Modelling Reductions of Carbon Emissions Under Various Scenarios of a Public Bicycle Share System Within Vancouver, BC

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EXECUTIVE SUMMARY

This study estimates the impact of a public bicycle share system (PBS) in Vancouver on carbon dioxide (CO_2) emissions reduction due to transportation mode-switching from fuel-propelled vehicles to bicycles. There has been little research on the potential of bicycle share systems to reduce urban carbon emissions; the results of this study contextualize the effectiveness of a bicycle share system as a potential greenhouse gas (GHG) reduction strategy.

From our research and survey results we formulated a numerical model, which was used to approximate the magnitude of carbon dioxide emissions reduction (tonnes per year) as a result of the implementation of a PBS in Vancouver. Our numerical model incorporates significant variables --such as season (precipitation) and the current law in British Columbia requiring cyclists to wear a helmet-- which significantly impact the use of a PBS within Vancouver. The model domain considers a limited geographical area within the City of Vancouver. A survey (sample size 231) was conducted in the chosen domain to provide input data for the numerical model, information about citizens' preferences and concerns, and to gain valuable information pertaining to the potential success of a PBS in Vancouver.

The projected CO_2 emissions reduction ranged from 820 to 990 tonnes CO_2 per year depending on the modelled scenario. The results of this study indicate that the potential of CO_2 emissions reduction from mode-switching resulting from the use of a PBS in Vancouver is 0.07% potential minimum to 0.14% potential maximum of total annual transportation emissions within the City of Vancouver. Thus, a bicycle share system may be more effectively marketed as a strategy for increasing physical activity and improving the population's health and lifestyle rather than a strategy, which mainly focuses on reducing CO_2 emissions.

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1. Introduction

The City of Vancouver is looking to implement a public bicycle share system (PBS) in order to support active and healthy living, increase the overall volume of cycling trips in Vancouver, extend the reach of vehicle, transit and walking trips, and replace vehicle and transit trips (City of Vancouver, 2009 c). A PBS is a system that allows users to borrow bicycles for short term use, often for a fee. The bicycles are generally integrated with specific docking stations, which are equipt with user-friendly self-service interfaces to borrow the bicycles at a station and return them at the same or other docking stations (City of Vancouver, 2009 c).

1.1 Objectives

This study aims to determine the impact of a PBS on carbon dioxide (CO_2) emissions reduction from transportation mode-switching from fuel-propelled vehicles within the City of Vancouver. We determine the CO_2 reductions associated with implementing a PBS in Vancouver through a numerical model. This model incorporates variables such as season, precipitation, and the BC Motor Vehicle Act's requirement for mandatory helmet usage (hereby referred to as the "helmet law"). We also attempted to examine which factors affect the use of a bicycle share system, and the overall impacts of a PBS on decreasing carbon emissions under various scenarios.

1.2 A Brief History of Public Bicycle Share Systems

The first generation of PBS started in Amsterdam in 1965, with white bicycles throughout the city. They were available for everyone to use with no associated cost. This form of bicycle share was largely unsuccessful due to vandalism and theft. The idea persisted and the second generation of PBS was born in 1991 in Denmark. Since then a number of cities, including Copenhagen, have adopted PBS programs with minor alterations to the system. The Copenhagen bicycles had advertising plates in their wheels and were to be picked up and returned to designated stations with a coin deposit. Despite the small deposit, the bicycles were still susceptible to theft, which eventually gave rise to the more technologically advanced third generation of PBS. In 1996, the first of third generation bicycle share program was developed in Portsmouth University in England. This new generation was more secure due to the magnetic stripe cards which were required to rent the bicycles. PBS systems are currently in the third generation, where technology is used to track users, collect deposits, and access online reservation systems (DeMaio, 2009). PBS began to expand outside of Europe since 2008, with programs in Brazil, Chile, China, New Zealand, South Korea, Taiwan, Italy, and the United States (DeMaio, 2009).

These bicycle share systems can be further categorized by the organizations that administer the systems: public, private, non-profit organizations or partnerships between these groups. The progression of change to different generations of PBS has been slow; however, newer generations of bicycle share systems have been extremely successful in parts of Europe and North America (Shaheen et al., 2010). The accounts of successes in other countries have set the stage for the development of a PBS that will meet the needs of Vancouverites.

1.3 Literature Review: PBS and Cycling

There is a large amount of academic literature focusing on cycling as form of transportation in urban areas. *Cycling in Cities* is a research program at the University of British Columbia investigating factors that encourage or discourage cycling for urban transportation including motivators and deterrents of cycling, and transportation infrastructure associated with increased or decreased risks of injuries to cyclists (Cycling in Cities, 2012).

There have been numerous studies done on PBS programs, which examine: feasibility, transportation mode share, and capital and operating expenses. PBS programs have had a significant effect on increasing the proportion of the cycling population, improving public health, increasing public transit use, and decreasing greenhouse gases (DeMaio, 2009). With the bicycle share program available for short trips, more people are willing to use the public transit and as a result reduce the use of personal automobiles and corresponding greenhouse gas emissions (DeMaio, 2009). According to a survey conducted by the City of Vancouver, 75% of people said that they would use the PBS for errands/social/leisure trips (2009).

The proximity of docking stations to the household of potential users has been found to have the greatest impact on the likelihood of using PBS systems (Fuller et al., 2011). However, due to weather, time of the day, and public holidays, the total number of cyclists fluctuates throughout the year (City of Vancouver, 2011). Social surveys have gathered information about public acceptability and likelihood of use. From the feasibility study done for Vancouver in 2009 (sample size , 81% of the respondents said they would use a PBS system if it were implemented in Vancouver, and 7% of the respondents said that they would use the program to commute to work. (City of Vancouver, 2009 d).

Despite the existing literature on bicycle share systems and urban cycling, little research has been done on the potential reduction of greenhouse gas (GHG) emissions from mode-share changes when a bicycle share system is implemented. In fact, no studies to date have attempted to model the GHG emissions changes for the city of Vancouver with the introduction of a bicycle share system.

1.4 Context and Rationale

In the face of the environmental, economic and social costs linked to over-reliance on the automobile, urban planners and transportation professionals around the world are promoting sustainable alternatives such as walking, cycling, and public transit either as single modes or in combination (Bachand-Marleau, 2011).

In 2007, the provincial government of British Columbia (BC) declared a goal of reducing GHG emissions by 33% below 2007 levels by the year 2020 and 80% below 2007 levels by 2050 (Campbell, 2008; City of Vancouver, 2009 a). It will be particularly important to cut down automobile emissions, since it accounts for a third of the total GHG emission (City of Vancouver, 2009 a).

Vancouver has a high influx of immigrants and a population that is continuing to grow at a steady rate (AKCanada, 2011). This surging population has resulted in a rising number of transit and vehicle usages on the roads. This has created significant transit pressure and traffic congestion. Implementation of a PBS system may help to partially relieve these pressures by causing individuals to mode switch from transit or other vehicles to bicycles. BC's relatively high percentage of cyclists do not currently make a significant impact on GHG reductions since most of them are frequent cyclists who don't drive automobiles on a regular basis (Pucher & Buehler, 2005). Introducing a PBS system in Vancouver may encourage non-cyclists to cycle, and as a consequence may cause a mode shift from cars to bicycles. The City revealed interest in promoting a public cycling system in March 2009 (City of Vancouver, 2009 d). By implementing a properly designed bicycle share system, Vancouver may be able to decrease its greenhouse gas emissions from fuel vehicles, as well as mitigate transit pressure and traffic congestion. Cycling provides a cost-effective solution to alleviate the above symptoms and parallels the city's ambition of becoming the greenest city in the world by 2020 (City of Vancouver, 2009 b).

2. Methods

This study has two main components: a social survey and a numerical model. The scope of the study is restricted to a portion of the City of Vancouver, which comprises the domain of the model (Figure 1).

Figure 1: *Domain of model and survey. Red line indicates the zone boundaries.*

2.1 Population of Domain

We found the population size in our domain with the aid of graphical information system software (GIS) and Statistics Canada 2006. We calculated the adult population in each dissemination area in our research domain. We then used that information to map out the population density for survey distribution. Areas with higher population would require more survey results. Please refer to the population map in the Appendix C.

2.2 The Social Survey

We conducted a survey yielding 324 results, of that number we excluded people who lived outside our domain, leaving a sample size of 231. The survey was designed to gather data on the likelihoods of PBS use under various scenarios, as well as the magnitude of transportation mode switching from motor vehicles to bicycles for input into the numerical model. The survey also gathered data on citizens' preferences and concerns about a PBS, which is used for making recommendations for a successful PBS system in Vancouver in this report.

In order for individual responses to be included as valid data, there were two requirements the potential participant had to satisfy. First, he or she had to be 18 and older, and second, live within any of the zones listed in Figure 1. Our survey was reviewed and approved by the UBC Behavioural Research Ethics Board (Appendix D) The survey was only accessible online and for a period of five weeks in late February to Mid-March of 2012. Please refer to the survey questionnaire in the Appendix B.

2.3 The Numerical Model

We developed a numerical accounting model using Excel. The spreadsheet is available for download from cIRcle (https://circle.ubc.ca/).

2.3a. Model Descriptors: Definitions

Survey respondents who selected "yes" to using a PBS system are hereafter referred to as "users". "Ideally" refers to the survey projected usage of the PBS system without factoring in seasonal and helmet requirement factors. "Replaced" refers to LDV travel distance replaced by PBS bicycles. "Winter" refers to the 26 weeks from October to March inclusively. "Summer" refers to the 26 weeks from April to September inclusively.

2.3b. Model Calculations

The following is a list of values that were calculated within the model. For a detailed explanation of the calculations please refer to Appendix A. A conceptual flowchart representing the factors that contributed to the model is found in figure 2.

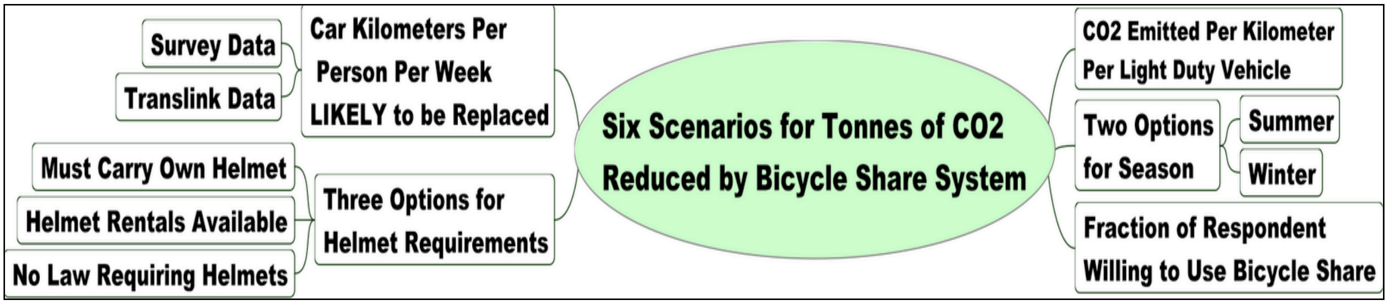

Figure 2: Conceptual flowchart for the proposed model

1. *Current LDV emissions within domain*
2. *Distance (km) ideally to be replaced by users*
3. *Probabilities of use given various conditions*
4. CO_2 *Reduction per week for various scenarios*
5. CO_2 *reduction per season (Winter, Summer)*
6. *Calculating weighted concerns*

2.4 Model Assumptions

A literature review indicates that any data set values for Metro Vancouver will include (but are not limited to) surrounding municipalities such as Surrey, Burnaby and West Vancouver. The scope of our project focused on a smaller portion, namely, a part of City of Vancouver and part of the Greater Vancouver Electoral A (i.e. University of British Columbia). In order to utilize Environment Canada data and data from the City Vancouver, we assumed a proportional relationship between the data and our domain.

In order to create a numerical model, we needed specific data that was attained via the survey that we administered. This survey was solely available in an electronic format that required internet access. Forms of advertising were limited to word of mouth, email listservs, paper flyers and handbills and social media such as Facebook. Due to time constraints, personal bias and platforms of advertising, we believe that there may be substantial bias in the surveyed participants.

To simplify our numerical model, we assumed that some factors such as winter and precipitation were not mutually exclusive (i.e. dependent). Instead we took the lower of the two values to create a conservative estimate for a coefficient value.

3. RESULTS and DISCUSSION

3.1. Trip Distribution by Distance and Activity

Figure 2 compares the trip length distribution for work, errand, post-secondary education, and recreational trips. Following data analysis, we realized that the survey lacked an option for people who were not attending post-secondary education or were not within in the labour force. These individuals were left with the only option of choosing ‘0 km’ to indicate that they were not part of either category. This would add a significant bias to our dataset and so the zero values were emitted from our graphed results below. It appeared that most people lived close to where they do their errands, assuming that the short distance of the majority of errand trips was reflective of the proximity of participants’ houses to the destination for their errands. In contrast, trips categorized under ‘recreation’ appear to be approximately 2 to 4 km further than errand based trips.

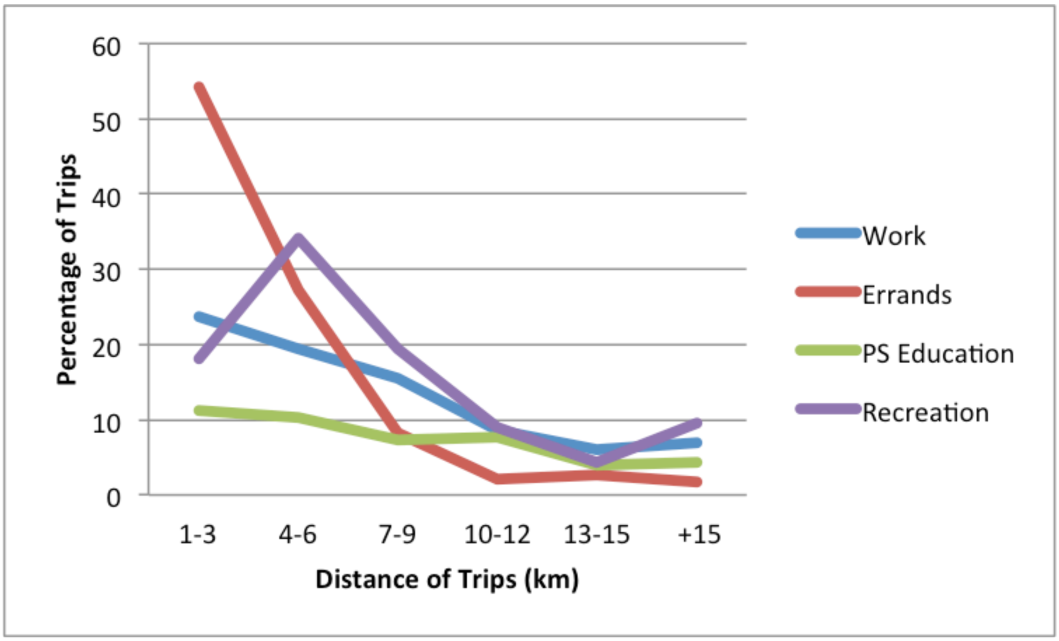

Figure 3: Distribution of trips by distance and category of activity based on survey results from all respondents.

Note that the unit for the y-axis in Figure 3 is percentage of trips; therefore, this figure cannot be used to yield the possible vehicle distances displaced with a PBS. This figure is used to describe the general distances the surveyed population currently travels for regularly performed activities. Lastly, the majority of survey respondents generally travel under 10km for any listed activity. These short travel distances increase the likelihood of a PBS system to succeed in reducing CO_2 emissions, since our survey data indicated that individuals were willing to travel distances up to and including 13 km. Recreation may refer to several activities- the PBS can be used for a utilitarian purpose (i.e. travelling to a recreational activity) or for leisure (i.e. riding a bicycle around scenic route). This difference in perspective will be an important inconsistency when considering how people answered survey questions on activities for which they would use the PBS (based on trip purpose categories).

3.2. Current and Potential CO_2 Reductions

The most recent emissions data from 2008 reports Vancouver's CO_2 emissions from light duty vehicles was approximately 880,000 tonnes per year, and was projected to remain the same into 2012 (City of Vancouver, 2009). Thus, in order to determine a net reduction of CO_2 emissions, we used this value to represent current emissions and to calculate percent reductions. The helmet law and the seasonal variation have the greatest effect on respondents decisions to use the bicycle share (Table 1) and were chosen as the significant variables in our model. Under each variable, the amount of CO_2 reduced was found to be greatest in the summer and lowest in the winter (Table 1). Respondents' preference of using the PBS in the summer is likely due to the weather patterns in Vancouver--the seasonal difference in temperature and the amount of precipitation. Vancouver experiences on average 1588 mm of precipitation annually, most of which falls in the winter, whereas Toronto and Montreal experience 830 mm and 980 mm of annual precipitation respectively (Environment Canada, 2011). Thus the greater amount of precipitation in Vancouver may be an extra challenge. It is clear that weather has a large impact on when and how often people are willing to bicycle.

Table 1. CO_2 reductions in tonnes per year under various scenarios.

TOTALS WITH HELMET LAW	**CO_2 Reduced (tonnes)**
Per Winter	330 ± 70
Per Summer	490 ± 110
Total Per Year	820 ±180
TOTALS WITH HELMET RENTAL	
Per Winter	340 ±70
Per Summer	590 ±130
Total Per Year	930 ± 200
TOTALS WITHOUT HELMET LAW	
Per Winter	410 ± 90
Per Summer	590 ± 130
Total Per Year	990 ± 220

Moreover, it is important to note that the amount of CO_2 reduced is significantly influenced by the helmet law. With the current law and no helmet rentals, the maximum potential CO_2 reduction would be 820 ± 180 tonnes per year. With the current helmet law and helmet rentals provided, there is a maximum potential reduction of 930 ± 200 tonnes per year. Finally, with no helmet law there is an even greater reduction of 990 ± 220 tonnes of CO_2 per year. This variation is based on survey results which indicate there is greater likelihood of using the PBS in Vancouver if there were either helmet rentals, or no requirement for helmets.

Other studies have shown that the social benefits of programs to increase cycling outweigh the greenhouse gas emissions reductions in the short term (Bansal and Morrow, 2011). In Washington, DC, increasing cycling and walking resulted in a short term reduction of 0.02% and a long term reduction of 0.3% of transportation emissions (Bansal and Morrow, 2011). This indicates two major findings: firstly, increasing bicycle trips has a greater effect over the long term than the short term. Secondly the short term reductions we calculated are seven times greater than the ones calculated by Bansal and Morrow. Thus the longer term reduction may have a greater potential to reduce CO_2 emissions within the City of Vancouver. The study completed by Bansal and Morrow found that due to low reductions of CO_2 emissions associated with specific transportation, strategies such as a PBS should not be implemented solely for the purpose of CO_2 reductions but also for other benefits such as increased health benefits, mobility and accessibility as well as lowering other pollutants (Bansal and Morrow, 2011). Individuals' choice of transportation impacts many aspects of their lives in relation to health: road accidents, psychological well-being, air and noise pollution as well as health-related accessibility issues (Kingham et al., 2001).

It is difficult to analyze and quantify the effect that strategies such as a PBS may have on greenhouse gas reductions. Generally, the importance of this type of mode-switching is noticed over a longer time scale (i.e. it is cumulative), yet it is often analyzed on a short term basis. By analyzing greenhouse gas emissions over the long term, better long term planning strategies can be developed (Bansal and Morrow, 2011). However, reductions on a short time scale are still important and can have a compounding effect on future emissions. Making early emission reduction targets can help the strategy gain momentum and support from the community (Bansal and Morrow, 2011).

3.3. Distance Replaced per Activity with PBS

There is a substantial difference in commute distances for work between the suburban areas of Metro Vancouver and the urban area of Vancouver. The median commute distance for Metro Vancouver is 7.4 km, whereas the median commute distance for the City of Vancouver is 5 km (Metro Vancouver, 2008). This indicates greater commute distances for those living in an area of lower population density (suburban areas). Our survey shows that people are most likely to use the PBS for trips under 7 km. Therefore, there is a greater likelihood that commuter trips can be replaced by the PBS as the median of commuter trips in Vancouver is 5 km. It should also be noted that Vancouver has been found to already have a large commuter population using bicycles as their main mode of transportation. Vancouver was ranked third after Portland and Minneapolis respectively, for number of bicycle commuters in North America (Pucher et al., 2011). Work trips comprise roughly 20% of all trips which makes them an excellent target for mode switching in order to reduce CO_2 emissions.

It is also important to note that commuter mode choices may reflect their concerns with a PBS system. For example, a study done on commuter mode choices in the United Kingdom had a significant number of respondents reply that less traffic on the roads would encourage them to cycle to work more often (Kingham et al., 2001). This creates a paradoxical situation: people are discouraged from cycling to work because they are concerned about the high volume of traffic related to single occupancy LDV, however, if more people were to cycle, then the traffic congestion would lessen. From the study done by Kingham et al. it is apparent that people were aware of both pollution and congestion due to excessive car use and that most people were prepared to act in some way to improve the situation (2001). However, convincing people to move out of their cars (specifically commuters) may be a difficult task as many people were concerned about the convenience of alternative transportation options (Kingham et al., 2001). If it were possible to get a lot of people occasionally to change their typical mode, this could have a significant impact on emissions as well as traffic levels and congestion which are related to high emission travel modes (Kingham et al., 2001).

Most people were willing to replace trips to their post-secondary education trips which were less than 5 km with bicycle share trips, suggesting a potential reduction of transit pressures to and from Zone B (University of British Columbia- Greater Electorial A). Since the trips which are most likely to be replaced are under 5 km, this would not solve the issue of high congestion and overcrowded buses during peak times in the Broadway corridor (City of Vancouver, 2010 a). Also, our survey indicated that many of the trips to post-secondary educational facilities are done by walking and cycling.

3.4. Ranking of Concerns with a PBS System

In order from highest to lowest, the top concerns that survey respondents had with implementing a PBS in Vancouver were poor weather, the helmet law, road safety and cycling infrastructure (Table 2). The majority of people were not overly concerned with night-time riding or end-of-trip facilities. It is interesting to note that safety was a top concern for cyclists in the city of Montreal when the BIXI Program was implemented (Bachand-Marleau, 2011). Nonetheless, it is difficult to directly compare concerns with a PBS specifically for Vancouver with the concerns of other cities because British Columbia is one of the few places in the world that has mandatory helmet legislation that is actively enforced. Melbourne, Australia is one of the few exceptions and that has both a helmet requirement and a PBS. However very few scientific articles have been published, there have been a number of news articles stating that the Melbourne Bicycle Share was not very successful in its first 2 years (Preiss, 2011).

Table 2. Weighted concerns associated with bicycle share system.

Concerns	Percentage of Total	Standard Error
Poor weather conditions	21.54	0.009
Helmet law (i.e. the helmet is NOT included in the bicycle rental)	19.83	0.009
Road safety	14.43	0.009
Current cycling infrastructure (e.g. bicycle lanes)	13.01	0.009
Transporting materials (e.g. electronics, groceries)	11.37	0.009
Costs	9.38	0.0108
End of trip facilities (e.g. shower station, lockers, etc)	6.61	0.013
Night time riding	3.84	0.013

A study on concerns with cycling in cities and health benefits found that the health benefits far exceed any health risks from traffic injuries. This indicates that our surveyed population has a misconception about the magnitude of the dangers of cycling, which is common in many cities (Pucher et al., 2010). In a comparative study of North American cities which have PBS systems, Vancouver was found to have the fewest annual fatalities per year than any other city in North America (Pucher et al., 2011). Increasing educational programs regarding cycling and road safety may help alleviate safety concerns. Moreover, the Pucher et al. revealed that as cycling levels increased, injury rates fell, which made cycling safer and provided greater net health benefits (2010). It has also been found that cities with outstanding bicycle safety rates and high levels of cycling tend to be cities which have extensive infrastructure and pro-bicycle policies and programs (Pucher et al., 2010). Thus, improving infrastructure and implementing these programs may increase the success of this PBS by helping to address safety concerns regarding cycling.

Vancouver has been steadily improving its cycling infrastructure, which will encourage more cyclists and thus more PBS users. Over the past seventeen years, Vancouver has implemented a number of programs to increase cycling rates in Vancouver, specifically on cycling infrastructure development. So far, major programs which have taken place in Vancouver include: the Greenways Plan, the Cycling Plan, Downtown Transport Plan, and the Cycling Network (Scott, 2009). All of these implemented plans or programs have helped to increase the distance and connectivity of cycling routes within Vancouver. The programs also improved laneways for bicycles by installing separated bicycle lanes and painted bicycle routes (Scott, 2009). Bicycle lanes encourage higher levels of cycling within cities, which is reflected in a number of statistically significant relationships from various studies (Pucher et al., 2010). A study done at the city level of over forty American cities found that each additional mile of bicycle lane per square mile corresponded with a 1% increase in the share of workers who regularly commute by bicycle (Pucher et al., 2010). Furthermore, in Seattle, it was found that the closer someone lives to a bicycle lane, the more likely they are to use it (Pucher et al., 2010). From that notion, increasing the number of bicycle routes may help to increase ridership. In addition, a study of regular commuters in the UK concluded that a significant number of respondents would cycle more with the improvement of cycling facilities (Kingham et al., 2001).

Other concerns with a PBS for Vancouver included the convenience of bicycle docking stations. From a social survey implemented in another study, 57% of respondents seemed to be highly concerned with the convenience and proximity of docking stations (Scott, 2009).

3.5. Willingness to use the PBS: Weather Conditions

There was high variation in the percentage of people willing to use the PBS in the summer versus the winter (Table 3). This confirms previous studies done in 2009 regarding the implementation of a PBS for Vancouver (Scott, 2009). Of the survey respondents who said that they would use the PBS, approximately 48% were willing to use the bicycle share in the winter, whereas approximately 77% were willing to use it in the summer. These results directly corresponded with the values obtained during the PBS trial which took place near the Science Center on the seawall in the summer of 2009 (Scott). The values were approximately 80% and 48% of respondents were willing to use the PBS during the summer and winter months respectively (Scott, 2009). This observation was mostly attributed to different weather conditions between the seasons. As Vancouver has heavy rainfall in the winter months, many cyclists may be discouraged from using the bicycle share program in the winter.

Table 3: Percentage of people surveyed who are willing to use the bicycle share under the following conditions from the survey results

Conditions	**Percentage (%)**
Winter	47.7
Summer	76.7
Rainy	43.1
With Helmet Law	46.1
With Helmet Law and Rentals	48
Without Helmet Law	**57.3**

Next, the helmet law also had a large influence on whether people will use the bicycle share program. Of the respondents who answered “yes” to using the bicycle share program, 46% of the respondents would use it if they were required to carry their own helmet, 48% would use the bicycle share program with current law but with helmet rentals as optional, and 57% would use the bicycle share program without a helmet law (Table 3). It is evident that the helmet law was a big concern for people interested in using the bicycle share program and could potentially act as an inhibitor to the success of a bicycle share program.

3.6. User Cost Preferences

From figure 4, it appears that the majority of respondents were willing to pay a maximum monthly fee of 10 dollars. Many respondents who commented on this section of the survey stated that they would use the PBS occasionally and thus would prefer to not purchase a membership but instead opt for a pay per use fee. Next, a study on the PBS system in Montreal indicated that 63% of sampled population would integrate PBS use with public transit (Fuller et al., 2011). Thus, having transit passes which are transferable between the PBS and public transit services may enhance usage of the PBS. To further support this, 62 % of the people who would be willing to use the PBS in our survey said they would be highly likely to use it if it were included in a transit pass.

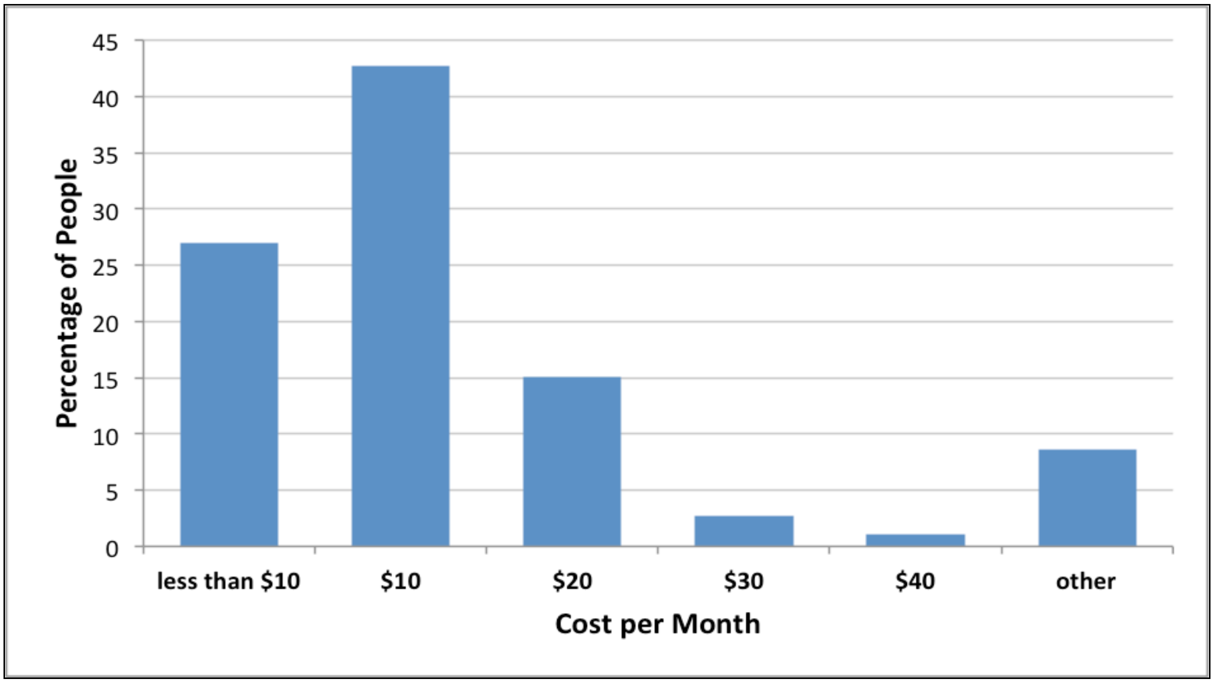

Figure 4: Maximum amount people are willing to pay for bicycle share system.

3.7. Discussion: Impact of Errors on Model

Bias may have had a large impact on our model output. Firstly, our networking was most effective at reaching the demographics aged 18-25. Secondly, volunteer bias may have been important. Individuals with an interest in cycling or vehicle cooperatives would be more likely to be willing to complete our survey than someone with a neutral standpoint. Survey respondents reported unusually high values for walking and cycling. These discrepancies may also reflect a bias in the people who have been surveyed.

We used census data to find the actual proportion of the population that lives in each zone considered in this model (Figure 1), and compared this to the proportion of respondents who live in each zone. We considered the difference between these proportions to be significant when it was greater than 5%. Within our survey there was overrepresentation and underrepresentation of specific zones: Zones A and E were significantly underrepresented, while zones B and C were significantly overrepresented. Basic statistical analysis indicated that there were significant differences between the zones, and this may have had an important impact on our results.

4. CONCLUSION

Through our research, we found that CO_2 emissions for LDVs were 880,000 tonnes/year in 2008; this value was also forecasted to remain the same for 2012. With the implementation of a PBS in Vancouver, we expect the potential maximum CO_2

reduction to be 1,210 tonnes/year. Comparing the pre and post-bicycle share scenarios, this yields a 0.14% maximum potential reduction of total LDV CO_2 emissions. According to our survey data collection, the top concerns that affect individuals' willingness to use a bicycle share system, in descending order, are: the poor weather condition, helmet law, road safety, and current cycling infrastructure.

4.1. Study Implications

Initially, we created research project based on the idea that a PBS would result in CO_2 emission reduction. However, upon more intensive research we noticed that many cities had different goals for implementing a PBS such as alleviating traffic pressures and improving public health. In the short term it seems that greenhouse gas emissions reductions will be largely overshadowed by the social impacts of implementing a PBS system. However, the use of the system may gain momentum over-time, and the increased bicycle use may have spill over effects that lead to a larger decrease in greenhouse gas emissions over the long term.

4.2. Recommendations

From the analysis of our social survey, it appeared that the majority of people were more likely to cycle distances within a 5 km range. Hence, it would be reasonable to install bicycle share docking stations at a maximum of 5 km apart. Nonetheless, ideally they should be closer than this to encourage short bicycle trips. All major transit hubs and areas for connections such as bus loops and skytrain stops are ideal locations to situate a PBS station. As the helmet law has a large influence on the usage of PBS, it could be beneficial if the city of Vancouver make the helmet law optional.

In regard to prices, the cost of using a PBS should be cheaper or the same as a single zone bus ticket (i.e. $2.50 per use) to encourage use of bicycle share over transit. A potentially effective strategy would be to include the PBS as part of the bus passes since 62% of potential users said they would be more likely to use the PBS if it was included in a transit pass.

Weather conditions remain a main deterrent on individuals' willingness to bicycle. Our social survey indicated that people are less likely to use bicycle share during winter. To alleviate this challenge, end-of-trip facilities could be set up for users to change, shower, rent helmets, and store bicycles. Providing such services not only gives user comforts and safe storage, but it also shields the bikes from elements that causes wear and tear. Alternatively, Vancouver could consider having a seasonal PBS that only operates in the summer.

5. ACKNOWLEDGEMENTS

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APPENDIX A: Model Calculations

1. Finding current emissions:

We separated current CO_2 emissions for light-duty vehicles (LDV) and buses. We assumed zero emissions from bicycles as we did not factor in the production or transportation of bicycles.

Total LDV CO_2 emissions in domain:

$e_{d,LDV} = AT \times D \times n \times e_{LDV}$

$e_{d,LDV}$ = total LDV CO_2 emissions in domain (g/week):
AT = average number of trips made per person per week (trips/[person $\times$week]), provided by Translink
D = trip distance distribution (km), provided by Translink
n = population of our domain (person)
e_{LDV} = CO_2 emissions for an average LDV in Vancouver (g/km), provided by Aircare

Total bus CO_2 emissions in domain:

$e_{d,BUS} = e_{BUS} \times d \times f$

$e_{d,BUS}$ = Total bus CO_2 emissions in domain (g/day)
e_{BUS}= average CO_2 emissions for buses (g/km)
d= distances travelled per trip (km)
f = frequency of bus trips per day (1/day)

2. *Finding distance (km) ideally to be replaced by users*

a. Trip distance distribution**** (from Translink) / person / day $\times$ number of trips / person / week (Translink) = Trip distance distribution / person / week
b. Trip length distribution was cut off at the maximum number of kilometers that survey respondents were willing to travel on a PBS bicycle to give [Trip length distribution PBS replaceable trips / user / week].
c. [Trip length distribution under 13 km / user / week] SUMMARIZED to [total distance of PBS replaceable trips / user / week]
d. [total distance of PBS replaceable trips] * [fraction of trips users willing to replace] * [fraction of travel distance users were willing to replace] = [car travel distance / user / week ideally replaced by PBS].

3. *Probabilities of use given various conditions*

a. PR[rain in winter] * (MINIMUM of PR[user uses in the rain] AND PR[user uses in winter]) + PR[not rain in winter] * PR[user uses in winter] = PR[user uses in winter]
b. PR[rain in summer] * (MINIMUM of PR[user uses in the rain] AND PR[user uses in summer]) + PR[not rain in summer] * PR[user uses in summer] = PR[user uses in summer]

a. PR[user uses if required to carry own helmet], PR[user uses if helmet rentals are available], and PR[user uses if not required to wear a helmet by law], were all taken directly from the survey results.

4. *Finding* CO_2 *Reduction per week for various scenarios*

a. [Fraction of respondents willing to use the PBS ("users")]*[car travel distance (km) / user / week ideally replaced by PBS] * [CO_2 / typical light duty vehicle / distance (km)] * [population of domain]= [CO_2 / day ideally replaced by PBS]
b. [CO_2 / day ideally replaced by PBS] * PR[user uses in winter] * PR[user uses if required to carry own helmet] = [CO_2 reduced / week during winter if users must carry their own helmet]
c. [CO_2 / day ideally replaced by PBS] * PR[user uses in summer] * PR[user uses if required to carry own helmet] = [CO_2 reduced / week during summer if users must carry their own helmet]
d. [CO_2 / day ideally replaced by PBS] * PR[user uses in winter] * PR[user uses if helmet rentals are available] = [CO_2 reduced / week during winter if helmet rentals are available]
e. [CO_2 / day ideally replaced by PBS] * PR[user uses in summer] * PR[user uses if helmet rentals are available] = [CO_2 reduced / week during summer if helmet rentals are available]
f. [CO_2 / day ideally replaced by PBS] * PR[user uses in winter] * PR[user uses if there were no law requiring helmets] = [CO_2 reduced / week during winter if there were no law requiring helmets]
g. [CO_2 / day ideally replaced by PBS] * PR[user uses in summer] * PR[user uses if there were no law requiring helmets] = [CO_2 reduced / week during summer if there were no law requiring helmets]

5. Finding CO_2 *reduction per season*

a. [CO_2 reduced / week during winter if users must carry their own helmet] * 26 weeks = [CO_2 reduced / during winter if users must carry their own helmet]
b. [CO_2 reduced / week during summer if users must carry their own helmet] * 26 weeks = [CO_2 reduced / during summer if users must carry their own helmet]
c. [CO_2 reduced / week during winter if helmet rentals are available] * 26 weeks = [CO_2 reduced / during winter if helmet rentals are available]
d. [CO_2 reduced / week during summer if helmet rentals are available] * 26 weeks = [CO_2 reduced / during summer if helmet rentals are available]
e. [CO_2 reduced / week during winter if there were no law requiring helmets] * 26 weeks = [CO_2 reduced / during winter if there were no law requiring helmets]

6. *Calculating weighted concerns*

are found by multiplying the highest concern by 4, the second highest concern by 2 and the third highest concern by 1. The percentage represents the count for each concern divided by the total count for all concerns.

information contained in the files listed is accurate, complete or current. Neither The South Coast British Columbia Transportation Authority nor any third parties, employees or other representatives will be liable for any damage of any kind, including, without limitation, direct, special, indirect, consequential, punitive or exemplary damages for loss of income profit or savings, and claims of third parties, arising out of or in connection with the use of the files provided. All files are released “as is” and cannot be re-distributed without permission.

APPENDIX B: Survey Questionnaire

We conducted a survey to help us factor the bicycle share into our model. We asked respondents whether or not they would use the bicycle share, how likely they were to use it under certain conditions (winter, rain, summer), with the current helmet law, without a helmet law, with helmet rentals, and the distance of one way trip they would be willing to replace with the bicycle share. Likelihoods were presented as very likely, likely, don't know/ unsure, unlikely, and very unlikely. We took these as probabilities that an individual would use the bicycle share under each condition, with very likely, likely, don't know/ unsure, unlikely, and very unlikely, corresponding to the following probabilities; .9, .7, .5, .3, and .1 respectively.

Survey Questionnaire:

1) **Which gender do you identify with?**

    a. Male
    b. Female
    c. Other or prefer not to disclose

2) **What is your age?**

    a. 18-25
    b. 25-35
    c. 35-45
    d. 45-65
    e. 65+

3) **Which of the following best describes your current occupation?**

    a. Student
    b Research or lab work
    c. Trades (eg. construction, plumbing)
    d. Office work
    e. Retail / sales / service
    f. Other (please specify)

If you selected other, please specify

____

4) **Would you use the bike share system?**

    a. Yes
    b. No

5) Please identify what zone you live in (see map):

a. Zone A
b. Zone B
c. Zone C
d. Zone D
e. Zone E
f. Zone F
g. Zone G
h. Zone H
i. Zone I
j. Zone J
k. None of the listed zones
l. None: I am visiting

6) Please identify what zone your workplace is in (see map):

a. Not Applicable
b. Zone A
c. Zone B
d. Zone C
e. Zone D
f. Zone E
g. Zone F
h. Zone F
i. Zone G
j. Zone H
k. Zone I
l. Zone J
m. None of the listed zones

7) Please identify which zone your post secondary institute is in (see map):

a. Not Applicable
b. Zone A
c. Zone B
d. Zone C
e. Zone D
f. Zone E
g. Zone F
h. Zone F
i. Zone G
j. Zone H
k. Zone I
l. Zone J

m. None of the listed zones

8) What is your typical mode of transportation for the following activities. Please choose all that apply:

	Walking	Cycling	Driving (Single Occupancy Vehicle)	Carpooling	Public transportation (e.g. bus or skytrain)	Not Applicable
Work	q	q	q	q	q	q
Post secondary education	q	q	q	q	q	q
Personal errands	q	q	q	q	q	q
Social and recreational activities	q	q	q	q	q	q

9) How likely would you be to use public transit (or use it more often) if it was less crowded?

a. Very Unlikely
b. Unlikely
c. Don't know/ unsure/ not applicable
d. Likely
e. Very Likely
f. Does not affect my decision

10) Which of the following activities would you use the bike share for? Check all that apply.

a. Work
b. Post secondary education
c. Errands
d. Social and recreational activities
e. Other (please specify)

If you selected other, please specify

____

11) On average how many one way trips per week do you make for:

	0	1-3	4-6	7-9	10 or more
Work	m	m	m	m	M
Post secondary education	m	m	m	m	M
Errands	m	m	m	m	M
Social and Recreational Activities (e.g. dining out, etc)	m	m	m	m	M

12) On average how many one way car trips per week would you replace with the bike share system:

	0	1-3	4-6	7-9	10 or more
Work	m	m	m	m	M
Post secondary education	m	m	m	m	M
Errands	m	m	m	m	M
Social and Recreational Activities (e.g. dining out, etc)	m	m	m	m	M

13) In an average week, how far is a one way trip (in km) for:

	0	1-3	4-6	7-9	10-12	13-15	Over 15
Work	m	m	m	m	m	m	M
Errands	m	m	m	m	m	m	M
Post secondary education	m	m	m	m	m	m	M
Recreation and Leisure	m	m	m	m	m	m	M

14) How many km for one trip by car would you replace with the bike share?

	0	1-3	4-6	7-9	10-12	13-15	Over 15
Work	m	m	m	m	m	m	M
Errands	m	m	m	m	m	m	M
Post secondary education	m	m	m	m	m	m	M
Recreation and Leisure	m	m	m	m	m	m	M

15) How likely would you be to use the bike share under the following conditions?

	Very unlikely	Unlikely	Don't know/ Unsure	Likely	Very likely	Does not affect decision
Winter	m	m	m	m	m	M
Summer	m	m	m	m	m	M
Rainy conditions	m	m	m	m	m	M
With the current helmet law (i.e. you are required to carry your own helmet)	m	m	m	m	m	M
With the current helmet law, but where helment rental would be available	m	m	m	m	m	M
Without a law requiring helmets	m	m	m	m	m	M

16) What is the maximum amount you would be willing to pay for access to the bike share ?

a. Less than $10 per month
b. $10 per month
c. $20 per month

d. $30 per month
e. $40 per month
f. Other (please specify)

If you selected other, please specify
____

17) How likely are you to use the bike share if the service was included in a transit pass? (Eg. Zone transit passes or U-Pass)

a. Very Unlikely
b. Unlikely
c. Don't know/ unsure/ not applicable
d. Likely
e. Very Likely

18) Please rank your concerns with a public bike share system in Vancouver with 1 being the largest concern.

helmet law (i.e. the helmet is **NOT** included in the bike rental)	____________
current cycling infrastructure (e.g. bike lanes)	____________
end of trip facilities (e.g. shower station, lockers, etc)	____________
road safety	____________
poor weather conditions	____________
Costs	____________
night time riding	____________
transporting materials (e.g. electronics, groceries)	____________

Thank you for completing our survey!

APPENDIX C: Survey Sample Demographics

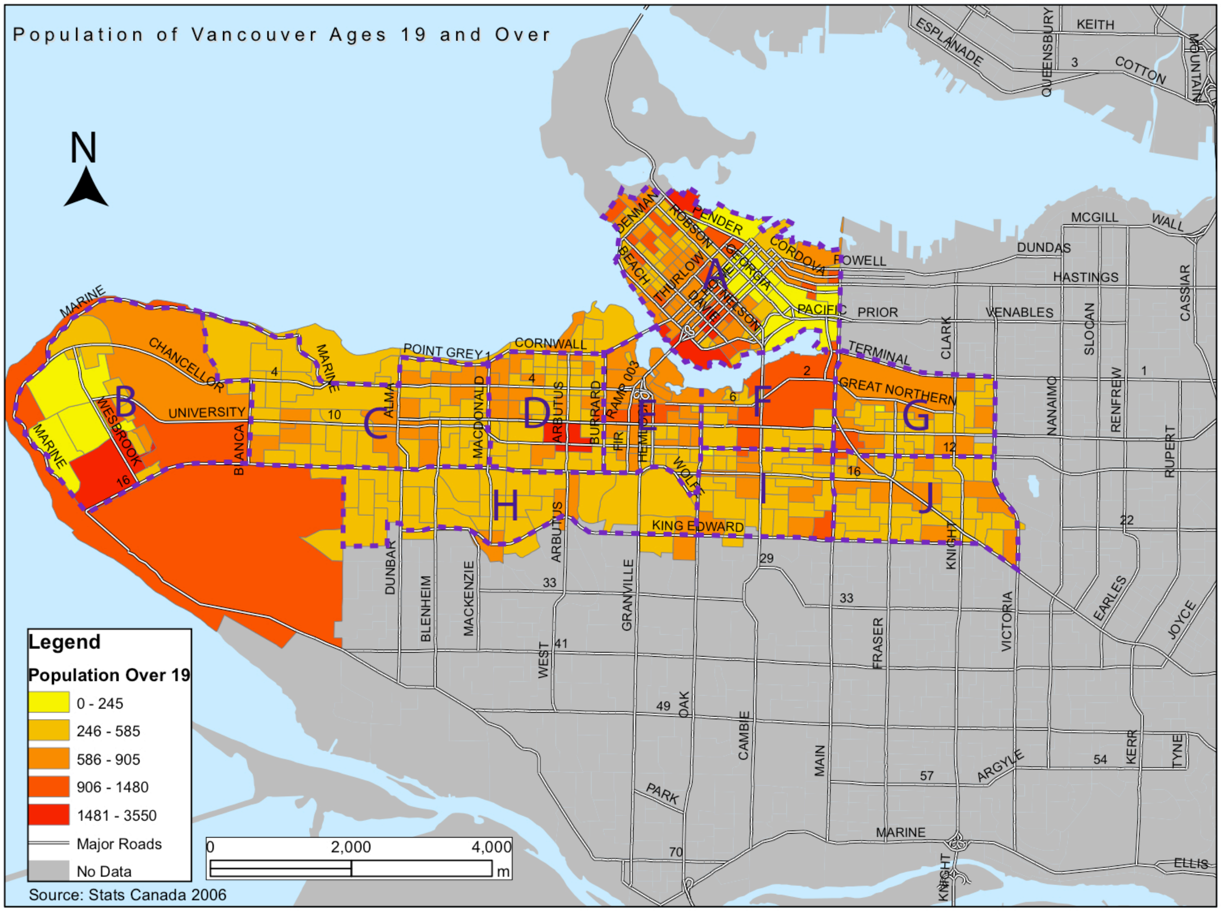

Figure C1: Adult population density within domain.

Table C1: Willingness to use bicycle share program grouped by zone of residence.

Residence	Yes	No	Total Count
Zone A	35	10	45
Zone B	23	5	28
Zone C	41	5	46
Zone D	23	7	30
Zone E	8	3	11
Zone F	11	4	15
Zone G	19	2	21
Zone H	10	6	16
Zone I	9	4	13
Zone J	5	1	6
Total			231

Table C2: Survey results of distance willing to travel on bicycle share system, grouped by zone of residence.

	1-3km	4-6km	7-9km	10-12km	13-15km	>15 km
Zone A	41	14	2	1	3	2
Zone B	32	9	3	2	0	8
Zone C	34	21	18	1	0	2
Zone D	25	15	4	0	0	0
Zone E	6	3	0	0	0	0
Zone F	9	3	0	0	0	0
Zone G	14	6	2	2	1	0
Zone H	12	2	1	0	0	1
Zone I	6	4	4	2	0	0
Zone J	4	0	1	1	1	0

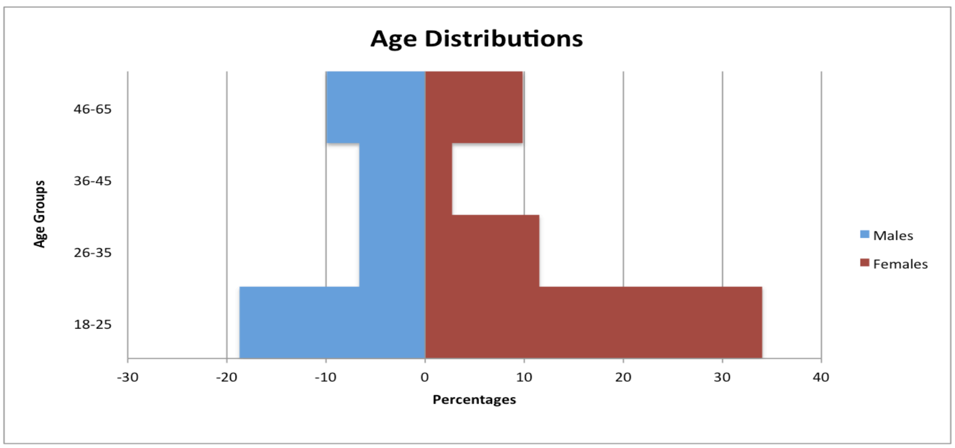

Figure C3: Age and gender distribution of survey participants.

APPENDIX D: Ethics Board Approval Certificate

The University of British Columbia
Office of Research Services
Behavioural Research Ethics Board
Suite 102, 6190 Agronomy Road, Vancouver, B.C. V6T 1Z3

CERTIFICATE OF APPROVAL - MINIMAL RISK

PRINCIPAL INVESTIGATOR:	INSTITUTION / DEPARTMENT:	UBC BREB NUMBER:
Douw G. Steyn	UBC/Science/Earth & Ocean Sciences	H11-03217

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT:

Institution	Site
UBC	Vancouver (excludes UBC Hospital)

CO-INVESTIGATOR(S):
Erin S. Lane

SPONSORING AGENCIES:
N/A

PROJECT TITLE:
Modelling Reductions of Carbon Emissions Under Various Scenarios of Bike Share Systems Within Vancouver, BC

CERTIFICATE EXPIRY DATE: February 20, 2013

DOCUMENTS INCLUDED IN THIS APPROVAL: **DATE APPROVED: February 20, 2012**

Document Name	Version	Date
Consent Forms:		
Consent Form	2	February 14, 2012
Consent Form - February 10, 2012	N/A	February 10, 2012
Advertisements:		
Flyer	N/A	February 14, 2012
Questionnaire, Questionnaire Cover Letter, Tests:		
Survey/Questionnaire Public Bike Share System	N/A	January 6, 2012
Other:		
http://www.surveyfeedback.ca/surveys/wsb.dll/s/1g1555		

The application for ethical review and the document(s) listed above have been reviewed and the procedures were found to be acceptable on ethical grounds for research involving human subjects.

This study has been approved either by the full Behavioural REB or by an authorized delegated reviewer