high frequency bus stops served by the *Société de transport de la Capitale*. The description of each indicator is presented below.

2.4.2.1 Existing Cyclist's Destinations

The first indicator used is the number of trips made by cyclists ending in each of the 5,185 grids. We used only home-based trips from the 2011 OD survey for all trip purposes. A total of 415 destinations were geocoded using x-y coordinates from the OD Survey. Next, we applied the expansion factor of each of these trips, to account for the expected magnitude of individuals in Quebec City making these trips. The expansion factor is described as a "sample weight" given to each trip according to their sample strata, and has the ability to adjust for potential bias introduced by the time and day that interviews took place or by underrepresented trips (Ministère des Transports du Québec, 2015). After applying the expansion factor, a total of 5,918 trips made by cyclists were spatially joined to our working grid. Finally, we standardized the number of existing cyclists' trips ending in each grid cell with a Z-Score to enable the combination of this measure with others generated later in the study. The distribution of the destinations of existing cyclists is displayed in Figure 3A, which shows that their destinations are highly concentrated in downtown Quebec.

2.4.2.2 Potential Cyclists' Destinations

The second indicator is the number of potential cyclists ending their trip in each of the grid cells using the 2011 OD Survey. Within the context of our study, a potential cyclist trip is defined as a short-distance non-cycling trip which could be converted into a bicycle trip. Specifically, we used a threshold distance of 5.8 kilometers, which corresponds to the 75th percentile distance of all commuting bicycle trips evaluated from the OD 2011 survey. These short distance trips by bicycle would on average take 22 minutes at a pace of 16km/h (El-Geneidy, Krizek, & Iacono, 2007). We calculated the trip length of these potential cyclists using a straight-line distance for simplicity between each origin and destination.

We adjusted the number of potential trips ending in each grid cell according to the expansion factor provided in the 2011 OD Survey. A total of 23,844 potential cyclist trips were extracted from the OD survey, which corresponds to 337,928 trips after applying the expansion factor. These trips were then spatially joined to the grid cells. Finally, we standardized the number of potential cyclists' trips ending in each grid cell with Z-Score. The results are shown in Figure 3B. Compared to the destinations of existing cyclists, the distribution of potential cyclists is more dispersed across the City of Quebec, however a similar high priority corridor in downtown Quebec is observed.

2.4.2.3 Number of Bus Stops

The last indicator used in our priority index is the number of bus stops served by high-frequency bus routes, named Metrobus. We incorporated proximity to these bus stops to improve the integration of bicycling and public transit. Metrobus service consists of six high-frequency bus routes that are equipped with bicycle racks holding a maximum of two bicycles, and are the only bus routes operated by RTC equipped with bicycle racks (Réseau de transport de la Capitale (RTC), 2017). These bus routes are the most efficient public transit routes to reach the main employment and activity nodes in Quebec City. However, it is recommended to adapt our proposed method based on the local supply of public transit service, for example, by using subway stations instead of bus stops or using both high frequency bus routes and rail stations.

Using the RTC data, we identified 231 bus stops served by high-frequency bus routes. To avoid duplicating the number of bus stops, we only considered bus stops serving one direction. We then generated a buffer of 100 meters around each of them, and spatially joined these buffers with the grid cells, which enabled us to systematically sum the number of bus stop buffers intersecting each grid cell. The results were standardized using a Z-score and are shown in Figure 3C.

2.4.2.4 Combining and Weighting Indicators into an Index

We combined and weighted the three standardized indicators into one bicycle parking index. To arrive at our final index, we used a weighting scheme, where we applied a higher weighting to the destinations of existing cyclists, namely a weighting of 3, and a weighting of 1.5 to potential cyclists. Whilst all three indicators are important, we decided to give more importance to existing cyclists' destinations to prioritize the current needs of bicycle parking. However, the application of a weighting scheme should vary according to a region's specific priorities or planning goals. The potential cyclists' trips are given a weight of 1.5 as we also wished to plan for potential needs of cyclists in a medium-term perspective. Finally, the number of bus stops was integrated without any weighting. The combined and weighted priority index result is displayed in Figure 3D.

After determining the priority areas for new bicycle parking, we identified grid cells falling within the top decile of the combined and weighted index, and selected which of these high priority areas are within 100 meters of the existing bicycle network. This resulted in 110 grid cells that are within proximity of a bicycle network. After locating these high priority areas for the installation of new bicycle parking, we first need to determine the recommended number of spaces that need to be installed in these grid cells, and second we consider where are the optimal locations to install new long-term bicycle parking within these grid cells.

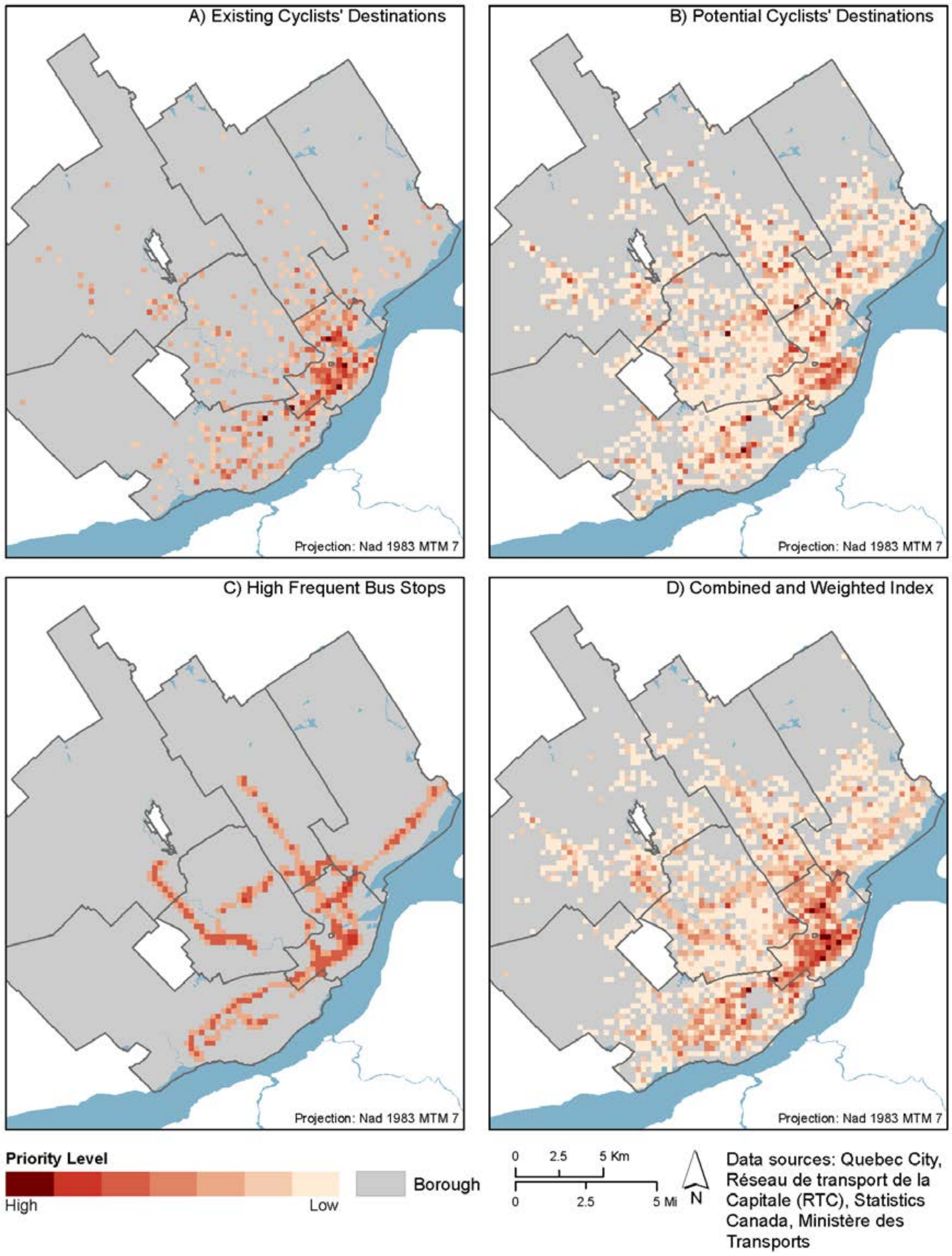

Figure 3: Standardized indicators and Combined and Weighted Index

To estimate the number of bicycle spaces needed in these high priority grid cells, we summed the number of trips made by existing cyclists and 10% of the trips made by potential cyclists that end in each grid cell. Ten percent of potential trips assumes a moderate mode shift from potential cyclists in the medium future. We then subtracted the bicycle parking demand, identified in the above step, from the existing public parking spaces. Figure 4 presents the final 110 grid cells of high priority for bicycle parking and the recommended number of new bicycle parking spaces in each grid. These locations can be mainly short-term (bicycle racks), if a region wants to propose long-term bicycle parking more analysis is needed and this will be explained in the following section.

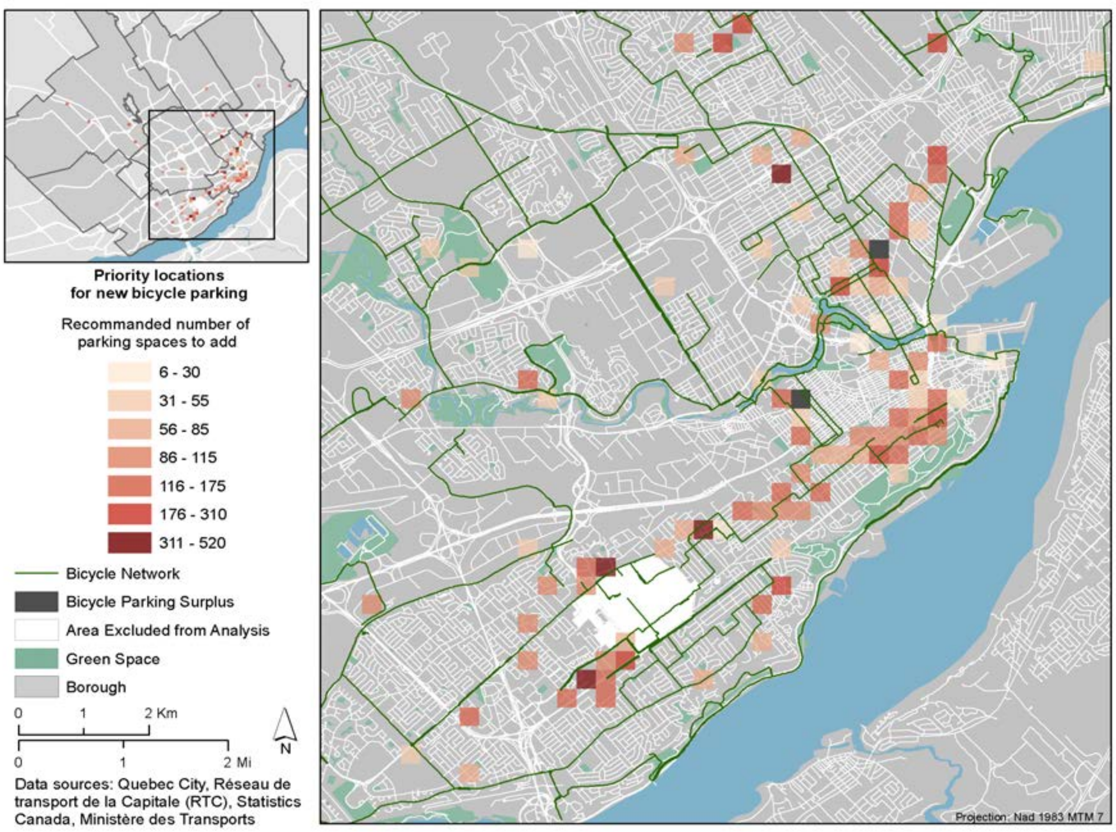

Figure 4: Priority locations to add new bicycle parking and recommended number of bicycle spaces to add

2.4.3 Long-term Bicycle Parking Index

Using the high priority bicycle parking locations identified above (Figure 4), we next developed a priority index to determine the best locations to invest in long-term bicycle parking. The indicators considered for the prioritization of secured bicycle parking include the location of stolen bicycles and the proportion of existing and potential trips ending in each priority grid cells that are work or school trips (please refer to Figure 2 methodology overview).

Using the 2015 Bicycle Travel Survey conducted by the Transportation Research at McGill (TRAM) group, we geocoded the locations where respondents reported a stolen bicycle. We then spatially joined each location of a reported stolen bicycle to the 110 priority grid cells and summed the total number of bicycles stolen per grid cell. Finally, we standardized the number of stolen bicycles in each grid cell using a Z-Score. The results are shown in Figure 5A.

We then evaluated trips made by existing and potential cyclists for the purpose of commuting to work or school. Specifically, we calculated a ratio of trips to work or school compared to trips for all other purposes (i.e. shopping, grocery, health). Cyclists who commute to work or school require access to bicycle parking for a longer time, and the availability of long-term bicycle parking for this type of trip has been found to be an important determinant for cycling to work (Hunt & Abraham, 2007; Rietveld & Daniel, 2004; Taylor & Mahmassani, 1996; Yan & Zheng, 1994). Accordingly, we want to prioritize locations with higher ratios of work or school trips, as a strategy to encourage more individuals to cycle to work or school. We standardized the ratios of the high priority grid cells separately for existing and potential cyclists, and the results are shown in Figures 5B and 5C.

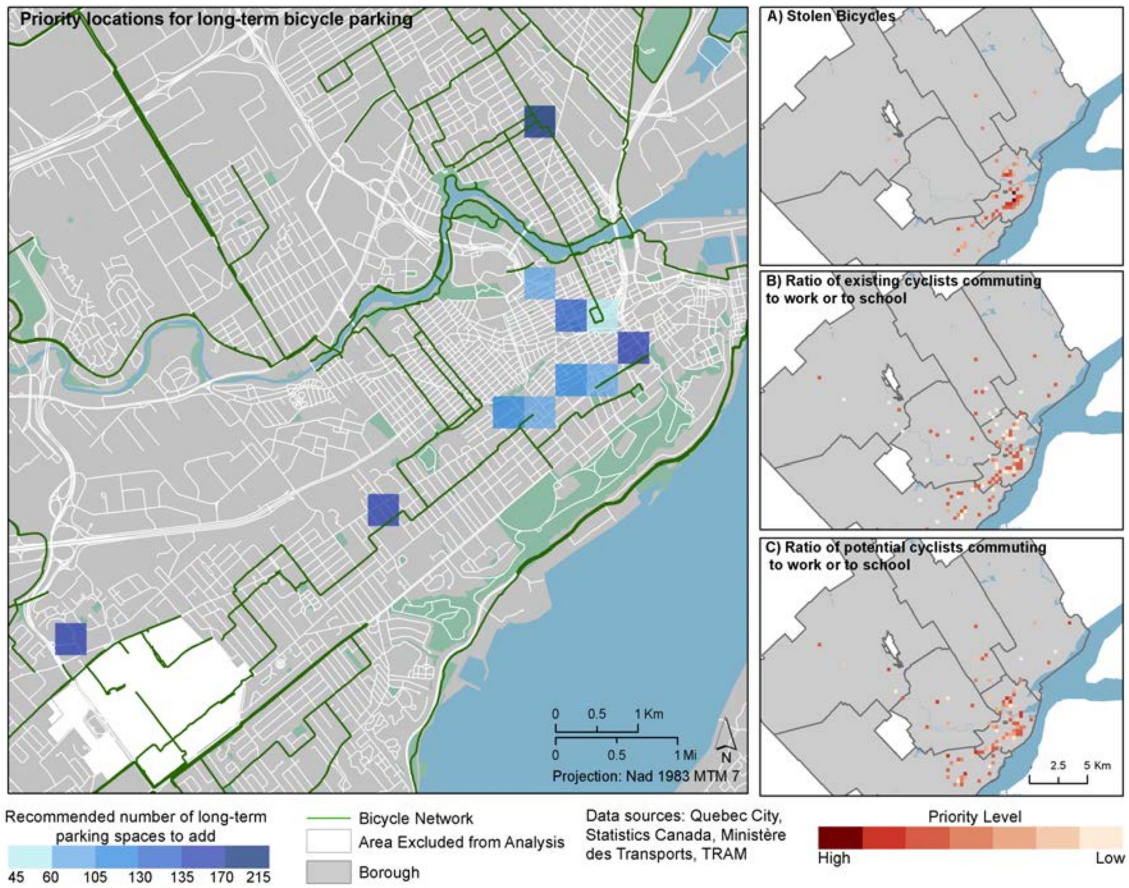

Figure 5: Standardized indicators for the long-term bicycle parking index

2.4.3.1 Combining and Weighting Indicators into an Index

To generate our secured parking index, we combined and weighted the three standardized indicators. While all three indicators were selected because of their importance for planning for new long-term bicycle parking, we decided to give more weight to the number of stolen bicycles, knowing that the perceived risk of bicycle theft can discourage individuals from using their bicycle (Rietveld, 2000;

Rietveld & Daniel, 2004). Accordingly, a weighting of 3 was attributed to this indicator. The ratio of existing cyclists commuting to work or school was assigned a weight of 2 and the ratio of potential cyclists commuting to work or school was assigned a weight of 1.5. With such criteria, we prioritize locations for investments in long-term bicycle parking in areas where we know there are cyclists currently commuting, however the weighting attributed to potential cyclists was not considerably lower, since we would hope that access to secure bicycle parking would lead to a major mode shift towards cycling.

The cells falling in the top decile of the combined and weighted index were identified as priority locations for investment in long-term bicycle parking. To recommend the number of secured bicycle spaces in each cell, we calculated the optimal number of spaces using the same method as the short-term bicycle parking. We calculated the difference between the number of existing bicycle parking spaces and the current and potential cycling demand in each grid cell, where we estimated the demand to be the number of existing cyclists whose trip ends in each grid cell plus 10% of all potential cyclists whose trips end in each grid cell. The recommended locations and number of long-term bicycle parking spaces to be installed are displayed in Figure 5. It is important to note that this step can be adjusted if there is an existing supply of long-term bicycle parking in a region.

2.5 DISCUSSION AND CONCLUSION

The objective of this paper was to develop a practice ready GIS-based method to identify optimal locations to add both short-term and long-term bicycle parking, which aims to be flexible and easily adaptable to different contexts. Using the City of Quebec as a case study, we first divided the city into 300 by 300 meter grid cells. The use of grid cells is recommended in this kind of analysis as it guides planners to areas according to needs, providing them with latitude to closely evaluate this zone and find the appropriate location based on the existing land use. This work must be followed by more detailed analysis to locate bicycle parking spaces within the identified grid cells, which requires more local knowledge that can only be present among local planning authorities. We generated the prioritization index for new bicycle parking according to what factors were identified as likely to contribute to the need for new long-term or short-term parking, namely the destinations of existing and potential cyclists and proximity to high frequency transit service. While we did not consider linked trips of existing and potential cyclists, practitioners and researchers could include them to tailor our method according to their needs. These indicators were then combined and a weighting scheme was applied, which is recommended to be devised according to the objectives or local planning goals and priorities of a region. Finally, we only selected grid cells within 100 meters of the existing bicycle network, to prioritize locations that contribute the most to the development of a complete cycling network and to ensure high usage levels of these newly proposed facilities. The recommended number of parking spaces for each grid cell was then calculated according to the existing supply of parking and the existing and potential demand for bicycle parking. For the recommended priority locations of long-term bicycle parking, we developed a priority index which considered the location of stolen bicycles and grid cells with high proportions of existing and potential cyclists commuting into each grid cell. The number and the type of indicators utilized could be tailored to other regions according to data availability and policy goals. Moreover, the weighting scheme applied to each indicator could also be modified according to different contexts and local planning goals and priorities.

The strength of our method lies in its flexibility and ability to account for long-term demand for bicycle parking as we specifically consider work and school trip purposes, as access to these secured bicycle facilities have been shown to encourage cyclists to commute to their workplace or school (Hunt & Abraham, 2007; Rietveld, 2000; Taylor & Mahmassani, 1996). Long-term bicycle parking is expected to be an integral part of the improvement of Quebec City's bicycle network, and is expected to help Quebec reach its goal of providing residents with a safe and connected bicycle network to attract and encourage cycling for everyday purposes, such as commuting.

It is important to note that our methodology to locate long-term bicycle parking, proceeded under the assumption that such facilities will be provided for free to users. As many regions provide these facilities to users for a fee, demand will need to be adjusted according to the willingness of cyclists to pay for access to this service. Knowledge of cyclists' willingness to pay for long-term bicycle parking can be the subject of a future study.

3. CHAPTER 3: Does one facility type fit all? Evaluating the stated usage of different types of bicycle facilities among cyclists in Quebec City, Canada

3.1 INTRODUCTION

Previous research has uncovered the importance of providing cycling facilities in order to increase bicycle usage (Buehler & Dill, 2016; Pucher et al., 2010). Bicycle facilities with greater separation from motorized traffic, as widely built in Copenhagen, are recognized to be preferred by a high number of cyclists (Broach et al., 2012; Buehler & Dill, 2016; Tilahun et al., 2007). Many cyclists are willing to diverge from their shortest route to use a preferred cycling facility (Broach et al., 2012; Buehler & Dill, 2016; Larsen & El-Geneidy, 2011; Tilahun et al., 2007). However, cyclists are not a homogenous group of individuals (Damant-Sirois et al., 2014; Dill & McNeil, 2013, 2016; Geller, 2006). Studies have revealed that among cyclists, unique groups are distinguishable according to their cycling facility preferences, motivations, experience, habits, etc. (Damant-Sirois et al., 2014; Li et al., 2013).

Performing a cyclist segmentation can help practitioners to uncover what cyclists preferred in terms of cycling facilities, thereby ensuring that newly built cycling facilities meet existing users' preferences, and that these are ultimately being utilized (Handy, van Wee, & Kroesen, 2014). This segmentation approach constitutes a planning tool that can inform planners on the optimal type of cycling facilities to invest in, which is particularly crucial for municipalities with scarce financial resources. As the construction of physically separated bicycle lanes generally require higher capital investments than other facility types, tradeoffs are often necessary between the choice of the cycling facility type to build and the possibility to add more kilometers of lanes to the existing cycling network. What type of cycling facility a municipality should build in order to increase cycling levels and make most of its investments? Are high capital investments in physically separated bicycle paths needed to transform cities into a bicycle paradise?

This study aims to predict the usage of different cycling facilities among various types of cyclists, while cyclists have reasonable access to a facility type. We define reasonable access as the maximum area (m^2) around each facility, inside which it is deemed reasonable to divert from the shortest route to reach a preferred cycling facility. This study employed a similar segmentation approach to the one developed by Damant-Sirois et al. (2014) who used a factor and *K*-means cluster analysis to divide cyclists into groups. Yet our paper differs from this study as it utilizes different variables to segment cyclists, and employs a different survey, which was conducted in another urban context.

This paper is divided in four sections. We will first explore the existing literature on cyclists' segmentation techniques and on the preferences of bicycle facilities among cyclists, which will be followed by a description of the data employed in this chapter. We will then present the methods used in our analysis and our findings. Finally, we will provide recommendations and highlight the implications of our results.

3.2 LITTERATURE REVIEW

3.2.1 Segmentation approaches

Over the past decades, a broad body of literature examining travel behavior has employed segmentation techniques to help formulate effective recommendations to increase bicycle usage. While cyclists are not a homogenous group of individuals, understanding cycling facility preferences and how these preferences differs for each type of cyclists is a keystone for successful active transportation planning (Damant-Sirois et al., 2014; Piatkowski & Marshall, 2015). Examples of cyclists' typologies include Jensen (1999) who grouped Danish survey participants into six mobility types, among which, cyclists and public transit users were categorized as *Cyclists/Public Transport Users at Heart*, *Cyclists/Public Transport Users of Convenience*, *Cyclist/Public Users of Necessity*. Moreover, Bergström and Magnusson (2003) classified Swedish cyclists into four groups based on cycling frequency levels and seasonality usage: *Winter Cyclist*, *Summer-Only Cyclist*, *Infrequent Cyclist* and *Never Cyclist*.

There are two main segmentation approaches that are commonly applied in both cycling research and by practitioners, as mentioned in Cote and Diana (2017) and Damant-Sirois et al. (2014). **The first approach** is to determine *a priori* a number of types of cyclists before analyzing a dataset or to adapt an existing typology, to thereafter make cyclists fit into these pre-defined categories. Geller's well-known and widely used typology was created in this fashion. In Geller's segmentation approach, individuals are classified into four types: *No Way No How, Interested But Concerned, Enthused and Confident, and Strong and Fearless* (Geller, 2006). Additionally, this segmentation approach includes both non-cyclists and cyclists, which can be somewhat confusing in interpreting the outcomes of Geller's approach. Dill & McNeill (2013 and 2016) 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* cities and urban context, despite acknowledging differences in cycling facility supplies and in the modal split between the studied areas. Generalizing one approach to all urban settings might not be a guarantee of success, as per Damant-Sirois et al. (2014)'s observations.

The second segmentation approach commonly employed by researchers utilizes empirical techniques, such as *K*-means clustering and principal component analysis, upon which a dataset is segmented into groups, and relationships are designed accordingly. These techniques are utilized, for example, by Cote and Diana (2017) and by Kruger, Myburgh, and Saayman (2016). Other studies include Gatersleben and Haddad (2010) who found four distinct types of cyclists' stereotypes in England : *Responsible Bicyclists*, *Lifestyle Bicyclists*, *Commuter Bicyclists*, and *Hippie-Go-Lucky Bicyclists*. Li et al. (2013)

used the 2009 City of Nanjing (China)'s Household survey to create six distinct types of commuters cycling to work according to their "willingness to bicycle, need for fixed schedule, desire for comfort and environmental awareness". Cycling facility improvements tailored to each type of cyclist, such as alleviating bicycle network disconnection, increasing the cycling network density, better integrating cycling facilities with land use were recommended (Li et al., 2013). Finally, Damant-Sirois et al. (2014) distinguished four groups of cyclists living in Montreal according to stated cycling facility preference, motivation, deterrent and social encouragement: *Dedicated Cyclists*, *Path-using Cyclists*, *Fairweather Utilitarians* and *Leisure Cyclists*.

Preferences for cycling facilities vary among cyclists based on trip purposes, motivations, gender and experiences (Heinen, van Wee, & Maat, 2010; Hunt & Abraham, 2007; Larsen & El-Geneidy, 2011). Some studies reveal that cyclists prefer using facilities separated from motorized traffic, such as bicycle lanes, bicycle tracks, and bike paths (Akar & Clifton, 2009; Buehler & Dill, 2016). Additionally, cyclists who commute to work appeared slightly more reluctant to cycle in busy mixed traffic than those who cycled for other purposes, mainly because many cyclists travel at peak hours, a period with high-motorized traffic volume (Broach et al., 2012). The characteristics of an intersection, such as the design, the presence of street lights, stop signs, and the travel speed also influence cyclists' route choice (Kircher, Ihlström, Nygårdhs, & Ahlstrom, 2018). In

Copenhagen, Vedel, Jacobsen, and Hans (2017) found that cyclists are willing to cycle 1.33 km further out of their way to avoid strops.

Other studies found contrasting results with these aforementioned findings, which demonstrates the importance of analyzing cautiously cycling preferences in relation to the studied area's specific characteristics (Buehler & Dill, 2016). For example, individuals who cycle on a regular basis for utilitarian purposes in Montreal are 64% less likely to use cycling designated facilities (Larsen & El-Geneidy, 2011). In a similar vein, *Dedicated Cyclists* in Montreal tend to prefer non-exclusive bicycle facilities and appear to be more willing to cycle in car traffic (Damant-Sirois et al., 2014). Moreover, studies reveal that woman preferred cycling on facilities with greater separation from traffic (Aldred & Dales, 2017), while other research did not find significant differences in facility usage for gender and age (Broach et al., 2012; Larsen & El-Geneidy, 2011). In reality, physical characteristics, design, location and conditions of bicycle facilities may be different according to specific urban settings (Buehler & Dill, 2016), which can partly explain these contrasting findings.

3.2.2 Types of facilities and their impacts

Painted bicycle lanes are recognized as a facility that separates cyclists from motorized traffic by lanes directly painted on the road pavement (Buehler & Dill, 2016; Pucher et al., 2010) (Figure 6). Dill and Carr (2003) examined 42 US cities and found that the increase on-street bicycle lanes (i.e.: "striping, signing, and pavement markings for the preferential or exclusive use of bicyclist") was associated with higher cycling levels for commuting purposes. However, Broach et al. (2012) found that individuals in Portland are willing to cycle greater distances to use a bicycle boulevard or a bicycle path rather than a bicycle lane, as most of bicycle lanes are located along arterial roads. This study indicates the importance of considering the urban surroundings of a cycling facility, and not only the design in itself (Broach et al., 2012). Moreover, not all types of bicycle painted lanes are perceived equally. For example, painted lanes running in the opposition traffic direction are the least preferred cycling facilities in Montreal, Canada (Damant-Sirois et al., 2014).

Figure 6: Example of a painted bicycle lane. Source: TRAM

Separated bicycle lanes/paths, also referred to as cycle tracks or protected lanes, are characterized by a median or curb that physically separate cyclists from traffic (Buehler & Dill, 2016; Pucher et al., 2010) (Figure 7). The exhaustive literature review of Buehler and Dill (2016) demonstrates that this facility type is the most preferred one according to several studies using stated and revealed preference surveys. Using a stated preference survey, Vedel et al. (2017) found that cyclists are willing to cycle an additional 1.84 km to use a cycle track, which designates both separated lanes by a curb or by a painted lane. In Denmark, the presence of a separated bicycle lane along a cyclist's route increased the odds of a cyclist to have an overall positive cycling experience, whereas cycling on primary or secondary roads decreases the likeliness of a cyclist to have a positive experience (Buehler & Dill, 2016; Snizek, Nielsen, & Skov-Petersen, 2013). Using a GPS device, a study revealed that cyclists living in Portland have a preference for separated bicycle paths (Broach et al., 2012). Finally, regarding the real impact of these facilities on safety, a recent study by Lusk et al. (2011) conducted in Montreal found that cycling on bidirectional facilities had the effect to reduce the risk of injuries or crashes compared to using a street with no facilities. In areas where using this facility type did not reduce the risk of injuries or crashes, it also did not worsen cyclist safety.

Figure 7: Example of a separated bi-directional lane . Source: TRAM

Cycling Paths *are* off-street facilities in parks or along a waterfront that also refers to as trails or recreational paths (Buehler & Dill, 2016; Pucher et al., 2010) (Figure 8). Tilahun et al. (2007) found that cyclists are willing to cycle twenty minutes more than their shortest route in order to use an off-road bicycle trail instead of being on an on-road facility. In Minneapolis (Minnesota), Krizek, El-Geneidy, and Thompson (2007) found that cyclists were increasing their travel time on average by 67% in order to reach an off-street bicycle path.

Figure 8: Example of a cycling path. Source: TRAM

In addition to observed and stated preferences of some cyclists towards using specific types of cycling facilities, some cyclists are willing to divert from their shortest route to use a preferred cycling facility and to avoid steep topography (Broach et al., 2012; Larsen & El-Geneidy, 2011; Tilahun et al., 2007; Winters, Teschke, Grant, Setton, & Brauer, 2010). Winters et al. (2010) uncovered that cyclists in Vancouver travelled on average 350 meters more than their shortest route. Moreover, the longer a trip is, the further a cyclist is willing to divert from its shortest route (Broach et al., 2012).

To our knowledge, no study has predicted the odds of cyclists type to use a particular bicycle facilities while having reasonable access to it. Krizek and Johnson (2006) examined the odds of increasing cycling in Minnesota when respondents lived in proximity of an on-street bicycle lane or off-street trail. Using

GIS, the authors calculated the Euclidian distance between home location and each type of bicycle facility (Krizek & Johnson, 2006). Whilst, Moudon et al. (2005) conducted a logistic modelling analysis to understand built environment determinants on the odds of cycling for all trip purposes in King County, Washington. The study examined two ways to assess the effect of having a cycling facility at proximity on cycling usage; the first one is the straight-line distance from home to the closest cycling trail, and the second one is the presence of facilities within a 3 km buffer around home location (Moudon et al., 2005). Neither of these studies focused on the odds of usage of each specific cycling facility type. Instead, they uncovered the effect of proximity of various facility type on cycling levels. Moreover, they do not precisely consider the possibility that a cyclist can divert all along their way, rather than solely modifying their route around their residence to reach a preferred bicycle facility. Other studies examined cyclists' route choice, using stated preference survey and GPS devices, in order to compare the facility used to the computed shortest paths (Broach, Gliebe, & Dill, 2009). These studies used the entire cyclist population as a homogenous group. Our study tries to fill this gap by first segmenting utilitarian cyclists into distinct types and then by predicting the odds of using a cycling facility through an analysis of a stated preference survey. We propose a methodology to account for potential access to cycling facilities when only a respondents' origin and destination are available.

3.3 DATA

This study employed data collected in the 2015 Quebec City Bicycle Travel Survey, which was conducted by the Transportation Research at McGill (TRAM) group in collaboration with Quebec City. 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 were the importance of various factors in cyclists' decision to cycle and whether or not each respondent reported using each facility. Each bicycle facility type that was included in the survey was accompanied by a picture to ensure that respondents associated the right facility type to each question while completing the survey.

A total of 1823 full responses were collected in this survey. We excluded respondents that did not provide their home, workplace or school geographic locations (e.g. postal codes). Additionally, we omitted respondents that cycled for recreation and grocery shopping purposes only. Moreover, we did not consider respondents who travelled less than 1 km to reach their workplace or school. As a result, our sample is composed of 877 home and work/school cycling trips that are more than 1 km in length.

To obtain information about the bicycle facilities present around the route of each respondent, we used a shapefile of the bicycle network that was present in 2015. In this shapefile, cycling facilities were classified into four categories: bi-directional path, painted bicycle symbol, painted lane and shoulder. Data cleaning was performed to ensure that the cycling facility questions and their associated pictures matched the shapefile facility classification. As a result, three types of facility were selected to conduct further analysis: recreational path, bi-directional path and painted lane (Figure 9). We omitted from our analysis painted bicycle symbols as we were unable to match this facility type, present in the shapefile facility classification, with the survey questions. Moreover, we did not consider shoulders as they remain rather marginal.

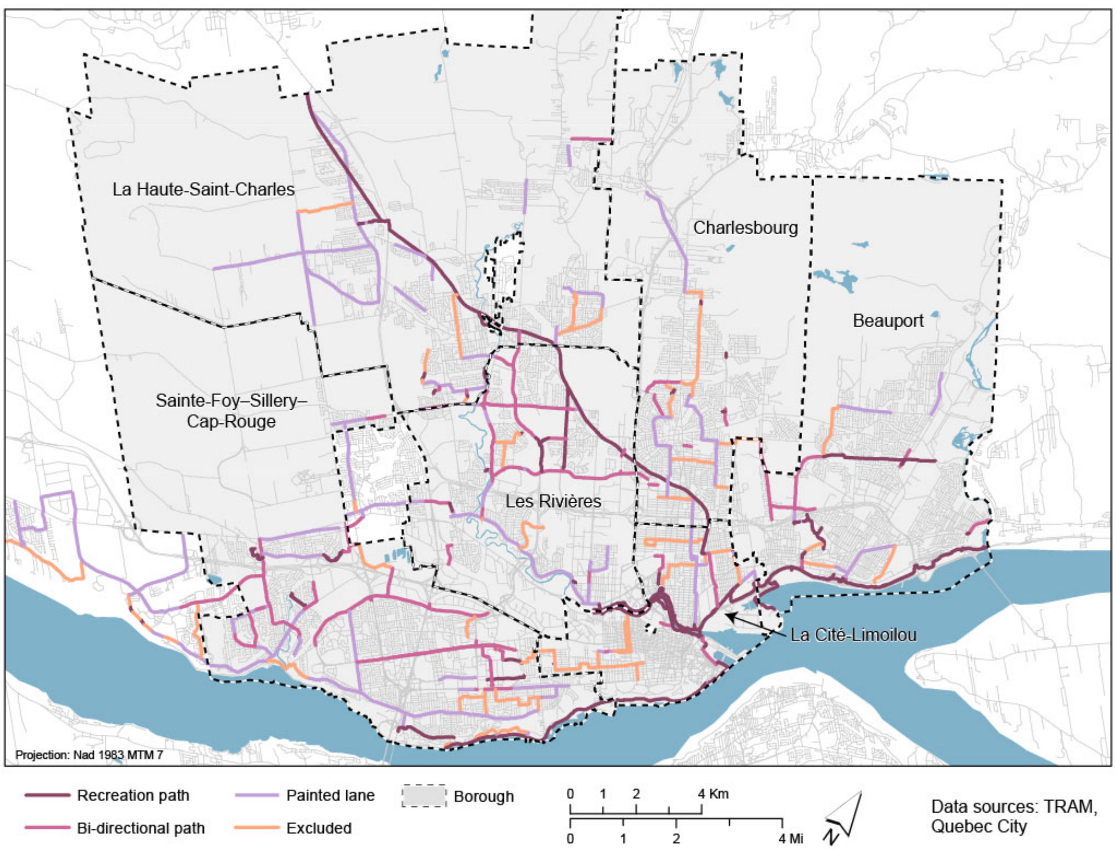

Figure 9: Location of recreational paths, bi-directional paths, and painted lanes in Quebec City, Canada

Table 1 summarizes the characteristics of the bicycle facilities in Quebec City. 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 facility are present, but are not being considered in the present research.

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

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.

3.4 ANALYSIS

Our analysis consists of a three-step procedure (Figure 10). First, we performed spatial analysis using ArcGIS to determine what types of bicycle facilities each respondent have reasonable access to, when commuting to work or school. In a second step, we carried out a factor analysis followed by a *K*-means cluster analysis to segment cyclists into distinct groups according to their motivations, deterrents to cycle, childhood characteristics and cycling habits. Finally, three logistic regression models were constructed to predict the odds of whether or not each group of cyclists reported using recreational paths, bi-directional paths and painted lanes to commute to work or school, while having reasonable access to these facility types.

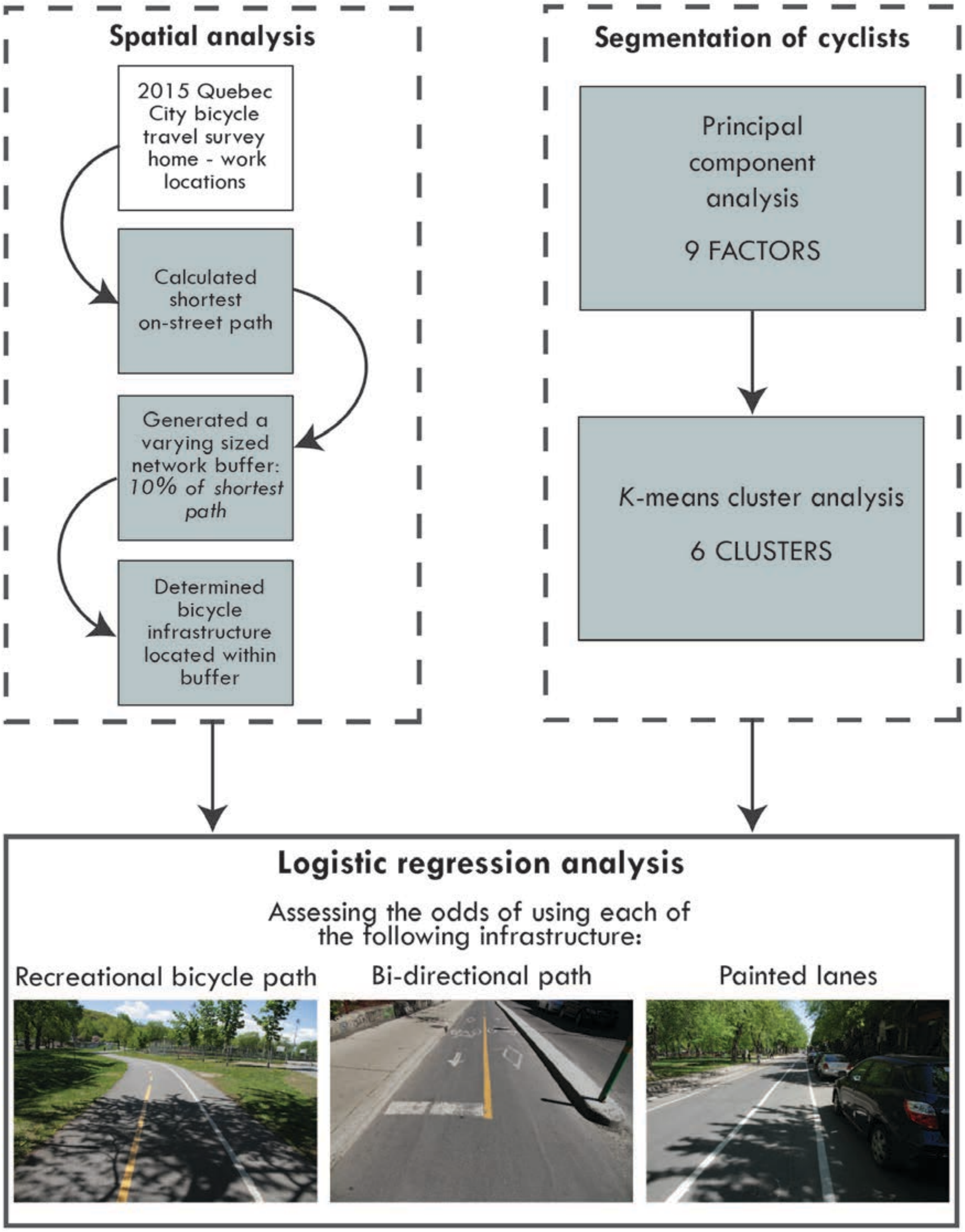

Figure 10: Analysis approach

3.4.1 Segmentation of cyclists

To segment our sample into distinct cyclist groups, we first conducted a principal component analysis (PCA) using satisfaction, motivation and habit related variables derived from the 2015 Bicycle Travel Survey. 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 that groups together responses that correlate among each other (Grisé & El-Geneidy, 2017; Washington, Karlaftis, & Mannering, 2011). 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 in SPSS (Grisé & El-Geneidy, 2017; van Lierop & El-Geneidy, 2017).

A total of 29 variables were grouped together to create 9 factors, which explained 59% of the variance. Table 2 shows the results of the principal component analysis, 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 in the principal component analysis. 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 (Damant-Sirois et al., 2014; Grisé & El-Geneidy, 2017). The final number of cyclist types was determined in an iterative fashion by evaluating the outcomes of different grouping options ranging from four to seven clusters. The number of clusters was decided according to criteria proposed by van Lierop and El-Geneidy (2017): 1- statistical output, 2- relevance and transferability to transport policy, 3- previous study, and 4-common sense and intuition.

Figure 11 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.

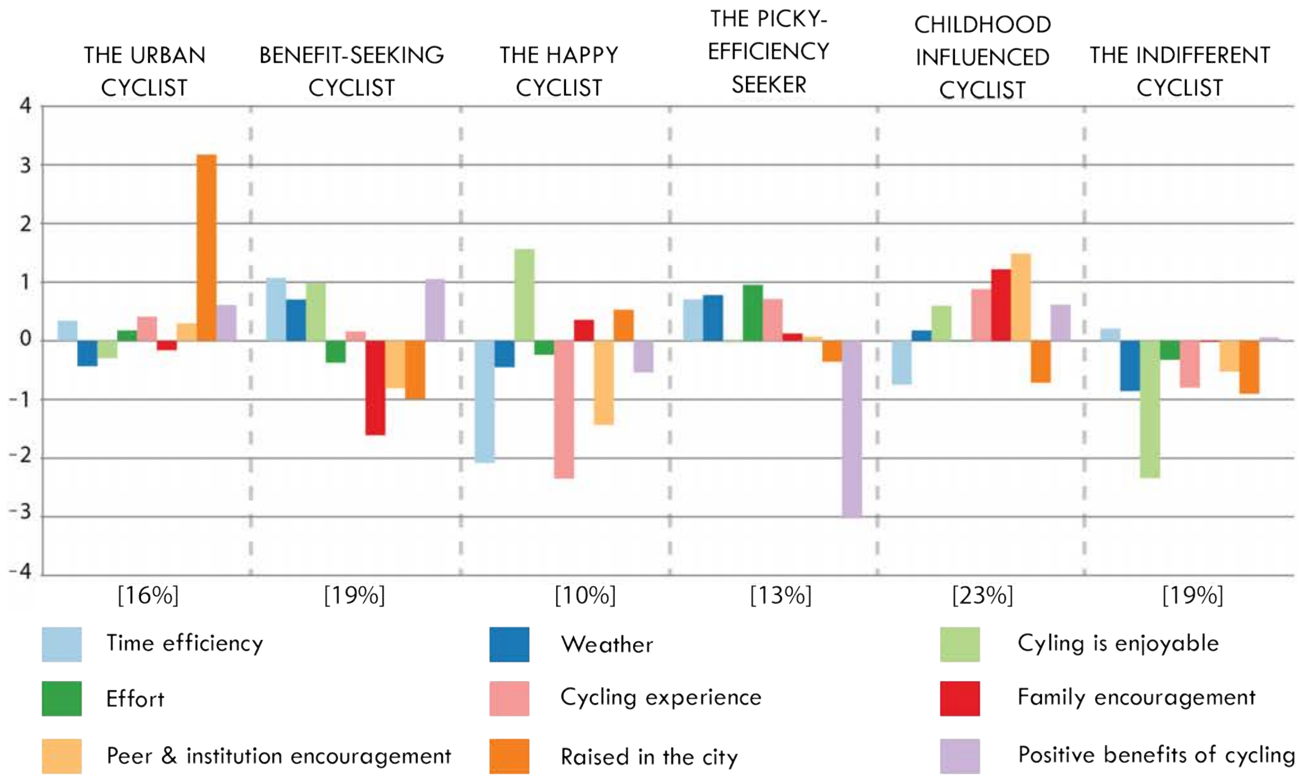

Figure 11: Cyclist segmentation derived from factor and cluster analysis

The urban cyclist – *16% of the sample* – is characterized by the predominance of individuals (75%) growing up in an urban environment. On average, they cycled 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 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. In fact, 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 it's snowy and the roads are covered in ice. Finally, in their childhood, *benefit-seeking 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, solely 30% used their bicycle to get around and 13% cycled to school when growing up. 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 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, which corresponds to 3.3 km less than the average commuting distance of *happy* *cyclists*. 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 affect negatively 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 and family or guardian encouragement. Finally, nearly 70% of this group grew up in a suburban environment, where cycling was not perceived as a common form of transport.

Our results stress the importance of producing a segmentation tailored to each urban context and according to planning goals. While Damant-Sirois et al. (2014) conducted a factor analysis followed by a *K*-mean cluster analysis in order to segment utilitarian and recreational cyclists in Montreal, important dissimilarities are observed between our study and this latter. The flexibility of the segmentation approach allows researchers and practitioners to utilize different variables according to a study objective and planning context. In fact, Damant-Sirois et al. (2014) employed 35 variables that were grouped into seven components, whereas our study utilized 29 variables that generated 9 factors. Moreover, Damant-Sirois et al. (2014) classified Montreal cyclists into four categories, while we obtained six types of utilitarian cyclists living in Quebec City. These differences can be explained by the fact that we did not consider in our factor analysis variables related to cyclists' facility preferences to avoid our segmentation interfering with our regression modelling analysis. It emphasis the relevance to undertake a segmentation analysis tailored to a specific urban setting, as cyclists and cycling network characteristics design may vary between cities.

3.4.2 Spatial Analysis

In order to determine what types of facilities a cyclist has access to when commuting to work and to include in our regression analysis cycling network variables, we performed spatial analysis using ArcGIS. We began our spatial analysis by georeferencing respondents' approximate home and work/school locations using the postal code provided by each respondent in the 2015 Bicycle Travel survey. We then produced a ready-to-use street network dataset.

Using these two shapefiles, we then modelled the shortest on-street route between each cyclist's home and school/work location using the Network Analyst extension in ArcGIS. Then, a street network buffer was produced around each cyclist's route to identify the maximum area (m^2) inside which it is deemed reasonable to divert from the shortest route to reach a preferred cycling facility. Note that we assumed that cyclists are willing to divert up to 10% of their shortest route to use a preferred facility. As such, to determine the buffer size, the length of each respondent's shortest route was multiplied by a diversion rate of 10 %. The outcome of this operation was employed to produce a personalized buffer around each respondent's route. More precisely, 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 shortest route's diversion rate previously calculated. Finally, buffers around points forming one route were merged together and were saved in a shapefile.

To identify the types of bicycle facilities that a cyclist has reasonable access to when commuting to work or school, we spatially joined the buffer shapefile aforementioned with the 2015 Bicycle Network shapefile. This operation was also used to determine the length (m) of each cycling facilities present within each buffer. A cycling facility was considered present within a buffer if the sum of all its segment's length equals 25 meters or above. By doing so, we ensured that a facility segment could be considered as a real potential option, in a cyclists' perspective, to divert from the shortest route to utilize it. This allowed us to determine whether or not each respondent had access to each facility type, so we can compare this to whether or not they reported using it.

Finally, to calculate the bicycle density within each route buffer, we summed the length of all bicycle facilities (m) located within one buffer and divided the result by the sum of the street length present within the same buffer. This ratio accounts for the range of possibilities, in terms of bicycle density and bicycle network density, one can take to commute to work or school by bicycle.

3.4.3 Logistic regression analysis

To predict the odds that each group of cyclists uses a recreational path, bi-directional path, or painted lane, we conducted 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?”. As per binary logistic modelling analysis requires, 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, neighborhood and personal characteristics.

Table 3 breaks down the percentage of cyclists according to facility type usage and reasonable access. 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 means that the majority of cyclists whose commuting route is in proximity to a bi-directional path decides not to cycle on this type of facility, even though such facility is within an acceptable diversion range (less than 10% of the total trip). It could also suggest that cyclists don’t necessarily value the safety added from physically separated bi-directional path to the extent that they are willing to divert from their routes to use them. This result indicates that other factors may also be important to influence facility usage than solely the facility design. In comparison, around a third of all cyclists who have reasonable access to recreational 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 no matter cyclists' access (%)	Have access and not reported using it (%)	Do not have access and do not use it (%)	Reported usage no matter cyclists' access (%)	Have access and not reported using it (%)	Do not have access and do not use it (%)	Reported usage no matter cyclists' access (%)	Have access and not reported using it (%)	Do not have access and do not it (%)
Urban cyclist (N=141)	50.4	30.5	19.1	29.1	53.9	17.0	61.7	23.4	14.9
Benefit-seeking (N=166)	51.2	30.1	18.7	25.3	59.6	15.1	59.6	25.9	14.5
Happy cyclist (N=91)	61.5	28.6	9.9	25.3	62.6	12.1	57.1	35.2	7.7
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 (N=202)	57.4	31.7	10.9	30.7	57.4	11.9	54.5	37.1	8.4
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

Table 4 presents the results of the three binary logistic regressions. Holding all other variable constants, **model 1** shows that the likelihood of using a recreational path to commute to work or school is 3.84 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 1.40 times higher when cyclists have reasonable access to this facility type than those who do not. However, this finding is not statistically significant, meaning that having access to a bi-directional bicycle lane 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 1.71 times higher for cyclists who have reasonable access to this facility type than for those who do not. When comparing models 1 and 3, the finding reveals that cyclists are more than twice as likely to use recreational paths when having reasonable access to it than cyclists who have a reasonable access to painted lanes. Note that in Quebec City, recreational paths are off-street facilities going through parks or other spaces that do not follow motorized traffic. On average, recreational paths are intersected by the street grid every 500 meters, compared to 400 meters for bi-directional-paths and 200 meters for painted lanes.

The results of these three models could also 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 (Broach et al., 2012). 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 solely 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.

Table 4: Likelihood of using each bicycle facilities by cyclists' types.

Variable	Odds Ratio					
	Mode 1 Recreational path		Model 2 Bi-directional path with median		Model 3 Painted lane	
Presence of infrastructure within route buffer†	3.84	***	1.40		1.71	*
Cyclist segmentation						
The urban cyclist†	1.34		1.25		0.88	
Benefit-seeking cyclist†	1.45		1.10		0.77	
The happy cyclist†	1.68		0.83		0.63	
Childhood influenced cyclist†	1.46		1.03		0.57	*
The indifferent cyclist†	2.13	**	1.24		0.58	*
Ref : The picky efficiency seeker†	-		-		-	
Trip characteristics						
Frequency of usage in the summer (work/school)	1.16	*	0.79	*	1.10	
Frequency of usage in the winter (work/school)	0.86		0.94		0.93	
Length of work/school commute (km)	1.07	***	1.08	***	1.06	**
Neighborhood characteristics						
Density of bicycle facilities within route buffer	1.04	*	1.05	*	1.05	**
How cycle-friendly is your current neighborhood in terms of infrastructure?	1.38	***	1.09		1.00	
How satisfied are you with the current investment in cycling infrastructure taking place in Quebec City?	1.26	**	1.13		0.94	
Personal characteristics						
Age 24 years and under†	0.17	*	0.76		0.93	
Age 25 - 64 years old†	0.25		0.72		0.30	
Ref Age 65 years and over	-		-		-	
Gender - Female†	0.85		0.53	***	0.86	

Dependent variable: Reported usage (1 = used and 0 = not used)
† Represents a binary dummy variable
* 95% significance level | ** 99% significance level | *** 99.9% significance level

Cycling Segmentation

Model 1 reveals that the odds of *Indifferent cyclists* to use recreational paths when commuting to work is 2.13 times higher compared to *Picky-efficiency* seekers. *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 reason under certain conditions.

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 this existing literature on how different types of cyclists have specific preferences in terms of bicycle facility. Note that for all groups, over 45% to 63% reported having access to bi-directional path but are not using it to commute to work. The design and locations of bi-directional path in Quebec City could perhaps explain this result, but further analysis would be required to understand.

In **model 3**, the odds of *Childhood-influenced cyclists* and *Indifferent cyclists* of using painted lanes are respectively 43% and 42% lower than picky-efficiency seekers. Both *Childhood-influenced cyclists* and *Indifferent cyclists* travel on average lower distances to reach their destination than *Indifferent cyclists*, which could potentially affect their willingness to divert further away from their shortest route to use painted lanes.

Trip, Neighborhood and Personal Characteristics

Commuting trip distance influences positively the odds of cycling on all cycling facility types. For every additional kilometer cycled, the odds of using recreational, bi-directional and painted lanes increase respectively by 7%, 8% and 6%. This finding suggests that cyclists commuting longer distances to work have more chances to use a bicycle facility, which is consistent with Larsen and El-Geneidy (2011). Based on our method, a greater trip distance increases chances of having cycling facilities within reasonable. Finally, a one category increase in frequency of usage in summer for work or school purpose, on a 5-likert scale, increases the odds of using a recreational path by 16% and decreases the likelihood of using bi-directional path with median by 21%. These results could be explained that cyclists try to avoid being near traffic and perhaps find more convenient using recreational path as they cycle more regularly. As Larsen and El-Geneidy (2011) uncovered, regular cyclists tend to cycle on-street without facilities.

Additionally, an increase of bicycle facility density within cyclists' route buffer increases the odds of using all cycling facilities by 4% to 5%. Our results also reveal that a one category increase in satisfaction with current cycling infrastructure investment, on a 5-likert scale, increases the odds of using a recreational path by 26%. Moreover, a one category increase in cycle-friendly neighborhood in terms of infrastructure, on a 5-likert scale, increases the odds of using a recreational path by 38%.

Finally, cyclists 24 years old and under are 83% less likely to use recreational paths compared to cyclists of 65 years old and over to reach their workplace or school. This finding could indicate that younger cyclists' home and work/school locations are not situated in areas where recreational path are easily accessible compared to senior cyclists. Additionally, older cyclists are potentially more risk adverse, and are more willing to travel further distances to use less stressful bicycle infrastructure. Furthermore, women are 47% less likely to use a physically separated bi-directional path compared to men, which is contrasting with other studies that found that woman preferred to cycle protected bicycle path (Aldred & Dales, 2017; Lusk, Wen, & Zhou, 2014)

3.5 CONCLUSION AND RECOMMENDATIONS

The objective of this study was to predict the usage of recreational, bi-directional, and painted bicycle lanes for different types of cyclists, while controlling for their access to each facility type. Using the 2015 Quebec City Bicycle Survey, we first segmented our sample into six distinct types of cyclists: Urban Cyclist, Benefit-Seeking Cyclist, Happy Cyclist, Picky-Efficiency Seeker, Childhood-Influenced Cyclist and Indifferent Cyclist. We derived our cyclist typology from their motivations, childhood characteristics, sensitivity to peer and family encouragement and efforts, etc. While we did not consider bicycle facility preferences in our segmentation approach to avoid interfering with our logistic analysis, practitioners could have included this factor and tailored this method to their needs and the city context.

The second part of this analysis consisted of routing each respondents' commute trip, and determining what bicycle facilities each respondent had access to along his route, assuming that cyclists are willing to divert from the shortest path to use a preferred cycling facility. We created personalized network buffers around each cyclist's commute route, 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 method to account for cyclists' willingness to divert from their shortest route to reach a preferred cycling facility. Further research can try different diversion rates options according to their city context and research goals. Further analysis would be required to examine the impacts of using different diversion rate options on our results.

We then constructed three logistic regression models; one for each facility type. We found that the odds of a cyclist to use a recreational path, when having access to it, is more than twice as high as the odds of a cyclist using a painted lane when they have access to this later facility type. Our study reveals that cyclists with access to bi-directional paths were least likely to use them. In a similar vein, we found that 57% of our sample have access to bi-directional path, but did not report using it to commute to work or school. More analysis would be required to understand the reasons why over half of cyclists are not using bi-directional path in Quebec City. In fact, this finding is surprising and raises questions regarding the influence of the bi-directional nature of these lanes. While these facilities are physically separated from traffic, and therefore may offer greater protection to cyclists than other facilities, the bi-directional nature of these lanes may be detrimental to how cyclist perceived their safety. In turn, this could ultimately deter cyclists of using bi-directional lanes. Accordingly, it would be interesting to verify how cycling usage differs between physically separated bi-directional and uni-directional bicycle path in a city where both types are available. The locations of these facilities could also be a factor to further investigate.

We recommend practitioners and researchers to ensure stated preference surveys include questions to assess the effects of a facility location, nearby motorized traffic, and overall design on cyclist decision to divert from their shortest route. Other questions should be integrated to stated preference surveys in order to investigate how cyclists‘ feelings regarding their safety and stress levels when using a cycling facility affect their decision to divert to reach a preferred route.

Our results highlight the importance of thinking critically about what type of bicycle infrastructure is preferable to build according to a specific urban context. 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 (Buehler & Dill, 2016). Ultimately, safety interventions at intersections may also improve the efficiency of existing facilities, which could potentially increase the attractiveness of a facility type. As such, not only facility design but also characteristics of adjacent streets, and neighborhood characteristics should be considered as a whole when deciding which facility type is best suited (Buehler & Dill, 2016). Moreover, giving the diversity in cycling facility preferences, planners should engage in a dialogue with cyclists, both novice and more experienced cyclists, with the goal of identifying optimal cycling facilities for future investments.

4. CHAPTER 4: AFTERWORD AND PLANNING IMPLICATIONS

The goal of this supervised research project (SRP) is to guide practitioners towards better planning for cyclists, to help cities and regions reach their goal of increasing cycling rates. Several studies uncovered that increasing cycling usage can be successfully achieved by implementing a combination of strategies (Dill, 2009; Dill & Carr, 2003; Handy et al., 2014; Handy & Xing, 2011; Pucher et al., 2010). Accordingly, using Quebec City as a case study, we focused on developing tools to generate a bicycle parking strategy and predicting bicycle facility usage based on different cycling facility designs, with the assumption that different groups of cyclists react differently to the same facility.

The first planning implication of this SRP is the creation of a GIS-based method to identify optimal locations to add both short-term and long-term bicycle parking. We used a combination of spatial and statistical analysis (Z-Score) that are flexible and easily adaptable to different contexts. To summarize, we created a first index to identify where to install short-term bicycle locations by using existing and potential cyclists as well as the locations of bus stops deserved by high-frequency bus routes. To determine optimal locations for long-term bicycle parking, a second index was generated using the locations where bicycles were stolen and trips purposes.

For planners willing to adapt this tool, the main feasibility challenge would be to mobilize resources to collect the data required to conduct the analysis. As we used variables commonly available in a non-specific bicycle origin-destination travel survey, such as trip purpose, origin, destinations and modes used, our method can be adapted by municipalities who already have this type of survey. In the event that a new bicycle travel survey is being developed, we recommend planners to include survey questions related to the locations of stolen bicycles and individuals' willingness to pay for long-term bicycle parking, e.g. bicycle lockers. Having access to the willingness to pay for bicycle parking facilities can ultimately help planners adjust long-term bicycle parking demand. In turn, it can result in a more efficient bicycle parking strategy, which can help to maximize municipal financial resources.

The second planning implication is the segmentation approach we employed in order to distinguished six types of utilitarian cyclists. Using SPSS, we segmented our sample by conducting a principal component analysis (PCA), which was followed by a K-mean cluster analysis. The analysis was conducted to distinguished groups of cyclists among our sample, according to their motivations to cycles, their childhood and habits, etc. The outcome of this operation was further used to understand facility usage. This segmentation approach can be used as a tool to help decide on the optimal bicycle facility design to build according to cyclists' preferences.

Finally, the third planning implication is the combined use of spatial and statistical analysis to predict the odds of cyclists to utilize bi-directional, painted lane and recreational cycling facilities, when controlling for their access. Our results show high capital investments in physically separated bi-directional bicycle paths may not be the most optimal facility to prioritize for all cities. Further analysis would be required to better understand cyclists' preferences and to test different personalized buffer size. Also, stated preference survey should include specific questions accordingly. Finally, it highlights the need to think critically about bicycle facilities to build, as one facility type may not fit all!.

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