Innovations in utilitarian cycling: Analyzing characteristics of users and factors influencing their travel behavior

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A Supervised Research Project in two parts

Prepared by

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Preface

A growing number of planning and transportation professionals are calling into question the car-oriented development that has been prevailing in North America for many decades. The over-reliance on the automobile has major consequences in terms of air pollution, road accidents, and congestion. The widespread car use is also linked to the adoption of a more sedentary lifestyle in the population, which can have important negative impacts on public health. On the other hand, the mobility needs of individuals keep on increasing. Transportation planners thus need to develop more sustainable and efficient alternatives in order to fulfill these mobility needs without generating the negative consequences associated with car use.

In this respect, cycling is considered as a particularly promising avenue as it offers a variety of advantages to its users and to the community as a whole. This travel mode produces virtually no air pollution, participates in reducing congestion, and yields health benefits to its users. Unfortunately, cycling for utilitarian purposes remains a marginal practice in most North American cities. The use of the term *utilitarian cycling* in this research paper refers to any form of cycling for transportation purposes (as opposed to recreation).

In order to attract new users, many measures were developed to make it easier for individuals to integrate cycling into their routine. Given their recent implementation, little is known about the users of these cycling innovations, or about the factors that influence their habits and frequency of use. The aim of this research paper is to study more specifically two of these cycling innovations, namely cycling-transit integration and shared bicycle programs, in order to maximize the potential of these new active travel options. A distinct chapter will be devoted to each of those two forms of utilitarian cycling. The first chapter was presented at the 90th Transportation Research Board Annual Meeting and will be published in the Transportation Research Record Journal in 2011 as

Bachand-Marleau, J., Larsen, J.& A. El-Geneidy (2011). *The much anticipated marriage of cycling and transit: But how will it work?*

This research project draws from the results of a survey conducted in the region of Montréal during summer 2010. While the focus of the research is on this area, it is expected that many of the findings can guide policy-makers in other regions to maximize the potential of these cycling innovations.

Abstract Part 1

In response to the environmental, economic and social costs associated with over-reliance on the automobile, planners and transportation professionals are promoting sustainable alternatives such as walking, cycling, and public transit, either as single modes or in combination. It has been argued that the marriage between cycling and transit presents opportunities for synergy by enlarging catchment areas of transit stations, while drawing in new users to both of these “green” modes. However, due to the marginality of this practice in North America, there is a shortage of reliable empirical studies in this area. The present research addresses this gap through an analysis of travel behavior and preferences related to cycle-transit integration (CT). An on-line survey was conducted in the region of Montréal, Canada during the summer of 2010. The questionnaire included a section on Montréal’s public bicycle sharing system, BIXI, and its potential for integration with transit. We identify three current or potential CT users groups using a factor-cluster analysis: current parking bike-and-riders, BIXI users and car drivers. Bringing a bicycle on transit is the preferred form of integration; however, scenarios involving bicycle parking (or using a public bicycle) are likely to be used more regularly. In order to accommodate the greatest number of bicycle-transit trips, measures facilitating parking at transit stops and those that enable bringing bicycles on board transit vehicles are recommended in tandem.

Keywords: Sustainability – Cycling – Transit – Multimodal – Bicycle sharing – Bike-and-ride

Résumé partie 1

Les coûts environnementaux, économiques et sociaux associés à l'utilisation massive de l'automobile incitent de plus en plus de professionnels du transport et de l'aménagement à promouvoir des alternatives de transport durables telles que la marche, le vélo et le transport en commun, utilisées seules ou combinées. Plusieurs experts avancent que la combinaison du vélo et du transport en commun offre des possibilités particulièrement prometteuses, car elle permet d'élargir les zones de chalandise des stations de transport en commun et d'attirer de nouveaux utilisateurs pour ces deux modes « verts ». Toutefois, étant donné la marginalité de ce type de déplacements en Amérique du Nord, il existe très peu de données fiables sur le sujet. Cette recherche vise à combler ce manque d'information par l'analyse des comportements de déplacement et des préférences concernant l'intégration du vélo et du transport en commun. Une enquête en ligne a été menée dans la région de Montréal, Canada au cours de l'été 2010. Le questionnaire incluait également une section sur le système de vélos en libre service de Montréal, BIXI, et son potentiel d'intégration avec le transport en commun. L'analyse (de type *factor-cluster*) a permis d'identifier trois groupes d'utilisateurs actuels ou potentiels de la combinaison vélo-transport en commun : les utilisateurs actuels qui stationnent leur vélo à proximité d'une station de transport en commun, les utilisateurs de BIXI et les conducteurs automobiles. L'option d'intégration la plus populaire est celle où l'utilisateur apporte son vélo à bord du transport en commun; toutefois, les options où l'utilisateur stationne son vélo (ou un vélo en libre-service) à proximité des stations seraient utilisées sur une base plus régulière. Afin de maximiser le potentiel de déplacements combinant le vélo et le transport en commun, les mesures qui facilitent le stationnement à proximité des stations et celles qui permettent d'apporter les vélos à bord des véhicules de transport en commun sont toutes deux recommandées.

Mots-clés: Développement durable – Vélo – Transport en commun – Intermodalité – Vélo en libre-service – Bike-and-ride

Abstract Part 2

Planning and transportation professionals are promoting a variety of more sustainable travel alternatives, such as public transit usage, walking and cycling, to counter the negative effects associated with widespread car use. In their traditional form, these alternative transport modes do not always provide the flexibility or convenience the car offers; therefore, innovative solutions have recently been developed to allow active and public transport to better compete with the car. The present paper will focus on one of those innovations, namely the shared bicycle system. This new cycling option is adopted by a growing number of cities or regions throughout the world, yet little is known about the users of the systems and their motivations. A survey was conducted in Montréal, Canada in the summer 2010 to determine the factors encouraging individuals to use the system and the elements influencing the frequency of use. The factor that was found to have the greatest impact on the likelihood of using a shared bicycle system is the proximity of home to docking stations. Owning a yearly shared bicycle membership would incite users to ride shared bicycles 15 additional times per year. Respondents have also shown that they value shared bicycle's "trendy" status and the role it can play in bicycle theft prevention. In order to maximize the potential of shared bicycle systems, it is recommended to increase the number of docking stations in residential neighborhoods, and to put the emphasis of advertizing campaigns on the popularity of shared bicycle and its role in theft prevention.

Keywords: bicycle sharing – BIXI – motivators – deterrents – frequency of use

Résumé partie 2

Les professionnels de l'aménagement et du transport font la promotion de plusieurs alternatives de transport durable, telles que le transport en commun, la marche et le vélo, pour contrer les effets négatifs associés à l'utilisation massive de la voiture. Dans leur forme traditionnelle, ces modes de transport alternatifs n'offrent pas toujours une flexibilité et une commodité comparables à celles de la voiture. Par conséquent, des solutions innovatrices ont été développées pour permettre aux modes de transport actifs et collectifs de mieux compétitionner face à l'automobile. L'article suivant porte sur l'une de ces innovations, soit le système de vélos en libre-service. Cette nouvelle option pour se déplacer à vélo est implantée dans un nombre grandissant de villes et régions à travers le monde, mais on en connaît peu sur les utilisateurs du système et leurs motivations. Une enquête a été menée à Montréal, Canada, durant l'été 2010 afin de déterminer les facteurs qui encouragent les individus à utiliser le système et les éléments influençant leur fréquence d'utilisation. Le facteur ayant le plus grand impact sur la probabilité d'utiliser un système de vélos en libre-service est la proximité des stations à la résidence d'un individu, et le fait de posséder un abonnement annuel au système inciteraient les membres à utiliser le service 15 fois de plus annuellement. Les répondants ont également indiqué qu'ils apprécient le statut « branché » des vélos en libre-service et le rôle que ceux-ci peuvent jouer dans la prévention du vol de vélos. Afin de maximiser le potentiel des systèmes de vélos en libre-service, il est recommandé d'augmenter le nombre de stations dans les secteurs résidentiels, et de mettre l'emphase des campagnes de promotion sur la popularité du vélo en libre-service et des avantages qu'il offre relativement au vol de vélos.

Mots-clés : vélo en libre-service – BIXI – incitatifs – dissuasion – fréquence d'utilisation

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Chapter 1 - The much anticipated marriage of cycling and transit: But how will it work?

Introduction

In response to concerns over congestion, air pollution and sedentary lifestyles related to automobile dependency, transportation professionals and researchers are seeking new solutions. Many cities have adopted strategies to increase the attractiveness of walking, cycling, and public transit usage. Among the measures implemented, some have been aimed at facilitating the combination of two or more of these transportation modes under the moniker “bike-and-ride”, cycle-transit integration (CT) or simply the transportation cocktail. Combining modes allows for more flexibility, making multi-modal transport more appealing and increases travel options. Similarly, integration can be beneficial for transit agencies as it expands transit stations’ service area at both ends of the transit trip(Doolittle & Porter, 1994). Some researchers claim that CT will increase the mode share of cycling and public transit at the expense of the use of private vehicle and help in decreasing congestion, while others debate this claim (Mees, 2010a). Up until this point, there has not been any study in the North American context that uses empirical data to measure the actual needs for such integration among cyclists and transit users.

Past literature has identified general measures that can facilitate bicycle and transit integration (John Pucher & Buehler, 2009), however details on how this union can work have been in short supply. Recognizing the need for elementary information on the subject for researchers and practitioners alike, this paper seeks to answer two basic questions related to bicycle-transit integration: 1) who are the potential users of this type of intermodal transport; and 2) what are their current needs and priorities. This research draws on a detailed online survey conducted in Montréal, Canada specifically for this purpose. The survey included demographic, travel behavior and spatial questions to explore the factors affecting the use of and opportunities for cycle-transit integration. Additionally, given the presence in Montréal of BIXI, North America’s first large-scale public bicycle sharing system, a set of questions were included to measure the potential of this new system to augment the existing public transit service.

Literature

The body of knowledge on CT is relatively small; however, as evidenced by the growing literature and transportation initiatives, interest in this form of multimodal transportation is growing. Researchers have identified four areas for CT implementation: 1) enabling bicycles to be brought on transit vehicles;

2) improving the availability of parking near transit stops 3) connecting transit stations to an existing network of bicycle paths/lanes; and 4) providing bicycle sharing systems near transit stations and major destinations (John Pucher & Buehler, 2009). However, beyond this general roadmap, little is known about demand for various integration measures. Developing a more detailed understanding of this market, the priorities of potential users and the specific benefits of integration is an essential next step.

Not surprisingly given the reliance on buses as the main mode of public transit in North America, bicycles on buses (BOB) is by far the most common type of CT. For example, of the CT measures of 83 North American transit authorities listed in an online database, 63 involve BOB (Spindler & Boyle, 2009). While no systematic method exists for monitoring usage of bus racks, reports from transit agencies range from 575,600 to less than 20 bicycle boardings per year, with an overall year-to-year growth documented in the share of BOB trips to total boardings (Schneider, 2006). Moreover, it appears that opportunities for BOB is growing; the provision of bicycle racks on buses has almost tripled in the U.S. in only eight years, from 27 percent in 2000 to 71 percent in 2008 (John Pucher & Buehler, 2009). Nonetheless, various criticisms have been raised about BOB, including delays to transit service and underuse (Mees, 2010a). More substantial, however, are the critiques that BOB will remain a marginal service, due to limited rack capacity and smaller bus stop catchment areas, in part due to stop spacing (Hagelin, 2005; K. Krizek & Stonebraker, 2009).

The question of catchment or service areas is central to the branch of CT research concerned with cycling to transit, or bike-and-ride. In one study, in which survey respondents were presented with bike-and-ride scenarios containing hypothetical access distances, researchers found that the majority of people willing to bike-and-ride were within 2.4 km of the transit station, while those between 3.2 and 4.8 km demonstrated equal preference for car and bicycle as an access mode to transit (Taylor & Mahmassani, 1997). A study from Mumbai revealed that while only 1 percent of commuters traveling 1.2 km or less used a bicycle to access transit, that figure climbed to 11 percent beyond that distance (Rastogi & Rao, 2003). Overall, the mean access distance by bicycle was found to be 2.7 km. A Dutch study found that cycling was the predominant train access mode between 1.2 and 3.7 km; compared with U.S and Indian cases, this similarity suggests that access distances may traverse across cultures (Rietveld, 2000). Further analysis from the Netherlands revealed that access and egress time is not equivalent for all trip purposes. It increases proportionately with in-vehicle time, then declines as total trip extends beyond 60 minutes (Krygsman, Dijst, & Arentze, 2004).

Although CT is related to the growing body of work on bicycle infrastructure usage generally, there has been only cursory study of the effect of bicycle lanes on increasing the attractiveness of CT. One such study indicated that the presence of bicycle facilities at the census tract level had a positive effect on demand for CT (K. Krizek & Stonebraker, 2009). However, the effect of bicycle infrastructure has been shown to vary depending on cycling experience; among Texas cyclists, the presence of bicycle lanes had four times the effect on encouraging bike-and-ride among inexperienced riders relative to those with more experience (Taylor & Mahmassani, 1997). It is logical to conclude that in other locations as well, the presence of infrastructure will have a greater effect attracting new and inexperienced cyclists to the CT option than among veteran cyclists.

Some research has been directed towards understanding the socio-demographic factors associated with current and potential CT users, although conclusions have been mixed. While preliminary research in the U.S. suggests that household income levels and vehicle ownership are negatively correlated to CT usage (Hagelin, 2005; K. Krizek & Stonebraker, 2009), studies from the Netherlands reveals the opposite (Krygsman & Dijst, 2001). This may indicate that CT usage in the U.S. is higher among individuals with fewer travel options. Another explanation for these mixed results may be that CT usage is in part determined by attitudinal factors which cut across socio-demographic lines, as demonstrated in related research on opportunities for mode shifting (Anable, 2004).

Data and Methodology

In order to better understand current and potential users of “bike and ride”, an online survey on CT was undertaken in the region of Montréal, Québec (see appendix 1 for the survey questionnaire). The official mode share of cycling for Montréal is 1.3% of all trips (J. Pucher & Buehler, 2006), which is around the national average, however central areas are between 6-7% (Vélo-Québec, 2005). Currently, bicycle and transit integration in Montréal is possible in some circumstances, while restricted at certain times and on certain transit vehicles. Bicycles are prohibited on the city’s metro during peak hours, on weekends and during special events, largely due to capacity limitations. While most stations are not equipped with aids for bringing bicycles to boarding platforms, newer and some downtown stations include elevators. Bicycles are allowed outside peak hours on two of the five commuter train lines. Buses operated by the Société de transport de Montréal (STM), the transit provider on the island of Montréal, are not equipped with bicycle racks; however, several other transit agencies in the region have installed such racks on their bus fleets. Regular outdoor bicycle parking can be found at most metro, bus and train stations; longer-term and covered parking is rare.

Given the limitations of online surveys, particularly for overrepresentation of certain groups, a variety of media were used to ensure a broad cross-section of the public was reached. The survey was publicized through a combination of email newsletters, mailing lists, several newspaper articles in English and French, a radio interview, and various social networking media. Flyers advertising the survey were distributed at major transit stations of the region. These measures allowed for broader exposure than would be possible with only email distribution, as recommended by Dillman, Smyth & Christian (2009). The total sample of the survey is 1,787 individuals. Incomplete and outlier observations were excluded from the analysis leading to a sample size of 1,432 individuals. This is approximately equivalent to the number of cycling trips recorded in the regional travel survey, which covers five percent of the region’s population and is considered a representative sample (Agence métropolitaine de transport, 2003). This is also larger than most of the samples used in previous cycling travel behavior research (Dill & Gliebe, 2008; Hyodo, Suzuki, & Takahashi, 2000; K. Krizek, El-Geneidy, & Thompson, 2007; Moudon, et al., 2005; Tilahun, Levinson, & Krizek, 2007). However, since the region’s AM peak transit mode share is over 20 percent, a larger sampling of transit users will be required to understand the preferences for CT integration among existing transit users.

The analysis section commences with an explanation of the state of CT in Montréal followed by descriptive statistics obtained from the survey. Descriptive statistics will concentrate on the demographics and travel habits of the surveyed population. Understanding the characteristics of CT potential users is the next step. This is done through a market segmentation analysis. Market segmentation is a common practice in the travel behavior research field, and has been used to develop a clearer portrait for new transit projects prior to major investments and to attract new patrons (K. J. Krizek & El-Geneidy, 2007; Outwater, et al., 2003; Shiftan, Outwater, & Zhou, 2008). Central to this type of analysis is the concept that the market for any given product or service is comprised of several segments, rather than one homogenous whole. Studies have used market segmentation to identify perceived types of cyclists by users and non-users (Gatersleben & Haddad, 2010), however this technique has not yet been used to identify opportunities for CT.

Factor-cluster market segmentation analysis, a two-step analytical procedure, is used to classify large datasets into meaningful groups (see (K. J. Krizek & El-Geneidy, 2007; Outwater, et al., 2003; Shiftan, et al., 2008) for examples of factor-cluster market segmentation analysis). We start with a principal component factor analysis to learn how each of our variables relates to one another. Factor analysis extracts a small number of fundamental dimensions (factors) from a larger set of inter-correlated variables measuring various aspects of those dimensions. The second step in our analysis is to perform a cluster analysis, using the newly generated factors as a “reduced-form” dataset, using the K-means statistical routine. Cluster analysis is used to sort different objects (in this case, a reduced form version of the responses to the survey questions) into groups wherein the degree of association between two objects is maximal if they belong to the same group and minimal otherwise. The purpose of the cluster analysis is to determine how each of the factors combines to represent different groups of bicycle and transit integrators and non-integrators.

After identifying the main factors affecting potential CT users, these factors are studied in detail in the following sections concentrating on priorities for integration, acceptable access and egress distances, and finally the role of bicycle sharing systems in promoting CT. This is done through a series of cross-tabulations of the relevant survey questions.

Analysis

Descriptive statistics

Respondents are aged from 18 to 87, however the majority fall between the ages of 25 and 35 (Figure 1a). Men are slightly overrepresented, constituting 58 percent of the sample, and represent a larger portion of regular and frequent cyclists (Figure 1b). Annual household income is quite evenly distributed among respondents and the majority live in small households of 1 or 2 people, indicating that young people with no families are overrepresented in the sample. In terms of transportation options, 94% of the respondents own a bicycle, 87% have a valid driver's license and 52% own at least one car per household, which is below the 89% car ownership rate for the region of Montreal (AMT, 2008). While respondents report driving and walking evenly throughout the year, cycling and transit usage have considerable variation; predictably, cycling decreases in winter months and transit usage increases, suggesting that individuals substitute one of these modes for another depending on weather conditions.

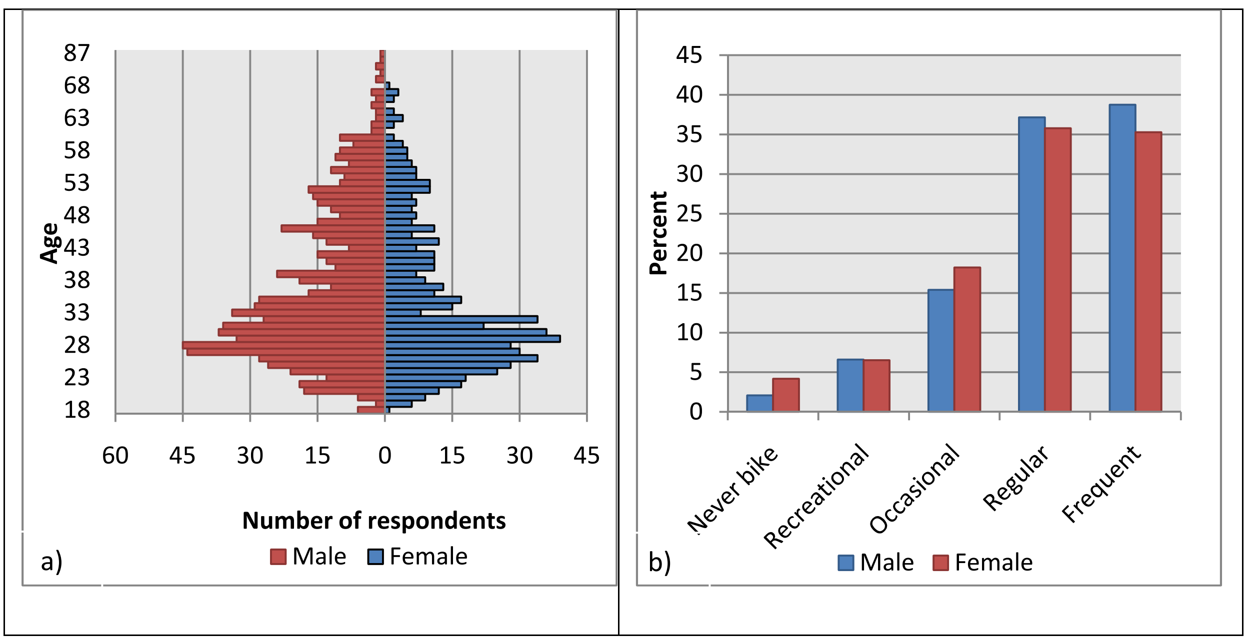


Figure 1: Socio-demographic characteristics and and travel habits

Overall, 63 percent of respondents indicated they would be willing to combine bicycle and public transit for a trip that they conduct. However, certain transit users report a greater interest in CT than others;

over 80 percent of respondents using the metro and train equally or metro, train and bus equally are likely CT users (Figure 2a). Commuter train users, especially those connecting between multiple transit vehicles, represent the prime set of candidates for cycling and transit integration. Based on respondents' reported cyling habits, we see that recreational and non-cyclists are least likely to integrate their cycling with transit (Figure 2b), while 68 percent of occasional cyclists reported that they would do so.

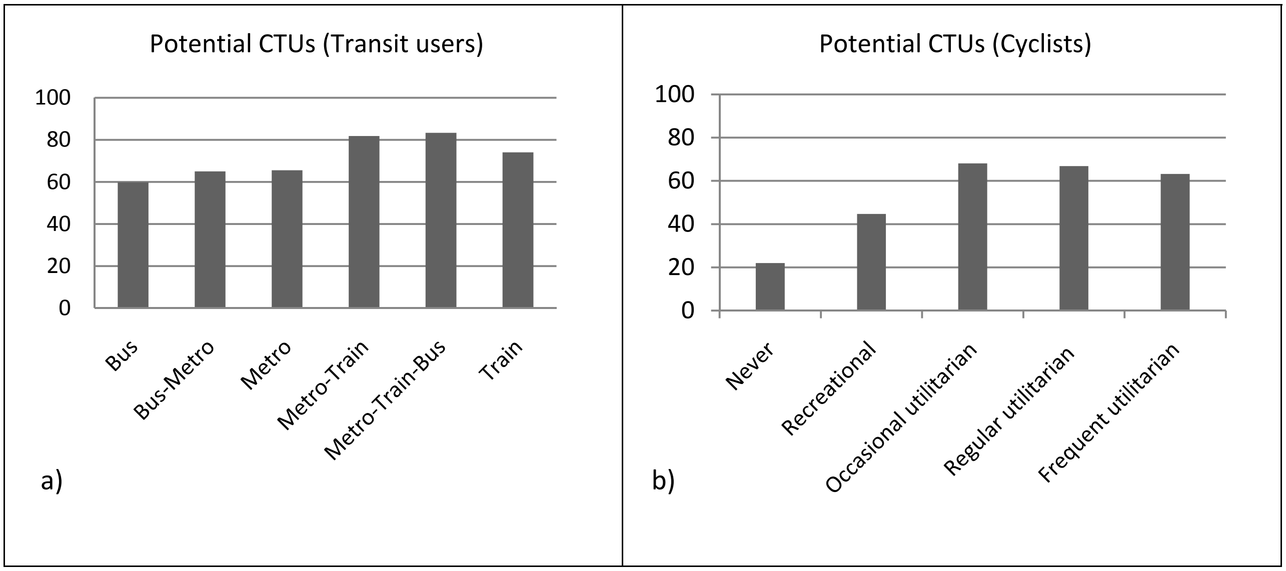


Figure 2: Travel habits of potential cycle-transit users

Also the highest values among potential transit users come from users who are using more than one mode of transit to reach their destination. This finding is consistent with Mees's (Mees, 2010b) observation that CT users will come mainly from existing transit users who would like to replace an inconvenient portion of their trip.

Factor-cluster analysis

Using 28 variables derived from responses to survey questions, we obtain thirteen factors with Eigen values above 1 which are used to define categories of current and potential users (Appendix 2). More questions were tested for this analysis yet they were dropped due to absence of statistical significance. The high values (above 0.5, indicated in bold) are all in a single column, each column representing one of the thirteen factors below. Cumulatively, these factors explain more than 75 percent of overall variation in the data. Using these newly generated factors, a cluster analysis is performed. In this type of analysis, it is important to determine the most appropriate number of clusters. We hypothesized that there are at least two, and possibly three, clusters representing general profiles: current CTUs, potential CTUs and non-CTUs. We tested for a variety of cluster numbers and obtained the best result with five groups.

The cluster average for each of the previously defined thirteen factors is represented by the height and direction of each bar, as shown in Figure 3. Current bicycle and transit integrators account for 23 percent of our sample, non-integrators represent 47 percent of our sample and the remaining 30 percent are potential integrators. In addition to presenting the cycling and transit integration potential for each group, the analysis shows that respondents are clustered according to their current transportation habits.

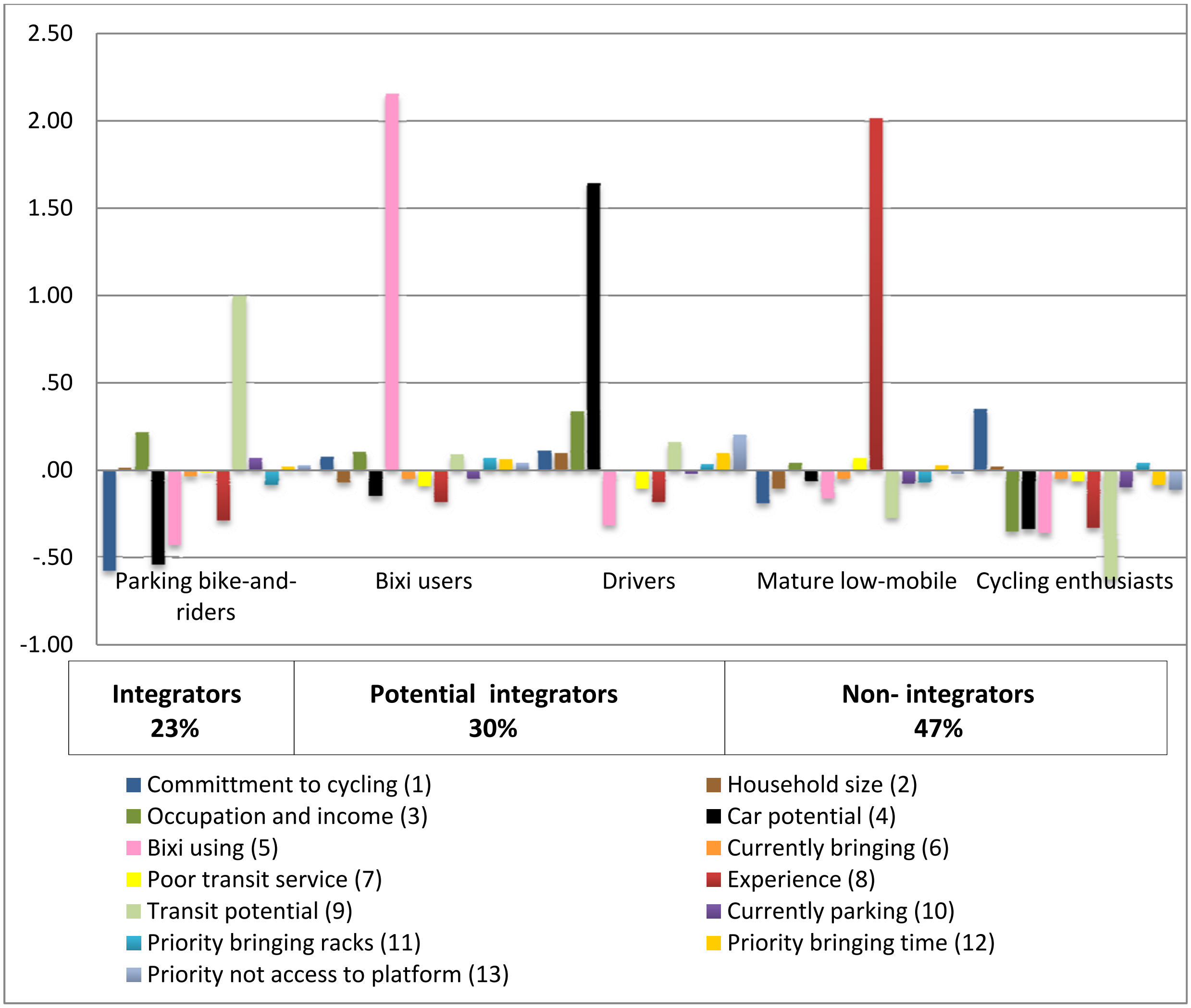


Figure 3: Current and potential CTUs based on factor-cluster analysis

The first cluster is characterized by a high value for the *transit potential* factor, a higher than average value for the *occupation and income* factor and a positive value for the *currently parking* factor; respondents in this cluster have a positive perception of CT and already park-and-ride. The second cluster is characterized by a high value in the *BIXI using* factor, a positive value in the *transit potential* factor and a positive value for the two factors indicating interest in bringing bicycles on transit (*priority bringing racks* and *priority bringing time*). These BIXI users are willing CT users and prioritize measures to bring bicycles on transit vehicles. The third cluster shows a high value for the *car potential* factor, a higher than average value for *household size, occupation* and *income*, and a positive value for the factors related to bringing bicycles on transit. This group represents respondents with children, currently driving and willing CT users, particularly if it involves bringing their bicycle on board. The fourth cluster is mostly characterized by a high value in the *experience* factor, and negative or low values for the other factors, indicating that these respondents are older and have been cycling for longer. They are poorly served by public transit and are not likely CT users. The last and largest of the clusters is composed of committed cyclists that have a lower value in the *occupation and income* factors and are relatively young; this group is considered non-potential CT users.

The factor and cluster analysis identified three willing groups of current and potential CT users: the current *parking bike-and-riders*, and two groups of potential CT users, the *BIXI users* and the *drivers*. Both *BIXI users* and *drivers* selected priorities related to bringing bicycle on transit vehicles; other priorities were selected by current parking bike-and-riders, indicating that different population groups have distinct needs and preferences for bicycle-transit integration. Awareness of these different groups, and a better understanding of their priorities, will enable transit authorities to provide appropriate services and facilities to satisfy existing demand and attract new users.

Identifying Priorities

Despite growing interest in bicycle CT schemes, little study has been directed at the travel circumstances in which individuals are most likely to desire and choose this option. We identified four possible scenarios in which bicycles could be incorporated into a transit trip, and asked survey respondents to select the one which they were most like to use (Figure 4). 56 percent of all respondents indicated a preference for one of the scenarios. Overall, 60 percent of respondents selected option C (bringing their bicycle with them on transit), followed by the option A (accessing transit by bicycle and walking to one's final destination (21 percent)). Since each different CT option entails different costs for transportation agencies and may appeal to different segments of the population, we explore these scenarios in greater detail.

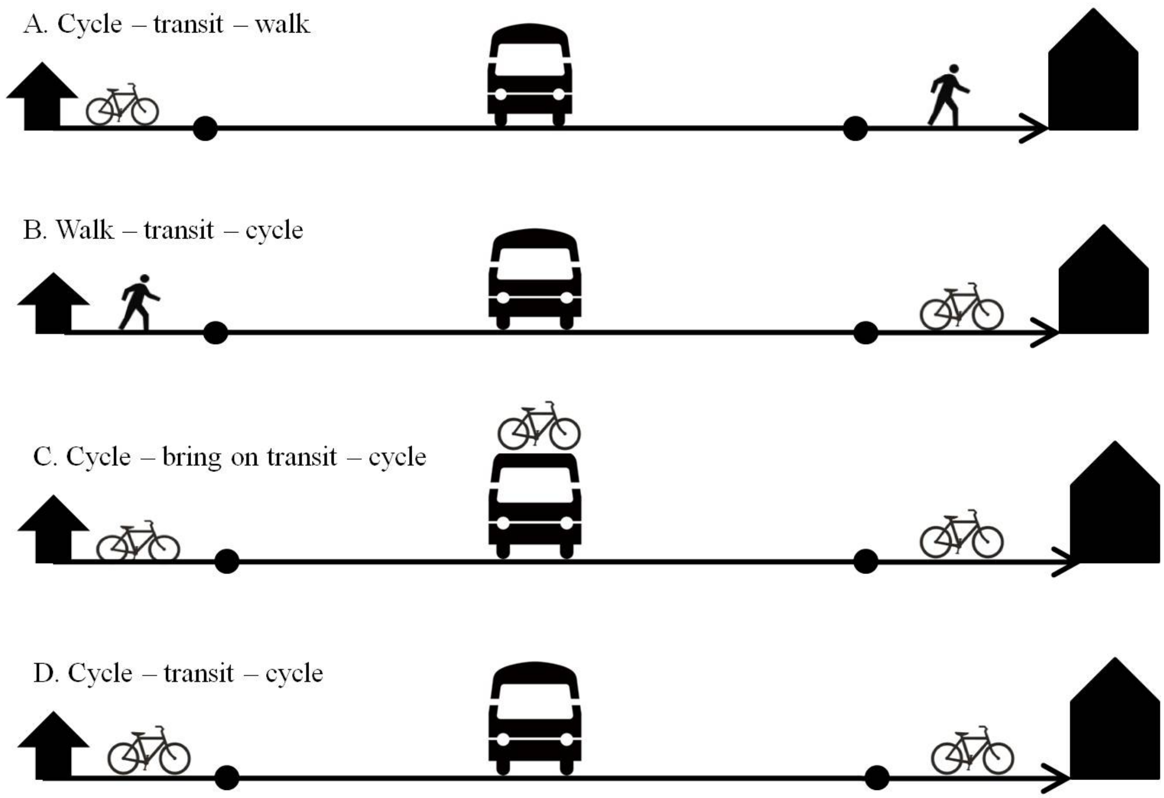


Figure 4: Four possible cycle-transit scenarios

Of those respondents expressing interest in combined CT trips, 40 percent reported they would do so for regular trips (eg. to work or school), while 60 percent would use this option primarily for irregular trips (eg. shopping, social visit). This contrasts with past research which has observed CT users to be primarily commuters (Givoni & Rietveld, 2007; Hagelin, 2005; Van Goeverden, 1993). Our research shows that the ratio of regular to irregular CT potential users varies according to the scenario selected (Figure 5); while only 34 percent of respondents who prefer to bring their bicycle on transit (option C) would be regular CT users, 48 percent of respondents who would cycle to transit (option A) would be regular CT users. These findings suggest that good quality bicycle parking facilities will be most useful to regular commuters, while racks on vehicles will appeal more to those irregularly using CT.

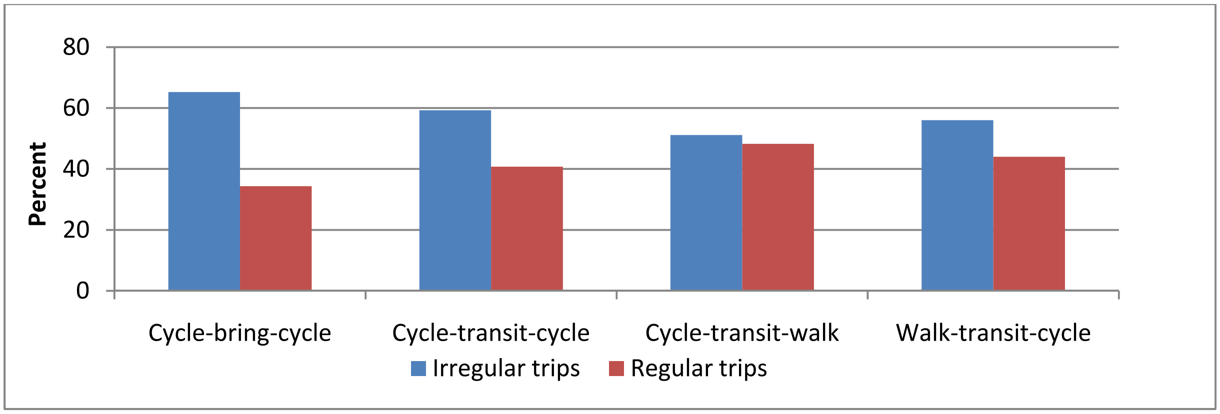


Figure 5: Preferred scenario by likely frequency of CT usage

Respondents were asked what type of a trip they were most likely to replace with a CT trip. Overall, trips made by one public transit vehicle accounted for 34 percent of potential CT trips, followed by car (25 percent), existing multimodal trips (24 percent), bicycle (9 percent), walking (5 percent) and taxi (3 percent). To better understand how opportunities for CT vary by location, respondents' distance from a central point in downtown is cross-tabulated with the mode most likely replaced by a CT trip (Figure 6). Not surprisingly, respondents living at central locations where private automobile ownership is lowest are more likely to replace trips involving transit as one of two or more modes. These are the *Parking bike-and-riders* and *BIXI users* identified in the factor-cluster analysis. Beyond 15 kilometers from downtown, *Drivers* are the group most likely to constitute the greatest share of replaced trips.

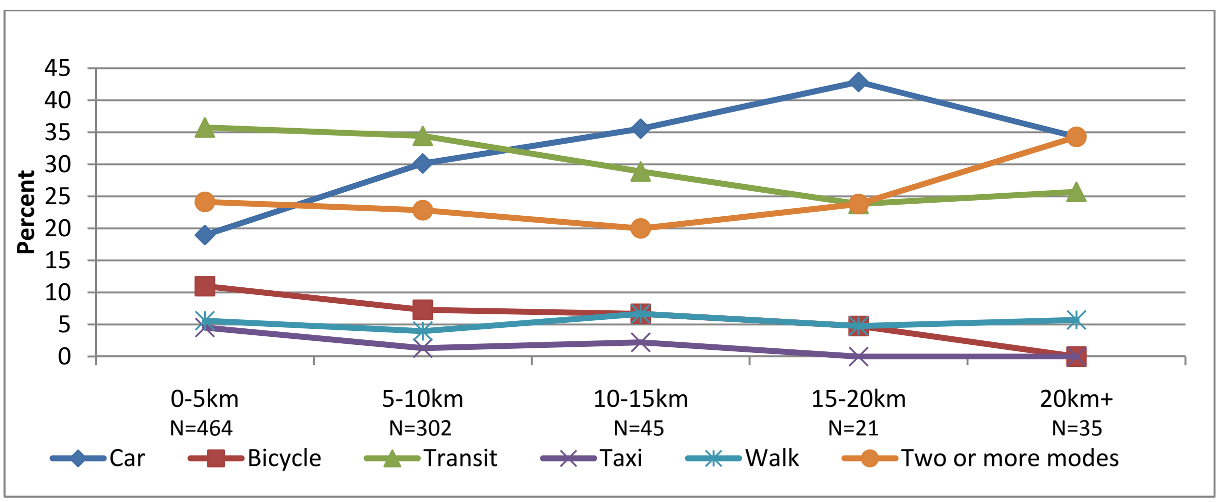


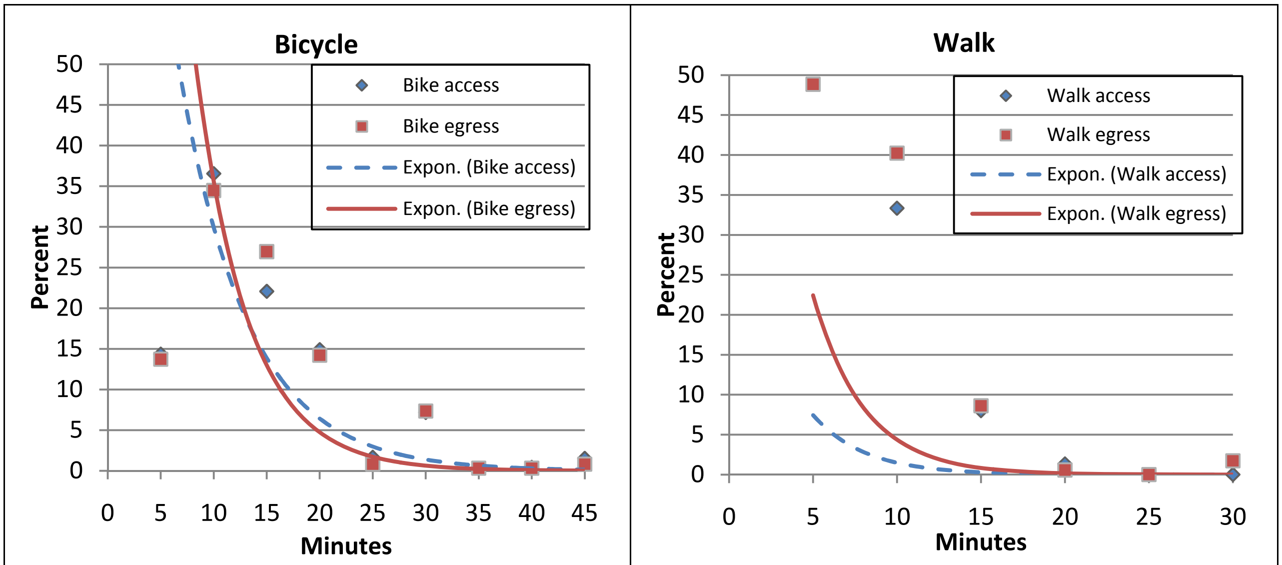
Figure 6: Stated mode replaced with CT by home- downtown distance

Every respondent was asked to provide his priority for a better integration of cycling and transit in Montréal. Of all priorities indicated, the preference for bringing bicycles on transit vehicles is dominant, particularly for extending the time in which the bicycles are allowed on board. More generally, measures facilitating bringing bicycles on transit account for 45 percent of the identified priorities, whereas various measures facilitating bicycle parking at transit stations represent 34 percent of the priorities. Another 13 percent identified bicycle network connectivity with transit stop as their top priority. That no single integration measure was clearly identified as the number one priority by a majority of respondents also reveals that a host of different interventions are needed to promote CT.

Respondents who said that they would not integrate cycling and transit indicated why they would not do so. The reason most commonly given was unwillingness to forego a bicycle trip, which speaks to the dedication of Montréal cyclists and the many short distance trips made. Over half of the reasons given are related to convenience (no time savings; impractical), while 20 percent indicated lack of appropriate parking facilities or fears about theft. This question underscores the difficulty of quantifying preference for a currently little-used practice; in particular, it is unclear whether the overwhelming preference for bringing bicycles on transit is the expression of a fundamental need, or whether it reflects a lack of other viable options, such as secure and convenient parking.

Acceptable distances

Those respondents that selected a CT integration scenario were then asked to indicate acceptable travel times for each portion of the trip: access, egress and on board transit. Using distance decay functions, these acceptable access and egress times by both walking and cycling are graphed. Respondents show markedly higher acceptable travel times by bicycle than by walking. Comparing access and egress distances (Figure 7), we note a steeper egress curve by both walking and cycling, indicating that a greater proportion of CT users are willing to accept longer access than egress times. This finding seems to confirm respondents' preference for using a bicycle at the home end rather than the destination end of a journey.



	Min	Max	Mean	Std	R^2
Access	1	60	14.51	9.27	0.4701
Egress	2	90	14.97	10.16	0.4880

	Min	Max	Mean	Std	R^2
Access	1	20	7.16	3.59	0.6986
Egress	1	30	8	4.58	0.7071

Figure 7: Distance decay of reported acceptable bicycle and walk times

Bicycle sharing

Given the recent implementation of BIXI (short for bicycle taxi), the public bicycle system in Montréal, a section was included in the survey to examine the role bicycle sharing systems can play in CT. Users can take a BIXI from one of 400 docking stations located in the city center, cycle to their destination and leave the bicycle at another station. There are three possible membership types: pay-per-use, monthly or yearly enrolment. 37 percent of respondents are BIXI users, traveling by BIXI on average 12 times per month when the service is available between May and November. Among the sample, memberships are split almost evenly between pay-per-use and yearly. Only 1 percent of the BIXI users indicated that they use a monthly membership; these users are not considered in the remainder of the analysis. More than half of the BIXI users live less than 0.8 kilometer from a metro station and pay-per-use users tend to live farther from metro stations. As indicated by the factor-cluster analysis, yearly BIXI members are more likely than pay-per-use users to integrate cycling and transit (Figure 8a).

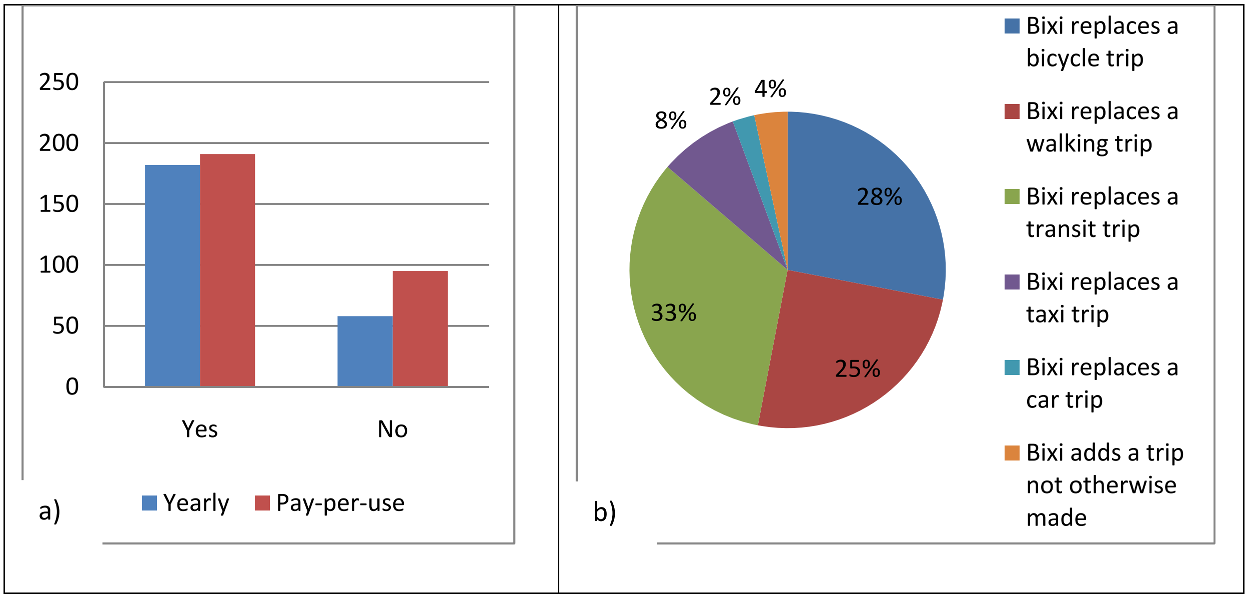


Figure 8: (a) Willingness to integrate by BIXI membership type; (b) trip types replaced by BIXI

In most cases, bicycle sharing usage replaces trips previously made by other "green" modes, namely public transit, bicycle or walking. Approximately 8 percent of BIXI users replaced taxi trips, while only 2 percent of the respondents use a BIXI instead of driving, revealing that official estimates of CO2 reduction due to the implementation of the program are exaggerated (BIXI, 2009). The availability of bicycle sharing encouraged 3 percent of the respondents to add an extra trip they would not otherwise have made. Among the different reasons for using BIXI, the most popular is their usefulness for one-way trips, which is followed by their practicality to use in conjunction with public transit; nonetheless, the majority of BIXI trips involve no other transportation mode. This may be due to the fact that BIXI stations are spatially concentrated, resulting in short-distance trips that can be made easily. Finally, many respondents expressed the need for BIXI stations outside the central neighbourhoods where transit stops cannot always be accessed by foot.

Discussion and Conclusions

As municipalities and transit providers aim to provide better options for "green" transport, cycle-transit integration offers significant opportunities for synergy between these modes. Existing knowledge has identified several factors affecting the cycle-transit usage including transit mode, urban form, access and egress catchment areas and trip purpose. Given the variety of options for increasing cycle-transit integration, and the significant costs associated with certain measures, the results in this paper may help to guide municipalities in selecting the most cost-effective solutions based on their goals and type of users they are trying to attract. However, the needs and preferences in terms of bicycle and transit integration may differ from one city to another; it is thus important to use locally obtained data when determining the most appropriate measures.

Through market segmentation using factor-cluster analysis, three of five distinct groups were found to be current or potential CT users: a) *Parking bike-and-riders*, b) *BIXI users*, and c) *Drivers*. Descriptive statistics confirmed this finding: self-described occasional cyclists are more likely to choose CT than those who cycle recreationally, regularly or almost always. Understanding the dynamics and preferences of these groups can significantly aid in the provision of cycle-transit integration services. A better knowledge of these groups' characteristics can also help transit agencies to effectively match resources to their potential users' preferences as part of a competitive positioning strategy to increase their market share (Shiftan, et al., 2008).

The present research reveals that transit users who primarily use Montréal's commuter rail train, or make train-based multimodal trips, are the most likely CT users, mirroring findings from locations where the practice is more common (Krygsman, et al., 2004; Replogle, 1992; Rietveld, 2000). In order to replace car trips with CT trips, a major preoccupation within this field, this research suggests that opportunities are greatest for people living farther than 15 km from the city center. Thus, improving the integration of cycling and rail transit, particularly if combined with suburban cycling infrastructure improvements, is expected to result in the greatest increase in CT rates. On the other hand, given the greater ridership of the city's metro system and its higher overall share of current CT trips, improvements focused on this transport mode will likely yield a greater gain in absolute terms, though more likely at the expense of other "green" modes. Specific policy objectives and the availability of resources will thus determine whether efforts are best directed towards replacing car trips, improving overall accessibility and mobility or working towards both of these goals.

The preference expressed by over 60 percent of respondents for the option to bring their bicycle on board transit presents serious challenges to promoting more widespread usage. Capacity limitations and capital costs associated with this option will necessitate more aggressive promotion of short- and longer-term parking options and public bicycle programs to significantly increase cycle-transit integration. This research makes several promising contributions to this dilemma: trips involving access or egress by bicycle at only one end of the trip accounted for the greatest proportion of respondents who stated they would be regular CT users. In other words, while the option to bring a bicycle on transit remain the most popular, scenarios involving parking a bicycle (or using a public bicycle) at one end are likely to be used more regularly. To the extent possible, measures facilitating both bicycle parking at transit and those enabling bringing bicycles on board transit are recommended.

Given the absence of research on public bicycle sharing systems, and their planned adoption in other North American cities, a section on Montreal's BIXI system was included. Over one third of survey respondents reported having used BIXI. As shown through factor-cluster analysis, BIXI users, especially those with a yearly membership, are most likely to integrate cycling and transit. However, despite the claims of reducing transportation emissions, this service appears to mostly replace trips made by "green modes". While the popularity of bicycle sharing suggests that there are significant benefits to users in terms of convenience and overall mobility, its environmental benefits have been grossly exaggerated. Further research into bicycle sharing systems will be needed.

After thoroughly reviewing the state of the knowledge from small but growing subset of transportation research, this paper includes a wide-ranging analysis into how and for whom to promote cycle-transit integration. The present study has several limitations, including risks for sample bias and the difficulty of analyzing atransportation practice adopted by a marginal proportion of the population. The former is addressed by using multiple dissemination tools; the latter is shortcoming that can only be overcome as this practice becomes more widespread.

Nonetheless, using the preferences and practices of current and potential CT users in Montréal, we make concrete conclusions that can guide transportation professionals in implementing cost-effective solutions for better bicycle-transit integration. While caution should be taken to avoid generalizations, it is believed that the results will be of use to transportation researchers and professionals as they seek to understand and promote this promising form of multimodal transportation.

Chapter 2 - Factors influencing likelihood of using shared bicycle systems and frequency of use

Introduction

Bicycle sharing systems are increasingly seen as a promising initiative to encourage cycling, whose benefits to the user and to the society as a whole are well known. Cycling is a form of physical activity in which health authorities place great hope as it can be easily incorporated into daily routines and yields cardiovascular benefits for both children and adults (Yang, Sahlqvist, McMinn, Griffin, & Ogilvie, 2010). It is also an environmentally friendly transportation mode (Shaheen, Guzman, & Zhang, 2010) that provides additional mobility options at an affordable cost.

Bicycle sharing systems are implemented with the intention to yield those benefits associated with cycling while providing additional convenience for the user, in the hope to convince more commuters to adopt the bicycle. A bicycle sharing program can be described as a system that enables individuals to use bicycles whenever they need it, without the costs and responsibilities associated with owning a bicycle (Shaheen, et al., 2010). The flexibility of this transport mode makes it especially suitable for short distances and for one-way trips. All these characteristics prompt a growing number of cities to implement bicycle sharing programs. Currently, bicycle sharing systems are present in over 125 cities on four continents, which translates into about 140,000 shared bicycles worldwide (Shaheen, et al., 2010).

Despite the growing popularity of shared bicycle systems, little is known about users of shared bicycles, their reasons for using this form of transportation, and more generally about the demand for shared bicycle programs. In the following paper, we will seek to shed light on these questions. More precisely, the purpose of the research is two-fold. First, we will try to determine the socioeconomic and spatial factors that influence someone’s likelihood of using shared bicycles. Then, we will look more specifically at people who are already using the bicycle sharing system, and analyze characteristics influencing their frequency of use. This research is based on a detailed online survey conducted in Montréal, Canada in summer 2010. The survey included demographic, travel behavior and spatial questions to determine the elements affecting the use of and opportunities for cycle-transit integration, and a distinct section on the use of BIXI, Montréal’s shared bicycle system.

Literature

Bicycle sharing is a relatively recent concept; the first large-scale system was implemented in the Netherlands less than fifty years ago, in 1965. Bicycle sharing systems went through four major phases. The first generation, labeled “White bikes”, consisted of unlocked bicycles randomly located throughout the city. The bicycles were painted in one bright color. They could be picked up and left anywhere in the city, and their use was free of charge. In most cases, including the Amsterdam, Cambridge and Milan experiences, the programs were put to an end after a few years due to the high number of bicycles damaged and/or stolen (DeMaio, 2009; Gradinger, 2007; Shaheen, et al., 2010).

A second generation of bicycle sharing systems, called the “Coin-deposit systems”, was introduced in the 1990s to overcome the problems encountered with the first-generation programs. These systems were characterized by the unique, robust design and bright color of the bicycles as well as designated docking stations where bicycles were borrowed and returned (DeMaio, 2009). The stations were equipped with a locking system to minimize theft risk and required a small deposit to borrow a bicycle that was generally refunded upon return. Although they were an improvement relative to the previous generation, the coin-deposit systems still did not completely solve the theft problem due to the anonymity of the borrowing process. Furthermore there was no time-limit to the bicycle usage which caused people to borrow bicycles for unduly long periods of time (Shaheen, et al., 2010). Most of these systems were implemented in Northern European countries, such as Denmark and the Netherlands (Gradinger, 2007).

The third generation “IT-based systems” kept some of the second generation’s features such as the distinctive design of the bicycles and the presence of docking stations. In addition, these bicycle sharing programs were incorporating transaction kiosks which allowed for the identification of users (with portable phone and/or credit card number). These systems have succeeded in declining theft rates since users are exposed to penalties if they failed to return the bicycles back to a station (Shaheen, et al., 2010). Users also had to get memberships to utilize the service. Typically, usage was free for a certain period of time (in most cases from half an hour to one hour) and then users were charged for the extra minutes, thus encouraging shorter trips. The first city to implement such a bicycle sharing system was Lyon, France (in 2005), soon followed by many other European cities (Krykewycz, Puchalsky, Rocks, Bonnette, & Jaskiewicz, 2010; Shaheen, et al., 2010).

The latest and fourth generation of bicycle sharing programs, the "Demand responsive, multimodal systems" consists mostly of management and efficiency improvements to the IT-based systems. The innovations include mobile and/or solar-powered docking stations, the use of smartcards, and bicycle distribution systems (DeMaio, 2009; Morency, Trépanier, & Godefroy, 2011; Shaheen, et al., 2010). Distribution systems involve moving shared bicycles from one station to another in order to ensure that bicycles and empty racks are always available for users to borrow or return a bicycle at any station. The shared bicycle system of Montréal can be included in this last category of shared bicycle systems.

The literature on the evolution of bicycle sharing systems is limited, but reliable and relatively easy to access. Unfortunately, the same cannot be said of literature exploring the characteristics of bicycle sharing users and the motivators or deterrents to the use of shared bicycles. Very little is known about the potential influence of socioeconomic, spatial or behavioral characteristics of bicycle sharing users or about the attributes of the system itself such as the pricing, the extent of the network, the availability of bicycles or the location of docking stations.

Case Study

Cycling and bicycle sharing in Montréal

According to the latest *Origine-Destination* survey (a regional transportation survey taking place every five years) the modal share of cycling in the region of Montréal is around 1.2% of all trips (AMT, 2008). In the past few years, the city of Montréal expressed a commitment to improve the cycling conditions. The transportation plan of the city, launched in 2008, specified many interventions to reach that goal, such as implementing the BIXI system, doubling the cycling network, and increasing the number of bicycle racks for parking by fivefold. Although the plan has not yet reached completion, the size of the network increased steadily since its implementation. Unfortunately, bicycle theft is a problem in Montréal. According to the police department of the city, about 2,500 bicycles are reported stolen every year on average, yet this number represents only a small proportion of all bicycle thefts (Tremblay, 2011).

BIXI – Montréal's bicycle sharing system

The bicycle sharing system of Montreal, BIXI (short for bicycle and taxi), was launched in the spring of 2009. It was one of the first "Demand responsive, multimodal systems" to be implemented. The BIXI system is in operation from May to November. At the time BIXI was launched, there were about 300 stations available, but the instant success of the system prompted the BIXI organization to implement the expansion phase ahead of schedule. There are currently about 450 stations distributed throughout the central neighborhoods of Montréal, and a total of 5,000 bicycles are in circulation (Fuller, 2010). The BIXIs were designed specifically for shared use in an urban context: they are robust, yet esthetically pleasant and convenient for users with their adjustable seats, front racks and integrated chain protector (Public-Bicycle-System, 2010). There are three BIXI membership types: the 24-hour pass, the monthly membership, and the yearly membership. The system is meant to accommodate short trips, with the first half-hour of use free and then a charge for additional time. Discounts are also available for individuals who combine their BIXI membership with an annual transit pass or a Communauto (the carsharing service in Montréal) membership. Since the implementation of the bicycle sharing system, over 3,000,000 trips have been made by BIXI, as of fall 2010 (Montréal, 2010).

Data

An online survey on cycling and transit integration was conducted in the region of Montréal, Canada during summer 2010. The questionnaire included a separate section on BIXI usage, since it is one of the viable options for integrating cycling and public transit. The survey was performed using an uncontrolled online distribution method, which means anyone could go on the web page and fill out the questionnaire. Many different media, such as mailing lists, email newsletters, social networking media, radio and newspaper interviews, and flyers distributed at major transit stations were used to publicize the survey, in order to ensure a large cross-section of the population would be reached. The use of such a variety of means allows for broader exposure, thus minimizing the bias that can be associated with online surveys (Dillman, et al., 2009).

A total of 1,787 responses were gathered for the survey; after removing the incomplete observations, we obtained a final sample of 1,432 respondents. The age of respondents ranges from 18 to 87, however the majority falls between the ages of 25 and 35. Men are slightly more numerous than women in the sample,accounting for 58% of the respondents. Young people with no child are overrepresented among our respondents, the majority of them living in small households of 1 or 2 people. More detailed descriptive statistics of our respondents are presented in Table 1.

Individuals who participated in the survey live on average 6km away from downtown Montréal, and they have a good access to transit with an average of 12 bus stops within a 400m distance from their residence. This might explain why the majority of respondents are bus users (they took the bus at least once in the past year). Respondents also enjoy good access to the shared bicycle system, with almost 60% of those who participated in the survey living within close proximity to a BIXI station. Around 87% of people in the sample have a valid driver's license and 52% own at least one car per household.

Table 1 – Selected descriptive statistics of the respondents

	Average	Max	Min
Age	35.7	87	18
Home-downtown distance	6.0	-	-
Number of bus stops within 400m from home	12.1	155	0
Number of bicycles stolen per respondent	0.7	9	0
	Average (%)		
Gender(female)	41.8		
Recreational cyclists only	6.6		
Year round cyclists	16.7		
Bus user	76.8		
Yearly BIXI membership	16.7		
People living within 500m from a BIXI station	59.4		
Respondents who had a bicycle stolen	39.0		

One section of the survey was also specifically about the cycling habits of our respondents. Almost all of them (94%) own a bicycle. Close to 40% of the respondents indicated they had already had one bicycle stolen, and 10% had two or more bicycles stolen. As for the cycling habits of our respondents, almost 17% of the participants to the survey use their bicycle for transportation year-round, while another 6% is cycling only for recreational purposes. In terms of bicycle sharing trends, 37% of our respondents indicated they had already used BIXI. From this number, membership types were split almost evenly between pay-per-use and yearly enrolments, while only 1% of BIXI users had acquired a monthly pass.

Respondents were also asked about their motivations for using BIXI These motivations and their answers to more specific questions concerning how they integrated BIXI in their transportation habits are presented in Figure 9.

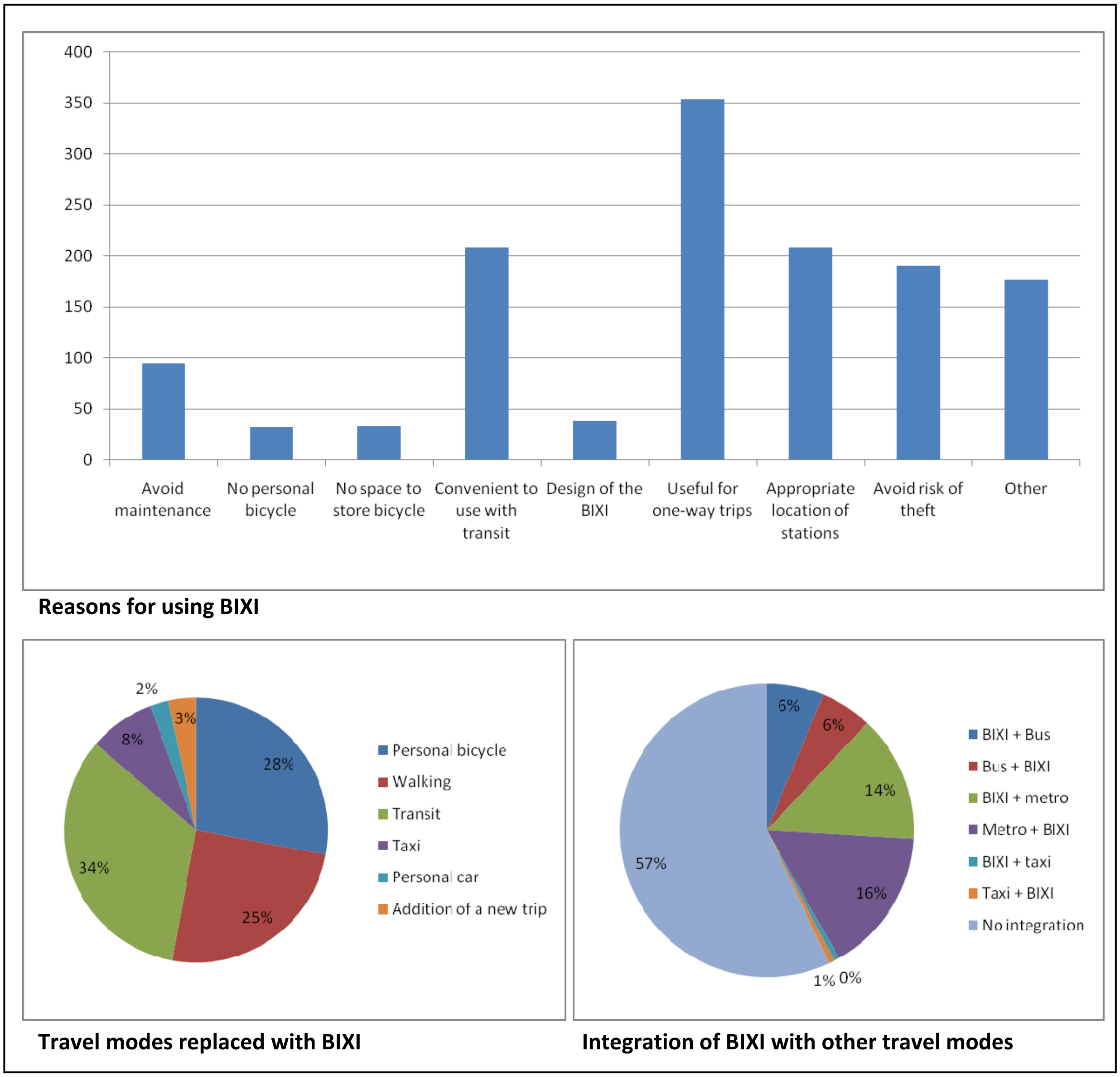


Figure 9: BIXI usage among our respondents

Figure 9 shows that our respondents use BIXIs for a variety of reasons, mostly related to convenience or to avoid maintenance and risk of theft. Most people in our sample are using BIXI for trips previously made by transit or with their own bicycle. Only 10% of the respondents indicated that they used a BIXI instead of taking their car or a taxi; the environmental benefits of BIXI are therefore probably not the main advantage of the system. Despite its potential for multimodal trips, acknowledged by the respondents themselves, less than half of the users combine BIXI with another mode for a trip. When they do so, most of our respondents use BIXI in combination with the metro.

Methodology

Two different types of regressions were used to answer our research questions. First, a binary logistic model is developed to determine factors encouraging the use of BIXI. A binary logistic model is a type of logistic regression in which the dependant variable is binary. In this case, the dependant variable is the previous use of a BIXI (yes/no). Then, a linear regression was applied on our subsample of BIXI users to identify factors that have an impact on the frequency of use of shared bicycles. The dependant variable in this second model is the number of BIXI uses for the 2010 season. A variety of variables were tested in the first model, based on results of previous studies examining the motivators to cycling in general or to using shared bicycle systems specifically. According to those studies, the typical user of shared bicycle system is a young man earning a medium-class income (Shaheen, et al., 2011). We hypothesized that our analysis would confirm that trend, and we therefore included age, gender, and income as variables in our model.

We also expected that travel habits would have an impact on the likelihood of using BIXI; we hypothesized that people cycling only for recreation would be less likely to be part a bicycle sharing system. We supposed that owning a bicycle and being a committed, year-round cyclist would decrease the probability of using BIXI. Shared bicycle systems offer potential for combined cycling-transit trips or for replacing short bus trips; therefore, we expected that bus users and people who already combined cycling and transit for a trip would be more likely to use shared bicycles. In contrast, we hypothesized that owning a driver's license would decrease the odds of being a BIXI adept.

A recent study on BIXI identified the proximity to docking stations as an important motivator to the use of the system (Morency, et al., 2011). We supposed that our analysis would generate similar results, especially since that paper focused specifically on shared bicycles in Montréal. We also expected that living close to downtown would increase one's likelihood of using BIXI, since this type of residential location is generally associated with shorter, more "bikeable" travel distances. Finally, we decided to explore a hypothesis not yet tested in the literature and specifically related to Montréal's cycling context. As previously mentioned, bicycle theft is a problem in Montréal, and fear of theft can deter people from using their bicycle for transportation. In this respect, shared bicycles represent a good alternative as users do not own the bicycles and therefore they do not need to worry about it being stolen while the bicycle is parked. Consequently, we expect that those who have had their bicycle stolen, and thus are more conscious of theft risk, will be more likely to use shared bicycles.

Many of the same variables were included in the second model, yet other distinct factors could also influence the frequency of use. First, we incorporated in the model the type of shared bicycle membership; we expected that owning a yearly membership, with unlimited access to BIXI system for the first half-hour would encourage people to use the system more often. We added variables representing reasons for using shared bicycles, in order to determine if some of the advantages of BIXI have an impact on users' behavior. Avoiding maintenance, avoiding risk of theft, and liking the design of BIXI (which can be considered as the "trendiness" factor of the BIXI) were among the most popular reasons mentioned by our respondents and therefore were included in the model. Finally, the number of bus stops within a 400m buffer from residential location was added as a variable representing the level of transit access of respondents. We expected that having a good access to transit would diminish the need for shared bicycles. All variables included in both models were tested for correlation. Other variables such as household size, car ownership and a variety of interaction variables were tested in the two regressions but proved to be insignificant and were therefore removed from the final models. The two models presented below are those which were able to explain the highest proportion of variance among the data with meaningful and significant variables.

Analysis

The result of the binary logistic regression measuring the probability of using a BIXI during the 2010 season is reported in table 2. There are three main types of variables that have shown to play a significant role in the likelihood of using shared bicycle systems: socioeconomic characteristics, transportation habits, and spatial characteristics. The variable that has the strongest impact is the presence of a BIXI station less than 500m from home, which makes an individual more than 300% more likely to use a shared bicycle, thus confirming results of previous studies stressing the importance of proximity to docking stations (Fuller, 2010) at the home location. The proximity of a BIXI station to respondent's most regular destination is also increasing one's probability of using a BIXI, but is not as critical as the proximity to home. Being a recreational only cyclist and being a female would decrease chances of an individual to use a BIXI, while combining cycling and transit for trips and owning a driver's license would have the opposite effect. Although it might seem counterintuitive that being a driver makes someone more likely to use shared bicycles, this result is consistent with findings from a Chinese study (Shaheen, et al., 2011). Age and distance from home to downtown would have a marginal but significant negative impact. The distance from home to downtown squared was also tested in this model to account for the possibility of a non-linear relationship between distance and probability of use, but the variable was not significant and was consequently removed from the final model.

Table 2 – Factors influencing the likelihood of using shared bicycle systems

Variable	Odds ratio
Age	0.965***
Gender (female)	0.585***
Owning a bicycle	0.5778**
Cycling for recreational purposes only	0.437**
Number of bicycle thefts	1.104*
Owning a driver's license	1.588**
Annual household income from 0 to 40,000$	0.539***
Being a bus user	1.486**
Distance from home to downtown	0.956**
Being a year-round cyclist	0.539***
Presence of a BIXI station less than 500m from home	3.245***
Presence of a BIXI station less than 500m from destination	1.559**
Already combined cycling and transit	1.772***
Constant	0.769
-2 Log likelihood	1509.905
Nagelkerke R square	.241

*Significant at the 90% confidence level

**Significant at the 95% confidence level

***Significant at the 99% confidence level

Interestingly, people who are earning less than $40,000 per year are 32% less likely to be adepts of bicycle sharing than people falling in other income brackets, thus corroborating findings from previous studies that users are mostly middle-income (Shaheen, et al., 2011). People cycling throughout the year and those owning a bicycle are less inclined to use shared bicycles, which might mean that "cycling enthusiasts" are not the typical BIXI users, who may be more casual cyclists. Finally, each time an individual gets his bicycle stolen increases the likelihood of being a BIXI user by 10%.

Table 3 reports the findings from the linear regression measuring the number of times a person has used the bicycle sharing system in the 2010 season.

Table 3 – Variables influencing frequency of use of shared bicycle systems per cycling season (spring to fall)

Variable	Coefficient
Constant	9.766**
Age	-0.004
Gender (female)	-1.335
Owning a bicycle	-5.680**
Owning a yearly BIXI membership	15.911***
Using BIXI to avoid risk of theft	5.310***
Using BIXI to avoid maintenance	10.992***
Using BIXI for its attractive design	10.352***
Number of bus stops 400m from home	-0.093*
Distance from home to downtown	-1.142*
Distance from home to downtown square	0.063**
Number of bicycle thefts	0.455
N	535
Adjusted R square	0.502

*Significant at the 90% confidence level

**Significant at the 95% confidence level

***Significant at the 99% confidence level

First, we can notice that some of the variables found in both models such as age, gender and number of bicycles stolen are not significant in predicting the frequency of shared bicycle use although they influence the probability of someone using shared bicycles. Owning a yearly BIXI membership has the greatest impact on the number of uses of a shared bicycle, increasing by 15 the number of times a person would ride a BIXI per season. People who want to avoid maintenance of a bicycle and those who appreciate the design of the BIXI are likely to use it 10 more times per season. Also, owning a bicycle decreases the number of uses of a shared bicycle by 5.6 times per season. As for spatial characteristics, living close to downtown slightly decreases the number of uses, yet past a certain threshold, distance to downtown has the opposite effect. The presence of a BIXI station within a 500m buffer at both ends of the trip was also tested in the linear regression, but proved to be insignificant and was consequently removed from the final model. Finally, the number of bus stops within 400m from home has a small but significant negative impact on frequency of use, which might indicate that BIXI is competing with transit

Discussion

The most obvious finding of our first model is that having a BIXI station close to home is the variable which increases most the chances of using shared bicycles. Proximity of the stations to regular destinations also augments the odds of being a BIXI user, yet the effect of this variable is not nearly as strong. This might also be partly due to the fact that only the most regular destination was included in the analysis. Therefore, to increase the modal share of BIXIs, more stations need to be installed in residential neighborhoods in priority.

As of now, docking stations are only available in some central neighborhoods with good access to the transit network, and most of the users do not combine their BIXI ride with another mode for a single trip (probably because of their good access to transit and proximity to downtown). It would be interesting to observe patterns of use if BIXI stations were installed in more peripheral neighborhoods or in areas with a more limited transit access. Many of the factors which increased the probability of using shared bicycles are related to transportation habits; those combining cycling and transit, bus users, and people owning a driver's license are more likely to be BIXI users. We originally expected the possession of a driver's license to have the opposite effect, yet our result is not counterintuitive as it seems. Most adults in Montréal have a driver's license; therefore, chances are great that an adult shared bicycle user also is a driver, whether or not they own a car or drive on a regular basis.

Inversely, being a very committed, year-round cyclist and owning a bicycle would decrease one's chances of using BIXI. People using their own bicycle have similar travel options and enjoy the same health benefits shared bicycle users do and are therefore not the group targeted in priority by promotion campaigns for shared bicycle programs. Yet it would still be worth investigating whether bicycle owners choose not to use BIXI for convenience reasons or because of the cost of the membership, which could be prohibitive for someone who already has access to a personal bicycle free of charge (except maintenance).

One very interesting finding from this study is that people who have already had their bicycle stolen are more likely to use shared bicycles. Respondents who expressed a concern about bicycle theft as a reason for using BIXI are also riding shared bicycles more often. This indicates that BIXI is perceived and indeed acts as an effective solution for those who want to cycle yet are afraid of bicycling theft. The potential of shared bicycle systems as a powerful tool to counteract the negative influence of bicycle theft on the modal share of cycling is obvious. This study goes one step further as we can now confirm that this advantage is valued by individuals, as it encourages those who experienced theft to start using the system and also increases the frequency of use of individuals concerned with bicycle theft.

More generally, we can conclude from the results of our analysis that factors prompting people to become shared bicycle users are not necessarily the same as those increasing the frequency of use of this transport mode. Spatial factors and transportation habits play an important role in encouraging individuals to use shared bicycles, yet specific the respondent’s motivations for using BIXIS have the greatest impact on the frequency of use.

Aside from fear of theft, another motivation that increases the frequency of using BIXI is the design of the BIXI, which makes individuals use it on average 10 more times per year. This is a clear indication of what we call the “trendiness factor” of the BIXI. The design of the BIXI and its promotion as an urban, environmentally-friendly mode contribute to make it “trendy” to be a shared bicycle user, and consequently to the popularity of the BIXI.

One limitation of our study is related to the distribution method of the survey, and the risk of bias associated with voluntary-based surveys. We addressed this shortcoming by using multiple dissemination tools to reach a broad cross-section of the population. The main limitation associated with our study is that we could only use socioeconomic, transportation habits and spatial variables to generate the model; therefore the influence of the values of respondents could not be evaluated in our analysis. . Finally it is important to note that tourists using the system during their visit were not included in the survey. Reaching out to this special population of Bixi users requires a different study and a different approach to capture their usage of the system.

Conclusion and policy recommendations

A growing number of municipal and regional governments recognize and wish to enjoy the benefits associated with shared bicycles. In order to make the shared bicycle programs successful and to maximize their potential, it is essential to get a good understanding of factors prompting or deterring individuals from using the system. The current study allowed us to have a better understanding of the factors influencing the use of shared bicycle systems and those impacting the frequency of use. The results of this research point out to some key elements to consider in the formulation of policies for promoting the use of shared bicycles.

We suggest that interventions focus on four major aspects which impact the likelihood of being a shared bicycle user and the frequency of use:

1) **The location of shared bicycle stations**: This study has shown that the location of docking stations plays a crucial role in encouraging individuals to use shared bicycles. A greater number of docking stations close to origins of potential users in residential neighborhoods is highly likely to generate an increase in the number of system users.

2) **The transportation habits of current and potential users:** Transit users, people combining cycling and transit for their trips, and those who have a driver's license are more likely to use shared bicycle systems. Special multimodal offers, including access to shared bicycle systems, carsharing systems, or integrated multimodal fare cards, would encourage individuals to adopt shared bicycles by making the integration into their current travel habits as seamless as possible.

3) **The fear of bicycle theft:** Our study confirms that individuals recognize shared bicycles as an interesting active travel option in minimizing bicycle theft. Promotion of the shared bicycle systems should insist on this advantage in order to attract new users and increase frequency of use among those who have already had bicycles stolen in the past or those concerned with the risk of theft.

4) **The status and perceptions associated with shared bicycles:** Individuals who like the design of shared bicycles tend to use the system more often. Advertizing campaigns sending the message that it is “trendy” to use shared bicycles are likely to encourage users to increase their frequency of usage of the system.

This research, based on a survey of people living in the region of Montréal, Québec, provided findings that are consistent with results of previous studies conducted elsewhere in the world. Although each region has its own particularities, we believe the main findings from this study could be useful for any city aiming to maximize the potential of its shared bicycle system.

In the specific case of Montréal, the implementation of the BIXI system had impacts that have gone beyond the augmentation in shared bicycle usage. Many experts have observed an increase in the overall number of cyclists, and a positive shift in the social status associated with utilitarian cycling in general. In this specific case, the implementation of a shared bicycle system in the city not only improved the range of sustainable travel options, but it also truly contributed to the cycling culture in Montréal, which requires some further investigation in the near future.

Afterword

Despite its numerous benefits to the user as well as to society as a whole, the practice of conventional utilitarian cycling is considered relatively marginal in North America. Cycling innovations such as shared bicycle systems and cycling-transit integration are meant to encourage more individuals to include the bicycle in their travel habits. This research project is another demonstration that there is an interest among the population for new forms of cycling. People value the convenience and the flexibility these new cycling innovations offer. It is hoped that findings from this research will provide useful insight to maximize the potential of these cycling innovations.

More generally, cycling is gaining popularity throughout North America, partly due to the efforts of municipal and regional governments to make it a more pleasant, safe, and convenient travel mode. However, it cannot alone fulfill all mobility needs. In order to break free from the automobile paradigm that guided urban development in the last decades, we have to replace it by something else. Authorities have to provide a variety of efficient travel options that can advantageously compare with the car if they want to convince individuals to modify their travel behavior. Transportation professionals have to continue to innovate in terms of sustainable travel; yet the conception and implementation of cycling innovations such as shared bicycle programs and cycling-transit integration measures is a great step towards a more sustainable lifestyle.

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Appendix 1: Questionnaire of the cycling and transit integration survey

A- General questions

What is your age?

What is your gender?

What is your home postal code or nearest intersection? (This will provide us with your approximate home location. Your identity will remain anonymous)

Do you own a bicycle? (Y/N)

Have you ever had your bicycle stolen in Montreal?

1. If so, how many times?
2. If so, where was it stolen (most recently, if multiple times)? _______ & _______

How would you describe your general commuting pattern?

a. Regular commuting (usually same work/school destination)
b. Irregular commuting (many different work/school destinations)

Check the statement which most applies to you.

a. I use a bicycle for recreational purposes only
b. I use a bicycle occasionally for transportation
c. I use a bicycle regularly for transportation
d. I use a bicycle almost all of the time for transportation
e. I never use a bicycle

What is the intersection or postal code of your primary destination (work, school, etc.)

In each of the following months, what is your primary (most frequent) mode of travel to this destination?

If you purchase a monthly, unlimited transit pass, in which months do you do so? (check)

B - Transit questions

Do you ever use public transit? (yes / no→end of survey)

Which of the following modes of public transit have you used in the past year?

Of the modes used in the past year, how many times did you use each of them? Count each direction of travel as one trip. (Note: Bus + metro + bus = 3 modes)

a. bus: __ times per __
b. metro : __ times per __
c. train : __ times per __
d. bus + metro: __ times per __
e. bus + train: __ times per __
f. metro + train : __ times per __
g. 3 modes or more : __ times per __

Do you have a “regular” destination that you frequently visit by public transit? Y/N
If you have a “regular” trip made by public transit, how many different transit vehicles do you use? (eg. bus + metro + bus = 3) ___

If you have a “regular” trip by public transit, at what station / intersection do you access this transit form? (drop-down menu)

At what station / intersection do you leave transit? (2 fields..)

Integrating bicycle travel with public transit can provide new opportunities for improving both forms of transportation; however, it may be more useful for certain types of trips.

C – Cycling-Transit questions

Would you ever combine cycling and transit for a trip? (Y/N)

(if no) Why not?

(if yes)Which of the following trip types are you **most** likely to **replace** with a **combined bicycle-public transit trip?** (Either with a Bixi or your own bicycle)

a. Regular car trip (eg. to work, school)
b. Occasional car trip (eg. social visit, shopping, etc)
c. Regular bicycle trip
d. Occasional bicycle trip
e. Regular transit trip
f. Occasional transit trip

If you already integrate cycling with public transit or would consider doing so, which of the following combinations of cycling and transit would be most useful to you?

- **a. Cycle to transit stop and park bicycle + take transit + walk from transit**
  - i. Imagine you are **cycling** to a transit stop, **parking** your bicycle there, taking **transit**, and **walking** the remaining distance to your destination.
- **b. Cycle to transit stop and park bicycle + take transit + use another bicycle to destination (could be Bixi or your own).**
  - i. Imagine you are cycling to a transit stop, parking your bicycle there, taking transit, and bicycling to your destination with a bicycle present at the end of your transit trip
- **c. Cycle to stop + bring bicycle on transit + cycle to destination**
  - i. Imagine you are cycling to a transit stop, bringing your bicycle on transit, and then cycling to your destination.
- **d. Walk to transit stop + take transit + cycle to destination (could be Bixi or your own).**
  - Imagine you are walking to a transit stop, taking transit, and then cycling to your destination (could be Bixi or your own).

What is the maximum travel time you would spend on each portion of the trip? Answer only for the mode which is most relevant to you. (bus, metro, train)

Bringing bicycles on transit

Have you ever brought your bicycle on a transit vehicle? Y/N (N--> parking)

What are the main obstacles to bringing your bicycle on transit vehicles? (check all that apply)

a. Difficulties accessing or boarding transit vehicles with bicycles
b. Lack of adequate facilities for supporting bicycles on transit vehicles
c. Prohibitions against bringing bicycle on vehicles
d. Lack of bicycle paths near transit stations
e. Unpleasant cycling conditions around transit stations
f. Other _____

On average, how often **do you currently bring your bicycle** on the following transit vehicles? Count each direction of travel as one trip. (Note: Bus + metro + bus = 3 modes)

a. Bus: __ times per __
b. metro: __ times per __
c. train : __ times per __
d. bus + metro: __ times per __
e. bus + train: __ times per __
f. metro + train : __ times per __
g. 3 modes or more : __ times per __

*Parking your bicycle **at** transit stations*

Have you ever parked your personal bicycle at a transit stop Y/N (N--> Bixi)

What are the main obstacles to parking at a transit stop / station?

a. There are not enough bicycle racks
b. I need a covered bicycle rack
c. I need an indoor, secure bicycle rack or box
c. Lack of safe and convenient routes to bicycle to local transit station
d. I need my bicycle for other trips during the day
e. Other _____

On average, how many times per month **do you currently park your bicycle** at the following types of transit stops?

a. bus __ times per __
b. metro __ times per __
c. train ___times per __

At which of the following types of transit stops do you believe bicycle parking is most needed? (select one)

a. Bus
b. Train
c. Metro
    i. What is the maximum time you would park your bicycle there? ___ ___

D-Cycling and Bixi questions

Have you ever used a Bixi? Y/N → next section

If yes,

1. How many times per month in 2009?
2. How many times per month in 2010?

What type of membership do you generally have?

a. Pay-per-use
b. Monthly
c. Yearly

If you use Bixi, does your Bixi usage generally:

a. Replace a trip using a personal bicycle?
b. Replace a walking trip?
c. Replace a transit trip?
d. Replace a taxi trip?
e. Replace a car trip?
f. Add a trip you would not otherwise have made?

If you are a Bixi user, why do you use this service? (check all that apply)

a. Avoid hassle of maintaining a bicycle
b. I don't own a bicycle
c. I don't have space to store a bicycle when not in use
d. It is convenient to use in conjunction with public transportation
e. Attractive design of Bixis
f. It is practical to use a Bixi for a one-way trip
g. Bixi stations are well located for my purposes
h. Avoid the risk of theft
i. Other ______________________

Do you integrate other modes of transportation into your travel when you use BIXI bicycles?

a. Yes, I take the bus at the beginning of my trip
b. Yes, I take the bus at the end of my trip
c. Yes, I take the subway at the beginning of my trip
d. Yes, I take the subway at the end of my trip
e. Yes, I take a taxi at the beginning of my trip
f. Yes, I take a taxi at the end of my trip
g. No, I walk to the BIXI station at the beginning and end of my trip

E – Priorities

Based on your current needs, what are your priorities for improving bicycle-transit integration?

a. More bicycle racks in general
b. Covered bicycle racks
c. Indoor, secure bicycle parking stations or bicycle box
d. More bicycle paths around transit stations
e. Aids to accessing transit vehicles (ramps/elevators) inside stops
f. Racks to hold bicycles on transit vehicles
g. Increasing the number of hours when bicycles are permitted on transit vehicles

h. More Bixi stations near destination transit stop
i. More Bixi stations near home transit stop
j. Integrated transit-Bixi fare card
k. Other (specify)

What is your #1 priority for improving bicycle-transit integration?

a. More bicycle racks in general
b. Covered bicycle racks
c. Indoor, secure bicycle parking stations or bicycle box
d. More bicycle paths around transit stations
e. Aids to accessing transit vehicles (ramps/elevators) inside stops
f. Racks to hold bicycles on transit vehicles
g. Increasing the number of hours when bicycles are permitted on transit vehicles
h. More Bixi stations near destination transit stop
i. More Bixi stations near home transit stop
j. Integrated transit-Bixi fare card
k. Other (specify)

If applicable, where should your #1 priority to the previous question be located? _____

F - Demographic info and comments

What is your annual household income? (range)

How many people are there in your household?

How many children are there in your household?

Do you own a motor vehicle? (Y/N)

If you would like to be part of future surveys related to transportation issues in Montreal, please enter your email address. This information will not be shared.

What other recommendation(s) or comments do you have to improve the integration of bicycle travel with public transit?

Appendix 2: Factors with values of constituent variables

		1	2	3	4	5	6	7	8	9	10	11	12	13
Commitment to cycling	Metro per year	**-0.61**	0.01	0.05	-0.4	0.07	0.11	-0.07	-0.14	0.19	0.17	-0.06	0.05	0.09
	Bus per year	**-0.57**	0.10	0.03	-0.34	0.03	0.11	-0.03	-0.05	0.24	0.21	0.07	0.01	0.14
	Seasons cycling	**0.81**	0.08	0.07	-0.15	0.01	0.06	-0.08	-0.04	0.11	0.13	0.00	0.05	0.05
	Cyclist type	**0.84**	0.05	0.00	-0.25	0.05	0.05	-0.10	-0.01	0.12	0.08	0.03	0.02	0.05
Household size	People per household	0.04	**0.92**	-0.02	0.06	-0.03	0.01	0.01	-0.03	0.01	-0.01	0.03	0.01	0.03
	Children per household	0.08	**0.86**	0.09	0.01	-0.05	0.01	0.06	0.09	-0.03	0.01	0.00	0.03	-0.03
Occupation and income	Full-time worker	0.03	0.04	**0.90**	0.04	0.03	0.01	0.04	0.00	-0.01	-0.03	-0.01	-0.01	0.03
	Income	-0.04	0.48	**0.56**	0.21	0.11	-0.08	0.01	0.12	-0.08	-0.11	0.02	-0.06	-0.01
	Full-time student	-0.01	0.00	**-0.86**	-0.05	0.01	-0.02	-0.05	-0.2	0.01	-0.04	0.02	-0.02	0.02
Car potential	Replace car by bike-and-ride	0.13	0.01	0.15	**0.73**	-0.05	0.04	-0.07	-0.03	0.18	0.07	0.10	0.05	0.10
	Seasons driving	-0.21	0.10	0.02	**0.67**	-0.01	-0.01	0.19	0.13	-0.13	0.01	-0.07	0.00	-0.01
	Cars per household	-0.17	0.50	0.09	**0.56**	0.00	0.03	0.17	0.08	-0.09	-0.05	-0.09	-0.09	0.02
BIXI using	BIXI yearly membership	-0.01	0.00	0.06	-0.04	**0.91**	-0.02	-0.05	-0.03	0.06	0.01	0.01	0.02	0.02
	BIXI uses per month (2010)	0.01	-0.05	0.00	-0.02	**0.91**	0.00	-0.02	-0.03	0.07	0.01	0.00	-0.01	0.03

Currently bringing	Bringing on bus / year	-0.01	0.04	0.01	0.01	0.00	**0.91**	0.01	0.02	-0.04	-0.03	0.03	-0.01	-0.02
	Bringing on metro / year	0.00	-0.03	-0.02	0.01	-0.02	**0.91**	-0.01	0.02	0.08	0.04	-0.03	0.02	0.03
Poor transit service	Home to bus station	0.00	-0.01	0.03	0.01	0.00	-0.01	**0.88**	-0.02	0.00	0.01	-0.03	0.05	0.01
	Home to metro station	-0.11	0.11	0.06	0.14	-0.07	0.01	**0.85**	0.05	0.02	-0.01	0.02	-0.04	0.04
Experience	Years cycling	0.03	0.05	0.00	0.01	-0.01	0.02	-0.01	**0.90**	-0.02	0.03	-0.03	0.00	0.00
	Age	0.02	0.08	0.33	0.15	-0.08	0.02	0.05	**0.77**	-0.07	-0.03	0.00	0.00	-0.07
Transit potential	Willing to combine	0.10	-0.06	-0.01	0.25	0.09	0.09	-0.01	-0.03	**0.84**	0.15	0.09	0.06	0.06
	Replace transit by bike-and-ride	-0.07	-0.02	-0.05	-0.24	0.07	-0.05	0.04	-0.06	**0.76**	-0.10	-0.07	-0.02	-0.08
Currently parking	Parking at a bus stop	0.03	-0.04	0.01	0.11	0.01	-0.01	0.02	-0.07	-0.13	**0.77**	0.00	0.07	-0.02
	Parking at a metro station	-0.01	0.01	-0.04	-0.08	0.02	0.01	-0.02	0.07	0.16	**0.73**	-0.03	-0.08	0.00
Priority bringing racks	Priority : racks inside transit vehicles	0.06	0.01	-0.02	0.00	-0.03	0.01	0.02	-0.02	0.03	-0.05	**0.90**	0.17	0.15
Priority bringing time	Priority: Extend hours	0.17	0.00	0.00	0.02	-0.12	0.01	0.10	0.05	0.06	-0.05	-0.57	**0.55**	0.39
	Priority NOT indoor parking	0.00	0.00	0.02	-0.01	-0.04	-0.02	0.01	0.00	-0.02	-0.01	-0.16	**-0.91**	0.15
Priority not access to platform	Priority NOT Access	0.03	0.00	0.00	-0.07	-0.06	-0.01	-0.04	0.05	0.02	0.02	-0.08	0.10	**-0.92**