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WINTER CYCLING IN VERY COLD CLIMATE – A CASE STUDY IN CALGARY

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ABSTRACT

A survey was conducted among cyclists in the city of Calgary, Canada, to identify the characteristics of winter cyclists in a metropolitan area with a very cold climate, and to investigate what variables are most likely to affect their cycling behavior. The findings of the survey reveal that even very low temperatures do not appear to be a major concern for most participants. Instead, the majority of cyclists mentioned road surface conditions, rather than the weather itself, to be the major deterrent to winter cycling. In order to analyze the direct and indirect relationships between the different variables affecting winter cycling, a multi-layered model was developed. The model distinguishes between the cyclists' inherent characteristics, cycling behavior variables and motivating factors that could both affect cycling behavior and be affected by inherent characteristics. Since the cyclists' inherent characteristics, such as age and gender, cannot be changed, identifying and addressing the cyclists' motivating factors could be a key to influencing cycling behavior.

Keywords: Cold Climate, Cyclists Characteristics, Cycling Behaviour, Statistical Analysis, Winter Cycling

1. INTRODUCTION

Car-based transportation has a negative impact on the environment, through air pollution, congestion, noise, and extensive land use for roads and parking facilities.

The importance of bringing about an increase in cycling as a method to reduce motor traffic has consequently been widely recognized over the past two decades (Hillman and Maughan, 1992). In addition to its beneficial impact on the environment, cycling also positively affects the health of individuals, and is accessible by all layers of society and economically affordable, hence addressing all three aspects of environmental, social and economical of sustainability (Pucher and Buehler 2008). For the above reasons, cycling is considered as an important and strategic mode of transportation in urban areas (Andrade et al., 2011; Brandenburg et al., 2007).

Past research indicates that the construction of cycling facilities in urban areas (i.e. off-street bike paths and on-street bike lanes) is associated with an increase in cycling (Buehler & Pucher, 2012). The construction of cycling facilities is, however, a major investment for cities. The six largest metropolitan areas in Canada – Toronto, Montreal, Vancouver, Ottawa, Calgary and Edmonton – have all initiated extensive initiatives to facilitate cycling, by providing additional bike paths and lanes and ample bike parking. With the exception of the province of Quebec, these initiatives are almost entirely dependent on municipal funding (Pucher & Buehler, 2006). Similar to other metropolitan areas, the city of Calgary has made major investments in order to support cycling, creating one of the most extensive networks of bike paths and lanes per capita in North America (Pucher & Buehler, 2006). Calgary's initiative is accompanied by policies to encourage the integration of transit and cycling, such as safe and secure bicycle parking at transit stations, allowing bicycles on trains and buses and improvements to bicycle routes and transit station access (CTP, 2009).

From an environmental perspective, it is especially important to reduce the number of car trips in wintertime, when colder ambient temperatures increase the emission rates for some pollutants caused by traffic (Bergström & Magnusson, 2003). However, cycling is generally considered to be constrained by weather conditions such as rain, strong winds and low temperatures (Nankervis, 1999). Therefore the benefit of investments in cycling facilities in cities with a very cold climate, such as Calgary, is uncertain in light of the extreme conditions prevailing during the extended winter season. A very cold climate zone is defined as a region with more than 5,000 heating degree days or greater, on an 180C basis, and less than 7,000 heating degree days (ASHRAE, 2007). Cities with a very cold climate can also be uncertain how to plan their cycling facilities, in light of the requirements of those who do cycle during winter. Questions include: how extended should the bike paths and lanes be, in light of the distances that winter cyclists are likely to cycle? And how should cycling infrastructure be maintained in order to satisfy the needs of those who cycle in winter?

The objective of the present research is to identify the characteristics of winter cyclists in a metropolitan area in North America with a very cold climate classification, and to investigate what variables are most likely to affect their cycling behavior. The results of this study can assist cities with a very cold climate in planning new cycling facilities, and maintaining existing ones, to support winter cycling.

2. LITERATURE REVIEW

A number of variables that can impact cycling in metropolitan areas were identified through an extensive review of cycling research literature. These variables include the gender and age of cyclists; trip distance and urban morphology; cycling safety; cycling facilities and route conditions; weather conditions; trip purpose; and use of intermodal transportation. Following is a summary of the literature on each one of these variables.

1) Gender and Age: Studies conducted in North America show that an individual's age is negatively associated with cycling, and that women are less likely to cycle than men (Kim & Ulfarsson, 2008; Moudon et al., 2005). In North America, cycling is more popular among male, younger adults, who are physically active and in good health. In Europe, on the other hand, men *and* women are equally likely to cycle, and cycling rates vary little across age strata (Winters et al., 2007). This indicates that there might be an opportunity in North America to increase cycling among women and older adults.

2) Trip distance and urban morphology: An increase in the distance between home and work tends to decrease the number of trips by bicycle (Bergström & Magnusson, 2003). This decrease becomes even more significant in winter. Similarly, greater proximity to offices, clinics, and restaurants contributes to the likelihood of cycling (Moudon et al., 2005). Pucher & Buehler (2006) identified higher densities and mixed-use development in Canadian cities, compared with cities in the U.S., as causes for Canada's relatively higher cycling rates. However, the most recent data shows that Canadian commuters spend an average of 25.4 minutes travelling to work, which is almost identical to the average in the United States (25.5 minutes) (Statistics Canada, 2011). Moreover, no correlation was found by the authors between cycling rates and commute times when comparing different Canadian metropolitan areas. Calgary specifically has a higher than average commute time, and a slightly lower than average cycling rate (Statistics Canada, 2011).

3) Cycling Safety: Higher cycling rates have been found to be strongly correlated with lower levels of cycling deaths and injuries.

Higher cycling rates have been considered to create a virtuous cycle that increases safety. In other words, safer cycling encourages more people to cycle, and as more people cycle, more cycling facilities will be provided and more consideration by motorists will be given to cyclists, which in turn make cycling even safer (Pucher & Buehler, 2006).

4) *Cycling facilities and route conditions:* Cities with more extensive cycling facilities have significantly higher rates of commuting by bikes (Buehler & Pucher, 2012). The road conditions on bike paths and lanes are, however, very important. A survey study in Sweden found that around 40% of the respondents stated that they would cycle more during winter, if the maintenance service level of bike paths were improved (Bergström & Magnusson, 2003). The most recurrent desires they expressed were more frequent snow clearance and de-icing. These findings echo the results of a survey in Vancouver, Canada, in which the top deterrent of cycling was identified as the route being icy or snowy (Winters et al., 2011).

5) *Climate and weather conditions:* The impact of route conditions during winter on cycling alludes to the importance of weather conditions. Various studies found rain, snow and freezing weather to be associated with lower levels of cycling (Flynn et al. 2012; Miranda-Moreno & Lahti, 2013; Nankervis, 1999; Thomas et al., 2009; Winters et al., 2007). These studies report a decrease of 30%-50% in cycling rates during winter, accompanied by an increase in the number of car trips. One study found low temperatures to be more important to women than to men (Bergström & Magnusson, 2003). It should be noted, that these findings reflect differences between cycling rates in summer and in winter at the same location. When different large cities are compared, annual precipitation and the number of cold and hot days are not found to be statistically significant predictors of the rates of commuting by bikes (Buehler & Pucher, 2012). This is demonstrated by the fact that cycling rates are considerably higher in Canada than in the United States, despite the much colder climate (Pucher & Buehler, 2006).

6) *Trip purpose:* While studies show that cycling levels do decrease during the winter, cyclists with less obligatory purposes such as recreation, are much more influenced by cold weather than commuting cyclists (Thomas et al., 2009; Nankervis, 1999; Brandenburg et al., 2007).

7) *Intermodal transportation*: Finally, studies have suggested that facilitating intermodal transportation can increase the distances travelled, eventually leading to more cycling (IST, 2010).

While research has shown that the above variables characterize cycling behavior, their impacts on cycling seem more complex, and in some cases, interrelated; e.g.:

- Age and gender are important factors in North America, but not in Europe (Winters et al., 2007).

- Better facilities do encourage cycling (Buehler & Pucher, 2012), but only if good surface conditions are maintained (Winters et al., 2011).
- High cycling rates and safety appear to be interrelated (Pucher & Buehler, 2006).
- Many people tend to cycle less in winter, but this does not necessarily mean that people cycle less in colder cities (Buehler & Pucher, 2012).
- Cold weather seems to affect commuters less, but women more (Bergström & Magnusson, 2003).

It is therefore important to identify not only the variables characterizing cycling behavior, but also their interdependencies. Previous studies on winter cycling have been few in number and mostly carried out in cities with *mildly cold* and *wet* winters in Europe, North America and Australia. One exception is the study carried out by Bergström & Magnusson (2003) that was conducted in the *subarctic* climate of northern Sweden. It dealt, however, with the relatively small, compact town of Lulea, which has an area of 28 km^2 and approximately 75,000 inhabitants. Moreover, most of the previous studies relied either on observing cyclists, or on questionnaires distributed among sampled respondents from the community at large, which were then answered via the web, mail or telephone.

3. THE PROPOSED MODEL

The model developed in this study was motivated by the results of an earlier city-wide public telephone survey conducted in Calgary (City of Calgary, 2011). The results of the study identified that "fearless" or "confident" cyclists were mostly male and middle aged, and cycled frequently. On the other hand, "interested" or "reluctant" cyclists" were more concerned about traffic and tended to cycle less frequently. These results suggested that maybe instead of a traditional model that defines relationship between dependent and independent variables, cycling behavior can be explained as a multi-layer model with relationships between three groups of variable: the *inherent characteristics* such as gender, the *concerns of cyclists*, such as cars on the road, and their actual *cycling behavior*, such as frequency of cycling. A multi-layered model was consequently hypothesized in which *inherent characteristics* of the cyclists (i.e. age, gender and thermal comfort) could have an impact on intermediate variables related to cyclists' *motivating factors* (i.e. safety concerns, infrastructure deficiencies, and trip purpose), which in turn can affect dependent variables related to *cycling behavior* (i.e. duration and distance of trips, the use of intermodal transportation and cycling frequency in summer and winter) (Figure 11). For example, a cyclist's safety concerns might increase or decrease the frequency of cycling, and at the same time be affected by the age of cyclist itself. Since cyclists' inherent characteristics cannot be changed, identifying and taking into account such motivating factors could be a key to influencing cycling behavior.

Thus, in this example, the definition of a strategy to increase the frequency of cycling among a specific age group might benefit from a better understanding of the safety concerns that are more common among cyclists in that age group.

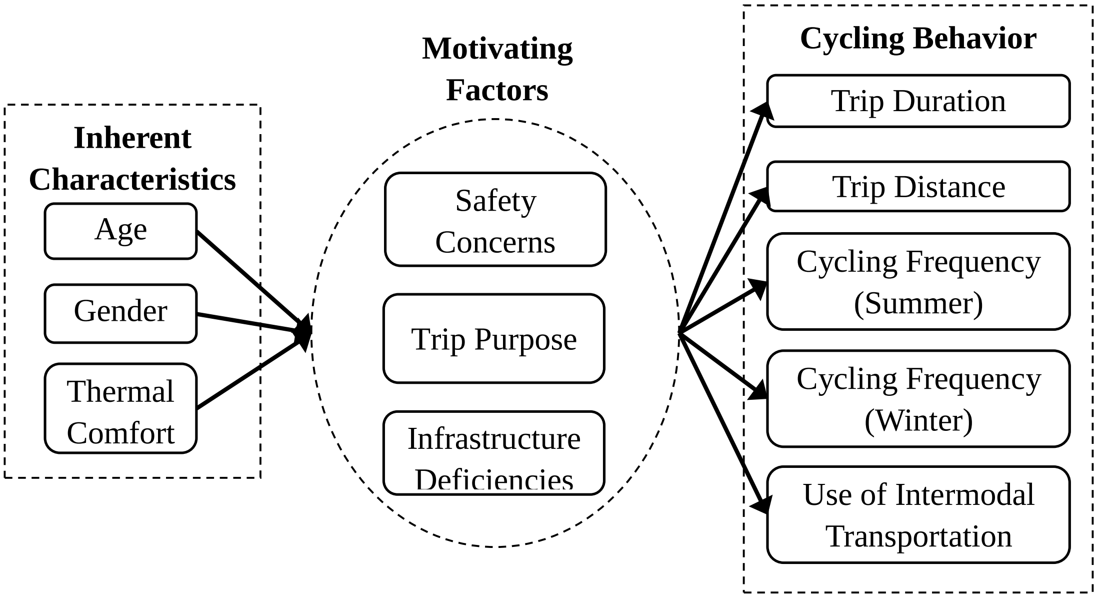

Figure 1: Hypothesized Model.

4. DATA COLLECTION METHODOLOGY

The objective of this study is to identify the variables affecting the cycling patterns in metropolitan areas with a very cold climate and to analyze the interrelationships between those variables. The present study seeks to broaden the existing knowledge on winter cycling by directly interviewing winter cyclists through an intercept survey on cycling routs during winter months. By asking the cyclists to answer questions in-situ, the intercept survey ensured that the respondents are those who actually cycle during winter and in a city categorized to have a very cold climate. The results of this study can be beneficial for planning of cycling infrastructure in cities with very cold climate by providing a better understanding of cycling behavior and concerns of winter cyclists.

4.1. Survey Instrument

Eleven variables, identified in the literature review that was summarized in previous section, were used to study the characteristics of winter cycling in this study. These variables are:

- Age
- Gender
- Safety concerns

- Infrastructure conditions
- Temperature
- Distance traveled
- Purpose of the trip and its duration
- Frequency of cycling (in winter as well as rest of the year)
- Use of intermodal transportation

A questionnaire was designed to collect data on these variables. In most cases, the measurement of the variable was straight forward. For questions regarding the age, thermal comfort, trip duration and trip distance (for the current trip), and the frequency of cycling (in winter and in summer) the respondents were provided options with numerical categories. Regarding the gender of the respondent and the use of intermodal transportation ("are you combining your trip with any other mode of transportation: walk, car, public transit?"), the possible options were also clear.

To develop a list of options for questions regarding the safety concerns of the respondents ("what are your most important safety concerns when cycling in winter?"), the infrastructure conditions ("what are the most important infrastructure deficiencies that you would like to see improved?"), and the trip purpose ("what is the purpose of your trip?"), the results of a previous survey conducted in Calgary regarding cycling in summer months were incorporated (Har 2011). Those options that received the highest number of responses in this survey were included in the questionnaire. For those three questions, the option of “Other” was also included to capture responses that could have been missed in the summer survey. If they selected “Other” as an answer, participants were asked to specify.

A pilot survey was performed using 5 participants who either had expertise in cycling infrastructure planning or were frequent cyclists themselves, to assess its logical consistency, ease of understanding and the sequence of questions. The feedback from these participants led to minor modifications in the wording of the questions and options available for each question. The complete list of options provided for each question can be found in figures presenting the survey summary in Section 4.

4.2. Survey Administration

The survey was conducted on a newly-implemented bike lane as a case study. The bike lane is located on 10th St. NW in the city of Calgary, Canada, which is a street with relatively high traffic, feeding to the downtown core (business district in Calgary). The implementation of this bike lane was a pilot project that had been carried out to investigate the feasibility of a new urban planning strategy to promote cycling as a means of sustainable transportation in Calgary (Pilot, 2013).

In addition to the variables mentioned above, one more question was added to the survey in order to measure the effect of the implementation of the bike lane on the frequency of cycling ("Did you cycle on this route before the implementation of the bike lane?"). The recent date of the implementation of the bike lane was helpful in ensuring that the participants remember their prior travel path and answer the question accurately.

The questionnaire was used to conduct an *intercept* survey. The use of an intercept survey ensured that the study reduces the perception error and targets actual winter cyclists. The ethical aspect of the survey was reviewed and approved by the University of Calgary's Conjoint Faculties Research Ethics Board. Signage indicating “Cycling Survey Ahead” was used few meters ahead of surveyors to give cyclist awareness of the activity. Upon stopping, cyclists were briefly explained the purpose of the survey, and provided with a consent form that summarized the voluntary nature of the survey. Once the cyclists agreed to participate, questions were read to them, and their answers were recorded in-situ by the surveyors.

The survey was conducted over nine days on the abovementioned bike lane in late winter (March) 2012. The timing of the survey was selected during the afternoon rush hour (4:30 to 6:30pm) to take advantage of the increased number of cyclists. Previous summer surveys in Calgary showed that the peak morning hour for cycling was 7:00 to 8:00 a.m. and the afternoon peak hour was 4:45 to 5:45 p.m. (Calgary 2013). During the first days of this survey it was quickly learned that during the morning rush hours cyclists were often not inclined to stop as they were rushed to get to work. However, during afternoon hours they were more willing to participate in the survey. The average temperatures during morning and afternoon rush hours were -1°C and +6.5°C, which is typical for Calgary in this time of year (Table 1). As survey results will demonstrate, the majority of participants were commuters, indicating that they had also cycled earlier in the morning, when the temperatures were as low as -5°C (Table 1). A total of 103 surveys were collected during the nine days of the survey. Of all the cyclists who were reached out to stop at the surveying points, only four did not stop for the survey, bringing the rate of response to 96%. Despite the cold temperatures, the participants were in general very enthusiastic and often offered extra explanations in answering the questions. Table 1 shows the distribution of the collected surveys and the temperatures over the surveying period.

Table 1: Temperature and number of surveys collected over data collection period.

Day #	Date (March 2012)	# of surveys collected	Temperature (°C)	
			8:00 AM	5:00 PM
1	3rd	12	-3.9	4.9
2	7th	6	-4.6	4.6
3	8th	23	3.4	10.8
4	9th	9	3.8	11.6
5	13th	9	4.4	2.0
6	14th	6	-4.8	4.8
7	15th	22	-3.6	12.2
8	20th	2	-3.5	4.9
9	21st	14	0.1	4.0
Average		11.4	-1.0	6.6

5. SURVEY SUMMARY

Following is a summary of the data collected in the survey, concerning each one of the previously identified variables:

5.1. Gender

85% of the participants were male (Figure 2). While previous studies also showed that women are generally less likely to cycle in North America, the gender gap among the winter cyclists in this survey is much wider than that found in previous studies, which reported women to be half as likely to cycle as men (Winters et al., 2007). A possible explanation that comes to mind is that women have been found to be more sensitive to low temperatures than men, feeling comfortable at temperatures that are on average higher by about 2°C (Van Hoof, 2008). However, the present study did not find any correlation between the participants' gender and the temperatures at which they reported feeling comfortable to cycle. Moreover, it is interesting to note that the findings do seem to correspond to those of a city-wide bicycle count that was recently conducted in Calgary during the spring and summer season, and in which 79% of the cyclers were male (Calgary 2013). Thus, the major cause for this gender gap does not seem to be directly related to thermal comfort.

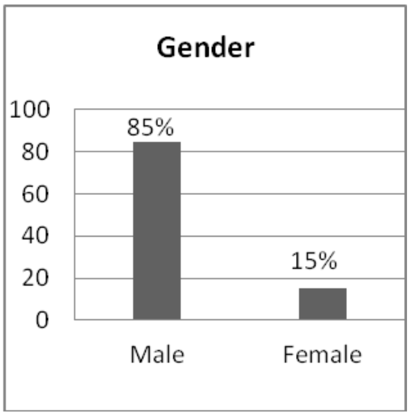

Figure 2. Gender distribution of the participants.

5.2.Age

More than 60% of the participants in this survey were than 35 years or older (Figure 3). It was interesting to observe that one third (33%) of the participants were more than 44 years old, which is only slightly lower than the share of this age group in the general population of Calgary (standing at 36%) (Statistics Canada, 2011). This seems to indicate that unlike what was reported in other studies (Kim & Ulfarsson, 2008; Moudon et al., 2005), in this case study an individual's age is not negatively associated with cycling, and that age does not significantly impede cycling in cold weather. These findings correspond to those in the previously conducted telephone survey, in which 66% of those who cycle regularly *year-round* were more than 35 years old, and 40% were more than 44 years old (Har 2011).

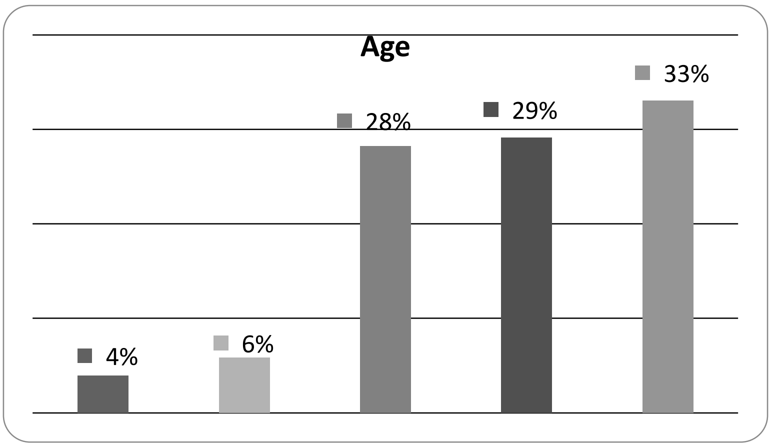

Figure 3. Age distribution of the participants.

5.3. Thermal Comfort

While it was expected that winter cyclists would display a relatively high tolerance for cold weather, the participants' answers, when asked to specify at how low a temperature they felt comfortable to cycle, were striking (Figure 4). Overall, the findings of this survey are in principle in line with results reported in the other study conducted on winter cycling in very cold climate (i.e. Lulea in Northern Sweden), where the majority of frequent cyclists mentioned road surface conditions, rather than the weather itself, to be the major deterrent to winter cycling (Bergström & Magnusson, 2003). However, even very low temperatures do not appear to be a major concern for most participants in this study. 33% indicated that they were comfortable cycling at temperatures down to -20°C, and another 38% said that they felt comfortable cycling at even lower temperatures; i.e. it did not matter to them how cold it is. As the average temperature during the coldest month in Calgary (January) is between -3°C and –15.7°C (Environment Canada, 2014), it appears that the majority of winter cyclists will be comfortable cycling in Calgary through all winter months. While it was expected that the winter cyclists in a city with very cold climate would have some tolerance to cold temperatures, such a high tolerance among more than 70% of the participants was surprising. It should be noted that thermal comfort has been found to depend, to a large degree, on cultural and social contexts, differing from one country to another (Andamon et al., 2006; Knez & Thorsson, 2006; Nikolopoulou & Lykoudis, 2006; Shove & Chappell, 2004; Stoops, 2002). For example, one study found people in different European countries felt comfortable in a variation of over 10°C (Nikolopoulou & Lykoudis, 2006).

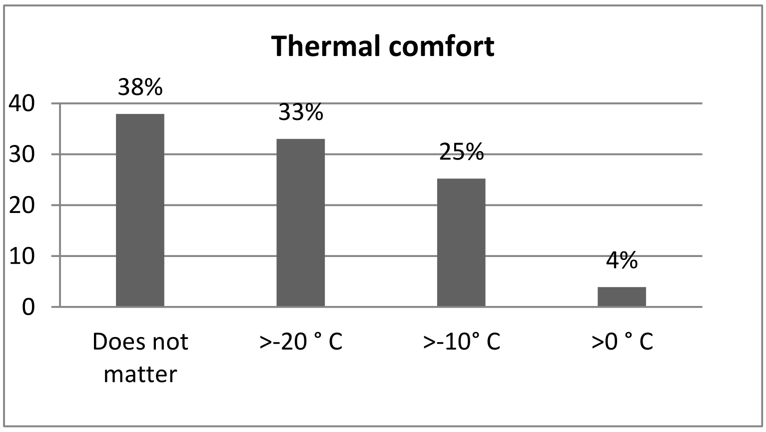

Figure 4: Distribution for thermal comfort of participants ("What Temperature is too cold for you to cycle?")

5.4. Safety

61% of the cyclists identified “icy conditions of the bike lane” as a major safety concern during the winter. Obstacles, other cyclists, and pedestrians on the lane did not seem to be a major concern for the participants (Figure 5). Approximately half (48%) of the cyclists, however, mentioned that they had “Other” safety concerns. When asked to specify, 40% were concerned with the existence of gravel and snow on the lane, and 30% named adjacent fast moving cars as a safety concern. In their explanation, cyclists also noted that besides being a safety issue due to slipping, the existence of the snow and gravel reduces the width of the bike lane, pushing cyclists closer to the adjacent car lane.

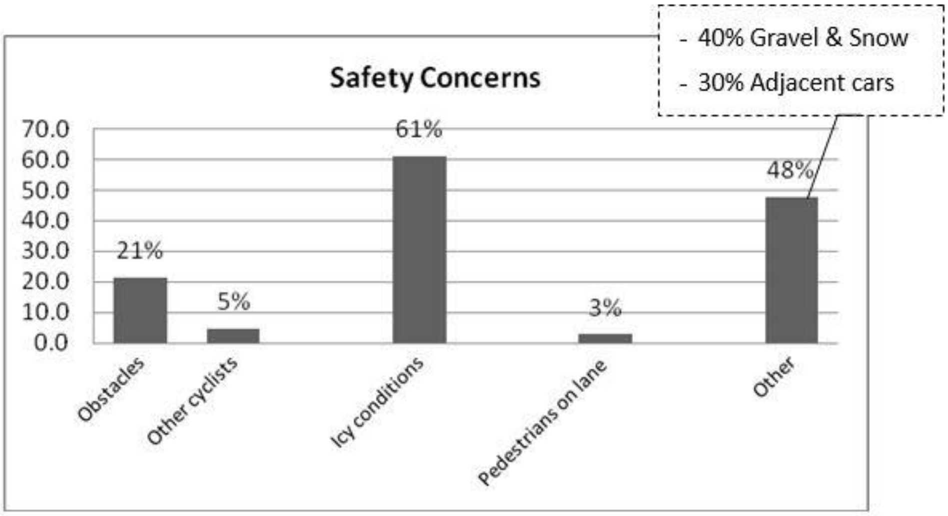

Figure 5. Most important safety concerns (multiple answers allowed).

5.5. Infrastructure Deficiencies

When asked to identify the most important deficiencies on the lane that needed to be addressed, the options mentioned most often by participants were snow and gravel removal under “Other” (25%), followed closely by cracked road surface (24%) (Figure 6). Interestingly and related to this study, both of these deficiencies are caused by cold weather conditions. The gravel used on the lanes in Calgary is in fact part of a sanding chip mixture (3% salt, 97% fine gravel) used by the municipality to melt accumulated snow and ice in Calgary in winter when road surface temperatures are below -5°C. Cracked surfaces can also be at least partly attributed to cold weather, as water from rain and snow penetrates through small existing cracks, and then expands when it freezes, putting stress on the pavement and increasing the size of the cracks.

Insufficient signage and lighting were the next two concerns. Narrow lane width was less of a concern for the participants in this study. The width of the bike lane on this case study ranges between 1.5 to 2 meters along its length.

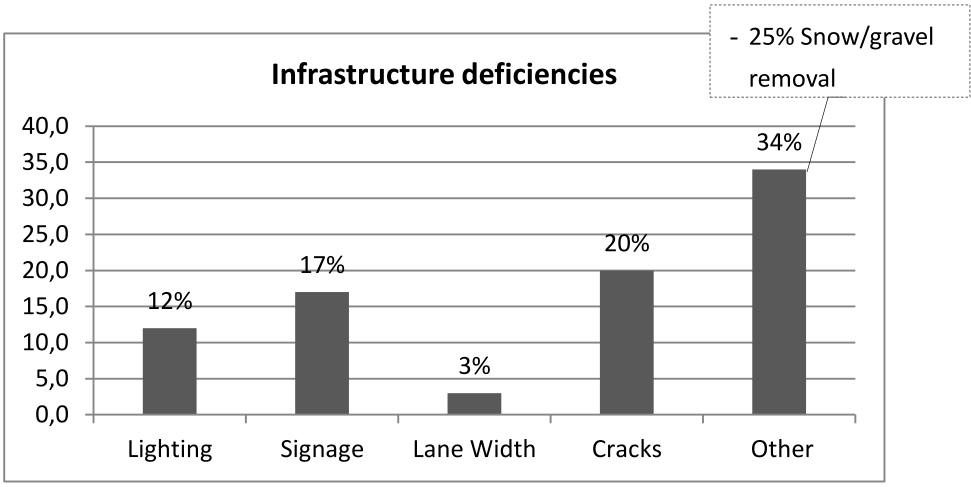

Figure 6. Participants perception of infrastructure deficiencies (multiple answers allowed).

5.6.Trip purpose

75% of the participants indicated that the purpose of their trip was commuting to work (Figure 7). This conforms to findings in previous studies, according to which the majority of winter cyclists are commuters (Brandenburg et al., 2007; Nankervis, 1999; Thomas et al., 2009). It could also be explained by the fact that the location of the survey was on a route exiting the downtown area, and that it was conducted during the afternoon rush hour. As participants were allowed to choose more than one choice for this question, the trip purpose distribution also demonstrated that many cyclists combined different purposes in one cycling trip, for example, exercise or shopping as well as commuting.

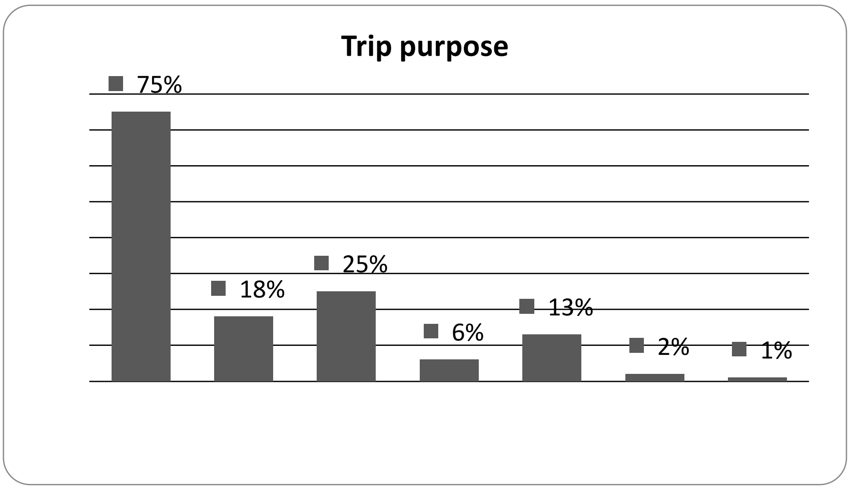

Figure 7. Trip purpose of the participants (multiple answers allowed).

5.7. Trip distance and duration

The average one-way trip distance for the cyclists in this study was 7.4 km, with about one third (28%) traveling distances of over 10 km (Figure 8). The majority of the participants – about 72% – had trip durations between 10 to 30 minutes. The duration of the trip for a quarter (25%) of the participating winter cyclists was more than 30 minutes, and for almost one third (62%) more than 20 minutes. Only 3% of the participants used cycling for trips shorter than 10 minutes. This seems to run counter to the results in Bergström & Magnusson (2003), who consider a distance of over 5 km to be a deterrent to cycling in winter. Moudon et al. (2005) consider a distance of 3 km, and Winters et al. (2011) a distance of 8 km, as being a reasonable for cycling year-round. However, Winters et al. (2011) also distinguish between regular and potential cyclists: while a distance of more than 10 km is found to be a strong deterrent for potential cyclists among the general public, it had no influence on regular cyclists, conforming to the results in the present study. The results here are also aligned with those of a study by Nankervis (1999), in which the mean travelling distance was found to be 7 km, while 25% of the trips were longer than 10 km. However, the study by Nankervis (1999) was carried out in the much milder climate of Melbourne, Australia. The results of the present study suggest that in practice longer distances and durations are not a deterrent for a significant number of regular cyclists, and that a very cold climate does not change this.

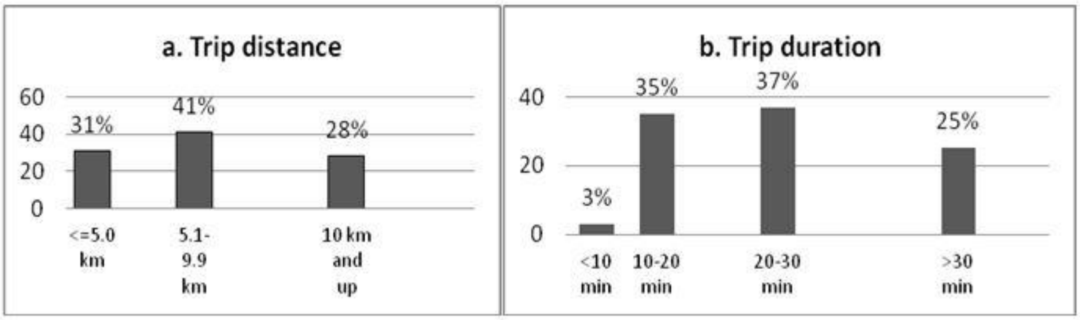

Figure 8. (a) Trip distance and (b) trip duration.

5.8. Usage of bike lane

25% of the participants reported that they had started to cycle on the route in this study only after the implementation of the new bike lane (Figure 9). This underlines the positive role of cycling facilities in increasing cycling rates. Although it was not part of the formal questionnaire, a large number of the participants who had been using this route before the implementation of the new bike lane expressed their satisfaction with the newly allocated bike lane upon answering this question. These findings conform to monitoring data from The City of Calgary's Transportation Department, which reported an increase in the year-round bicycle volumes recorded after the implementation of the bike lane (Pilot, 2013). The attraction of more cyclists to the bike lane reconfirms the results of the previous telephone survey conducted for the City of Calgary, in which more than half (57%) of the respondents reported being uncomfortable cycling on busy roads if specific bike lanes are not present (Har, 2011). This corresponds to the findings in other surveys (e.g. Transportation Research Board, 2006), which report that people living close to bike lanes have significantly increased odds of bike use compared with those living further away from such lanes.

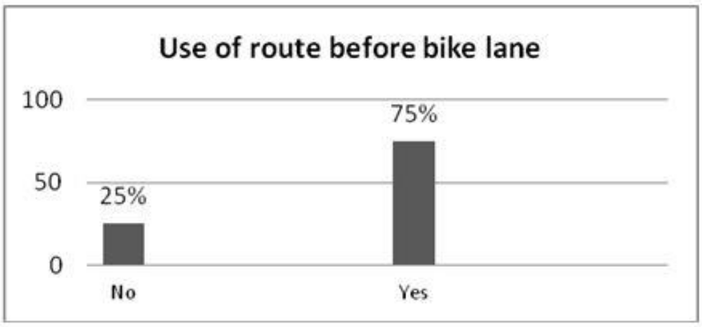

Figure 9. Use of the route before the implementation of the bike lane.

5.9. Intermodal transportation

75% of the participants stated that they used *only cycling* for the particular trip on which they were surveyed, without combining it with other modes of transportation (Figure 10a). Among those who did use intermodal transportation in their trip, the majority (59%) combined their cycling trip with public transit (Figure 10b). Though cyclists are generally allowed in Calgary to transport their bicycles on public transit, this does not apply on trains during rush hour. This might help explain the fact that only a small group of the participants chose to combine their trip with other modes of transportation.

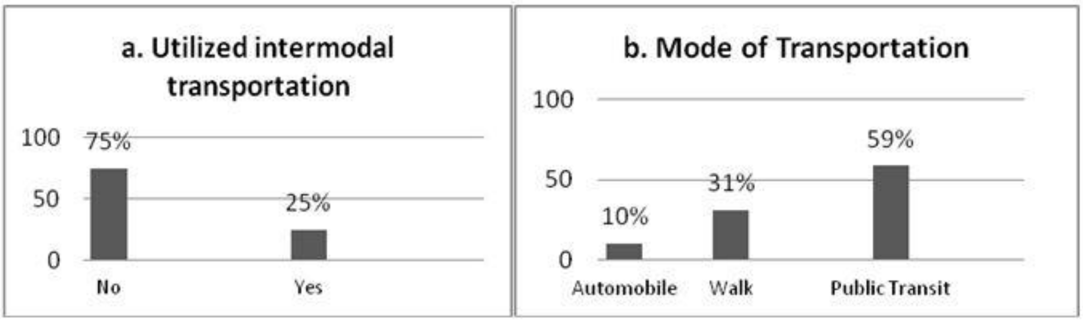

Figure 10. Use of intermodal transportation a) If cycling trip is combined with other modes of transportation; b) If yes: which mode of transportation.

5.10. Frequency of cycling

The majority of the participants in the present study were frequent cyclists: 72% of the participants cycled 10 times or more per week throughout the year, suggesting that they cycled on a daily basis (Figure 11). This is interesting when compared to the answer for that question from the general public in Calgary, where only 6% of the respondents reported cycling on a daily basis (Har, 2011). This indicates that the participants in the present study are significantly regular cyclists, who currently represent a relatively small part of the population. The share of participants who cycle 10 times or more per week *in winter* dropped by almost 1/3rd, to 47%. According to the monitoring data collected by the City of Calgary winter cycling on this lane drops to 30 per cent of summer trips (Pilot, 2013). While other studies have also reported lower cycling rates in winter compared to warmer months (Flynn et al. 2012; Miranda-Moreno & Lahti, 2013; Nankervis, 1999; Thomas et al., 2009; Winters et al., 2007), the present study identified the specific drop rate of cycling among avid winter cyclists.

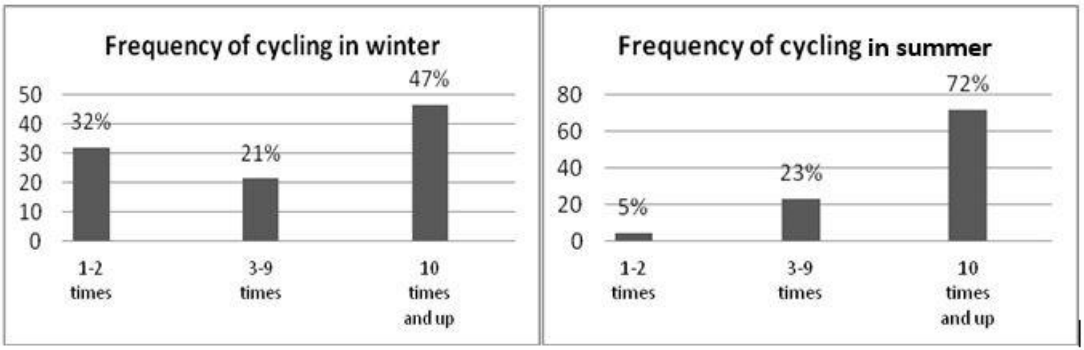

Figure 11. Frequency of cycling: a) in winter; b) in summer

5. SURVEY DATA ANALYSIS

To verify the hypothesized relationships shown in Figure 1, cross-tabulated analysis was carried out using two-tailed chi-squared test and Fisher's exact test. Statistical Package for Social Science (SPSS) was used to assess the relationship between the independent, intermediate, and dependent variables. In this study, a relationship between two variables was considered to be statistically significant when the *P*-value was smaller than 0.05; accepting 5% of type I error, which is commonly used for studies of this nature (Afifi and Azen, 1979). Whenever the sample size in a category was smaller than 5, the chi-squared tests were complemented by a Fisher's exact test to increase the reliability of the results (Agresti et al., 1990). Fisher's test returns exact *P*-values when dealing with small segmentation in the data. The results of the analysis are brought in the two groups below: 1) relationships with statistical significance between the independent and intermediate variable, and 2) relationships with statistical significance between intermediate and dependent variables.

6.1) Relationships between cyclist's inherent characteristics and motivating factors

Of all the three inherent characteristic variables, thermal comfort demonstrated to impact the trip purpose ($P<0.000$). Table 2 summarizes the results of the cross tabulated examination for this relationship, confirmed by Fisher's exact test.

Table 2. Relationship with statistical significance between *thermal comfort* and *trip purpose.*

Trip purpose: "Other"	Thermal comfort				Chi-squared result			Fisher's Exact Significance
	Doesn't matter	-20°C	-10°C	0°C	Value	df	Asymp.Sig.	
Yes	**0%**	**0%**	**0%**	25%	24.993	3	0.000	0.000
No	100%	100%	100%	75%				

As can be inferred from the table, none of the cyclists with higher tolerance for cycling in temperatures of -10◦C and lower were cycling for a purpose other than those identified in the survey. In other words, the trip purpose of those cyclists with high tolerance for cold temperature was work, exercise, recreation, leisure, shopping or school. Cyclists who traveled for any other purpose, also had relatively less tolerance for winter temperature, up to only 0◦C (Table 2).

Another relationship with statistical significance in this group was that between *age* and *safety concerns* as shown in Table 3. The majority (75%) of cyclists who found *other cyclists being too close or riding too fast* a safety concern were youth – those under 18 years old *(P<0.000)*. Only 16% of those who found other cyclists a safety concern were between the ages of 18 and 24. Almost none of the participants aged over 25 found that a safety concern and an increase in age did not notably affect their view (Table 3). The current study did not find statistical significance for any other relationships between *gender* and intermediate variables, despite the large gender gap that was identified in the survey. Also no relationship with statistical significance was established between concerns regarding *infrastructure deficiencies* and any of the independent variables.

Table 3. Relationship with statistical significance between *age* and *safety concerns.*

Safety concerns	**Age**					**Chi-squared result**			**Fisher's Exact Significance**.
	<18	18-24	25-34	35-44	>44	Value	df	Asymp.Sig.	
Cyclists riding too fast/close	75%	16.7%	3.4%	0%	0%	47.8	4	0.000	0.000

6.2) Relationships between Motivating Factors and Cycling Behavior

The relationship between safety concern of *icy surface* and the use of *intermodal transportation* was statistically significant *(P = 0.035).* A large majority of participants who identified *icy conditions* as a safety concern were *not* using intermodal transportation (82.5%), as compared with those who did not find *icy conditions* a concern (62%) (Table 4). In other words, if *ice on surface* is not a concern, chances are higher to use *intermodal transportation*. In informal communications with cyclists, they mentioned the cultural/social "awkwardness" and difficulty of use (e.g. getting the bike on and off the rack in front of the bus; getting the bicycle on and off a crowded train) as reasons for not combining trips with other modes of transportation. An explanation could be that those who do not find ice on surface a concern, are typically those who are most courageous in cycling, so they also do not shy away from the difficulties of using multimodal transportation.

Since multimodal transportation enables longer trips, to promote commuting in cities with cold climate, the easy use and access to public transit should be given serious considerations.

Table 4. Relationship with statistical significance between *safety concerns* and use of *intermodal transportation.*

Intermodal transportation	**Safety concern: Icy conditions**		**Chi-squared result**			**Fisher's Exact Significance**
	Yes	No	Value	df	Asymp.Sig.	
Yes	17.5%	37.5%	5.207	1	0.023	0.035
No	**82.5%**	**62.5%**				

Trip purpose showed to have the largest number of statistically significant relationships with variables in the Cycling Behavior group (Table 5). The majority (~ 60%) of those who reported work as being the purpose of their trip (*commuter* cyclists) were *frequent winter cyclists* (i.e. more than 10 times/week) *(P<0.000)* and over 80% were *frequent summer cyclists (P=0.03)*. Therefore as expected, commuters composed the largest portion of the frequent cyclists. Therefore it can be concluded that to increase cycling levels, introducing incentives for commuting to work could be one of the most effective strategies.

Just about half (48.1%) of the *commuter* cyclists had trips with medium distances (i.e. between 5.0 to 9.9 km). The other half was equally divided between those with short trips and long trips *(P=0.03)*; Trips of 5 km to 10 km are most common among winter cyclists who commute to work. If you want them to go longer, make it easier to combine with other modes of transportation.

Table 5. Statistically significant relationships between *dependent variables* and different *Trip Purposes* a) Commuting; b) Recreational; c) School; d) Other.

(a)		**Trip purpose - Commute**		**Chi-squared test**			**Fisher's Exact Significance**
		Yes	No	Value	df	Asymp.	
Frequency of cycling in winter	<=2 times/week	20.8%	65.4%	23.87	2	0.000	0.000
	2-10 times/week	19.5%	26.9%				
	>10 times/ week	**59.7%**	7.7%				
Frequency of cycling in summer	<=2 times/week	3.9%	7.7%	11.56	2	0.03	0.03
	2-10 times/week	15.6%	46.2%				
	>10 times/ week	**80.5%**	46.2%				
	<=5.0km	26.0%	46.2%	7.023	2	0.03	0.03
	5.0 - 9.9 km	**48.1%**	19.2%				

(b)		Trip purpose - Commute		Chi-squared test			Fisher's Exact Significance
		Yes	No	Value	df	Asymp.	
Frequency of cycling in winter	<=2 times/week	**65.4%**	20.8%				0.000
	2-10 times/week	11.5%	24.7%	17.771	2	0.000	
	>10 times/ week	23.1%	**54.5%**				
Intermodal Transp.: Walk	Yes	62.5%	22.2%	3.970	1	**0.046**	**0.078***
	No	37.5%	77.8%				
Intermodal Transportation: Public Transit	No	37.5%	83.3%	5.462	1	**0.019**	**0.06***
	Yes	62.5%	16.7%				
Trip Distance	10 km and up	26.0%	34.6%				
Intermodal Transp.- Walk	Yes	18.8%	**60.0%**	4.626	1	0.031	0.046
	No	**81.1%**	40.0%				

(c)		Trip purpose - School		Chi-squared result			Fisher's Exact Significance
		Yes	No	Value	df	Asymp.Sig.	
Intermodal Transportation	Yes	100.0%	23.8%	6.040	1	**0.014**	**0.062***

(d)		Trip purpose - Other		Chi-squared result			Fisher's Exact Significance
	minutes	Yes	No	Value	df	Asymp.Sig.	
Trip duration	<10	**100%**	2%				
	10-20	0%	35.3%	33.660	3	0.000	0.000
	20-30	0%	37.3%				
	>30	0%	25.5%				

Over 80% of *commuter* cyclists in this study did not combine their cycling trip with *walking*. The majority (60.0%) of those who combined walking with their cycling trip were non-commuters (i.e. those who had trip purposes other than commuting) *(P= 0.046).* As shown previously, non-commuters compose only a small portion (0.25%) of the population in this study compared with commuters (see Figure 6). This indicates that combining cycling with walking is not a big thing for winter commuters. As mentioned, it was not a well-designed question. The actual number can be even smaller.

A good majority (65.4%) of cyclists who were cycling for *recreational* purposes had the lowest frequency of *cycling* in *winter* (i.e. less than 2 times per week). In contrast, more than half (54.5%) of the cyclists who were cycling for purposes other than *recreation,* had the highest frequency of *winter cycling* (i.e. more than 10 times per week) *(P < 0.000).* (Table 5b); Recreational cyclists are not frequent in winter.

The relationship between using cycling for *recreational* purposes and combining the cycling trip with *walking* and *public transit* originally showed to be statistically significant. However, further Fisher's exact tests rejected the statistical significance for both relationships *(P = 0.078 and P = 0.06*, respectively) (Table 5b). Similarly, the statistical significance of relationship between cycling to *school* and use of *intermodal transportation* was rejected by Fisher's exact test (P = 0.062) (Table 5c).

Those participants who mentioned the purpose of their trip was something *other* than those indicated in the survey (i.e. commute, exercise, recreation, leisure, shopping, school) had a *very short* trip durations (less than 10 minutes) *(P<0.000)* (Table 5d). Revisiting Figure 7 also reveals that, interestingly, only a small part of the studied population selected the "Other" answer choice for the purpose of their trip (note that for this question the participants could select as many answers as they deemed relevant). This indicates the majority of longer cycling trips in winter (more than 10 minutes), occurs for the purposes that were listed in the survey.

6.3) Discussion

Figure 12 shows the relationships between cycling variables that were hypothesized and empirically supported in this study. This study could not find statistically significance for any of the relationships hypothesized for *gender* of the cyclists and their perception of *infrastructure deficiencies*. Nonetheless, the eight (8) relationships that were empirically supported by the statistical significance, as shown in Figure 12, provide an insight into the interrelationships among variables that are related to cycling for winter cyclists.

Once the results of assessing the hypothesized relationships were completed, it was speculated if relationship a relationship also existed *between* the motivating factors. In other words, the question raised if there was more than one layer among intermediate variables. More specifically, it was speculated if the *safety concerns* of cyclists affect the *purpose* of their trip. To test this hypothesis, the relationship between trip purpose and safety concerns within the intermediate layer of motivating factors was examined and the relationship in fact was statistically significant (Table 7).

The results of the Chi-squared and Fisher's exact test confirmed that a strong majority (80%) of the cyclists who considered *cyclists who ride too fast/too close* on the path as a safety concern were recreational cyclists. Conversely, the majority (77.6%) of those who did not consider *other cyclists* a safety concern were not cycling for recreational purposes *(P = 0.014)*. This can suggest that bike lanes are designed primarily for recreational cycling should be wider than others.

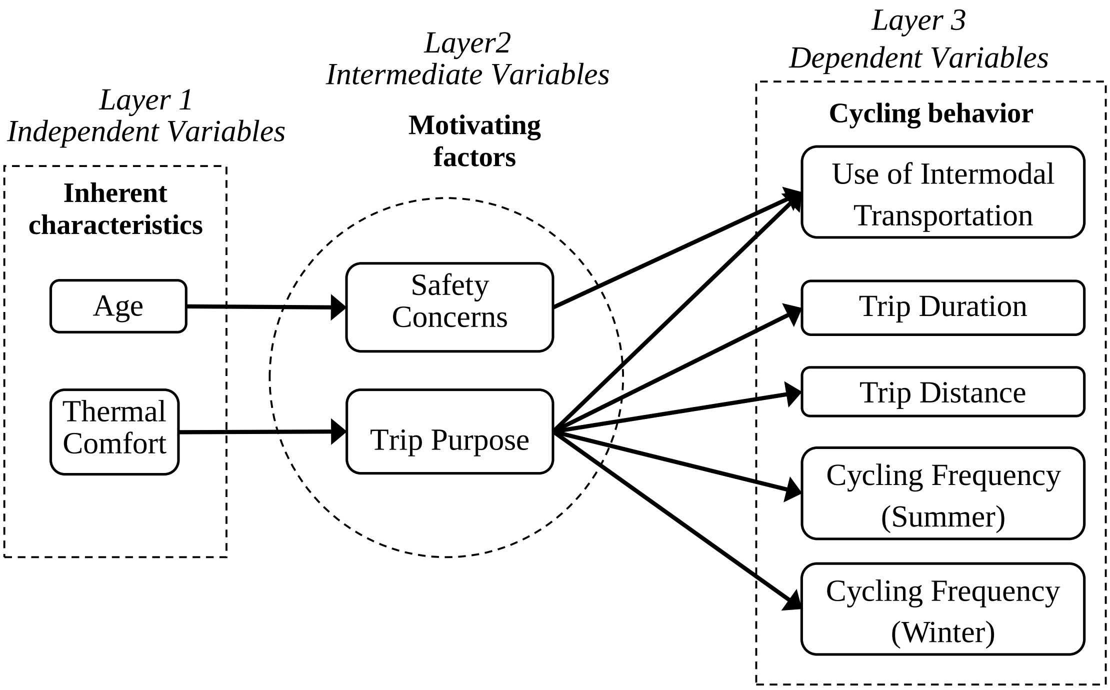

Figure 12. Empirically supported relationships.

6. SUMMARY AND CONCLUDING REMARKS

Cities with very cold climates experience cold weather for a large part of the year, and any effort to encourage cycling or expand their cycling infrastructure has to take the implications of this into account. This study was a very first intercept survey, conducted in a typical n.a. major city, with very cold climate, Calgary, as a case study. The focus of this study was a metropolitan area with a very cold climate. The study offered two contributions to the current body of the knowledge. First, it provided a profile of a typical winter cyclist in a city with very cold climate to provide planners and decision makers an understanding on their characteristics. Second, it examined the relationships between variables affecting cycling for winter cyclists to identify what affects what.

The profile of the average winter cyclist in this study can be portrayed as a middle aged male who is a frequent cyclist and uses cycling mostly for commuting, although he might use the trip for other purposes, such as shopping or exercise, as well. He is not inclined to combine other modes of transportation with his cycling trip. The main safety concern of the typical winter cyclist in this study was ice on the road. He is not deterred by very low temperatures, feeling comfortable to cycle in temperatures down to -20°C or even lower.

This finding of such high tolerance of cold by the cyclists was surprising to the authors as it was unprecedented in any other study. Perceptions of thermal comfort are known to vary by culture and country. Therefore it could be speculated that cyclists in climates with mild winters have a lower tolerance to cold temperatures than those in regions with *very* cold climates. More studies on the tolerance of winter cyclists in other cities are required to examine this speculation.

The most important infrastructure deficiency identified by the winter cyclists was ice or snow on the road, followed by poor physical conditions of the road surface, such as cracks. It is interesting to note that both of these concerns are an indirect result of the cold weather. This indicates that in order to facilitate the needs of winter cyclists and encourage more winter cycling, maintaining good road surface conditions on cycling routes should be a priority. For example, since the ice, snow, gravel or cracks on the road surface represent more of a hazard for cyclists than for cars, it could be worthwhile that the clearing frequency of cycling paths (e.g. ice/snow removal) be higher than that for roads. While this might not be feasible for cycling infrastructure that is combined with regular traffic (e.g. regular traffic lanes), separate bike lanes (cycle tracks) can facilitate different levels and frequency of ice and snow removal in addition to increasing the safety of cyclists. Further research into engineering solutions for offering clear road surface for cycling is needed.

With 25% of new cyclists on the newly implemented cycle path, the present research confirms the conclusion of previous studies that the implementation of cycling facilities increases cycling and provides a quantitative value. It should be noted that this study was conducted one year after the implementation of the new cycle path. It will be interesting to study what the increase rate over a number of years following the implementation of a path will be like.

The winter cyclists in this study traveled relatively long distances, most of which (~70%) exceeding the 3-5 km range that were assumed in previous studies to be reasonable for cycling in winter. This finding may have implications for the planning and construction of cycling networks in cities similar to Calgary with a very cold climate. Since longer trip distances are not uncommon, a cycling infrastructure with well-connected routes would be beneficial.

In order to identify interrelationships between variables related to cycling, a multi-layered model was hypothesized in this study composed of three groups of variables. In addition to the independent and dependent variables, an intermediate layer related to cyclists' motivating factors was considered in this model, which could both affect cycling behavior (the dependent variables), and at the same time be affected by the inherent characteristics of the cyclists (the independent variables).

Eight of the hypothesized relationships were empirically confirmed in this study.

As it can be seen in Figure 12, two clear relationship chains seem to emerge from the confirmed relationships; the first chains consists of Age- Safety Concerns – Use of Intermodal Transportation variables, and the second consists of Thermal Comfort – Trip Purpose – Cycling Behavior variables.

In this study, cyclists decision to combine their trip with other modes of *transportation* showed to be affected by the *safety concerns* of a cyclist, which in turn were affected by cyclist's *age*. The majority of the cyclists who found other cyclists a safety concern were the youth (under 18 years of age). Therefore, if increasing the ridership among the youth is intended, it is recommended to allow wider lanes in the cycling paths to provide more space for speeding cyclists to pass. In addition, regulations could also be created with regards to speed and distance limits when riding close to youth on the path.

In terms of relationship between safety concerns and use of intermodal transportation it was found that if *ice on surface* is not a concern, chances of using intermodal transportation is higher. In personal communications with cyclists, they referred to the social and physical difficulties (e.g. getting the bike on and off the rack in front of the bus while everyone else is waiting; getting the bicycle on and off a crowded train) as reasons for not combining trips with other modes of transportation. This particular finding could be explained as that those who do not find ice on surface a concern are probably most fearless cyclists and as a result they feel more comfortable to use multimodal transportation. However, since use of intermodal transportation makes longer trips more accessible to a wider range of cyclists it is recommended to implement regulations that facilitate used of intermodal transportation for all range of cyclists; for example making taking on and off the bicycles easier on public transit, or provide park and cycle facilities.

Trip purpose showed to have the largest statistically significant relationships with other identified variables in this study. Trip purpose was on one hand affected by the thermal comfort of the cyclists, and on the other hand affecting all five variables describing cycling behavior. In fact, trip purpose showed to be the pivotal core of the second identified relationship chain in this study. This indicates the importance of the trip purpose in determining the behavior of cyclists.

The *trip purpose* of those cyclists with high *tolerance for cold temperature* fell under one of the categories of commuting, exercise, recreation, leisure, shopping or school. Similarly, the most frequent winter cyclists were also conducting their trips for the aforementioned reasons. This is important for municipalities in very cold climate, as it can direct their focus of their attention for who cycles most frequently and in the coldest days. If the intention is to promote winter cycling, the most potential destinations are those associated with these six purposes. Among those purposes, commuters composed the largest portion of the frequent cyclists.

Conversely, the least frequent winter cyclists were recreational cyclists. This is understandable considering the nature of recreation (that it is highly associated with convenience?). Therefore to increase winter cycling, the most potential can be achieved by providing incentives for cycling to work. For commuter cyclists, trips of 5 to 10 kilometers were most common distance. To enable cyclists to reach longer distances, it is recommended to facilitate combining cycling with other modes of transportation – a point that was reached before.

Combining cycling trip with *walking* did not seem to be an attractive option for *commuter* winter cyclists. Although, as mentioned in the paper, the authors feel this was not a well-defined question. It is speculated that a well-defined question in future studies will show even less interest from cyclists' perspective to combine their trip with walking.

Interestingly, the current study did not find statistical significance for any of the hypothesized relationships between *gender* and *intermediate* variables, despite the large gender gap that was identified in the survey. As clearly there is an association between gender and frequency of cycling in winter, further studies are required to identify intermediate variables that can explain the reason for this difference. Similarly, this study did not find an empirically supported relationship between cyclists' perception of *infrastructure deficiencies* and dependent or independent variables. This can suggest that the indentified deficiencies are not biased by inherent characteristics such as age and gender. More importantly, it suggests that cyclists perception of deficiencies of the road, do not necessarily impact the cycling behavior such as frequency and length of trip. Clearly more studies with larger number of cyclists are required to confirm this.

These results indicate that cycling behavior in winter is affected by a large number of variables that are interrelated in complex ways. While this study could be viewed as pilot survey based on the number of respondents, the findings were encouraging, and indicate that the proposed model might be useful to gain a better understanding of cyclists. In particular, studying and addressing their motivating factors might be a key to influencing their behavior, unlike characteristics such as age and gender that cannot be changed.

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