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Transportation Research Procedia 00 (2018) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2019 Mumbai 26-31 May 2019

Assessing impacts on the utility of both winter cycling and fair-weather cycling in Calgary

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Abstract

A stated preference survey of Calgarians completed in 2015 considered the impacts of ride time, facility type and surface conditions on the utility of cycling. It provided numerical indications of the relative impacts of these factors for the full population and for sub-populations of all cyclists, male and female cyclists, and winter and fair-weather cyclists. Regarding facility types overall, mixed with traffic conditions had the lowest utility, adding bike signs to mixed with traffic conditions had only minor impacts, bike lanes garnered more utility, bike paths (particularly without pedestrians) added even more and cycle tracks provided the most utility – equivalent to a reduction in ride time of about 20 minutes. Regarding surface conditions overall, clear and no gravel had the highest utility with a few exceptions, adding gravel to clear had fairly modest impacts (which were generally negative but also were positive for fair-weather cyclists, male cyclists and all males as groups), fresh snow with no ice and some snow piles from clearing had more negative impact on utility, and ice (with or without snow) had the most negative impacts on utility – equivalent to a reduction in ride time of up to 50 minutes. The scale of these impacts varied across the sub-populations, with the facility types having more effects for the full population, males, male cyclists and fair-weather cyclists; and the surface conditions having more effects for winter cyclists, females and female cyclists. These indications can help guide the planning and development of cycling policy in Calgary.

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

Keywords: cycling and cycling utility; winter cycling; stated preference; cycling facilities and cycling surface conditions

1. Introduction

Winter conditions grip Calgary for several months every year. They bring challenging conditions for cycling, including freezing temperatures, strong cold winds and riding surfaces covered with snow and ice. Any strategy to support and encourage cycling as a viable mode alternative in Calgary should be informed by an understanding of the

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Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY

impacts of these conditions on the attractiveness of cycling, and of what can help mitigate against these impacts. An interview survey of Calgarians was completed in 2015 to gather information about current and potential cycling. The interview included a stated preference component asking respondents to indicate their preferences among hypothetical alternative cycle routes with different ride times, facility types and winter-related surface conditions. Analysis of the responses provided numerical indications of the relative impacts of these factors on the utility of cycling, which identified the conditions with the greatest negative impacts that would be the most effective to address.

This paper presents the design and implementation of the survey, the analysis of the survey data, and the interpretation of the results. Section 2, the next below, presents a brief review of previous research into the factors influencing the utility of cycling and of winter cycling in particular. Section 3 describes the design and implementation of the survey, with a focus on the stated preference (SP) component. Section 4 presents some basic analysis of the survey data to establish what it indicates about cycling in Calgary more generally. Section 5 sets out the method and the results for the analysis of the stated preference data, including some of the indications about impacts on cycling utility for the full population and for different sub-populations arising from the results. Finally, Section 6 offers conclusions about the cycling-related indications arising from the work described here, the implications of these results for cycling policy in Calgary and for both winter cycling and fair-weather cycling in Calgary, and the effectiveness of the approach used in the work, which has the potential to be used to establish greater understanding of the relative importance of impacts to help guide strategy in a wide range of contexts.

2. Previous Research About Influences on the Utility of Winter Cycling

Studies in diverse locations and over time have found that as the annual progression of seasons turns from autumn into winter, the attractiveness and consequent use of cycling drops for most people (Nankervis, 1999; Yang et al, 2014; Miranda-Moreno and Nosal, 2011; Miranda-Moreno *et al*, 2013). There is reasonable agreement that the drop in reaction to bad weather is more pronounced for women than men, and for seniors generally; with a greater tendency for men to continue cycling into the winter that increases with age in the range from about 25 to 60 years (Bergström and Magnusson, 2003; Flynn *et al*, 2012; Helbich *et al*, 2014; Winters *et al*, 2007; Amiri and Sadeghpour, 2013; Miranda-Moreno *et al*, 2013; Shirgaokar and Gillespie, 2016). This drop is also greater for recreational than for utilitarian (particularly commute) purposes, for longer rather than shorter trips, and on weekends more than weekdays (Bergström and Magnusson, 2003; Helbich *et al*, 2014; Amiri and Sadeghpour, 2013; Miranda-Moreno *et al*, 2013; Shirgaokar and Gillespie, 2016).

Several studies with survey components have found the dominant reasons cyclists cite for cycling, across travel purposes, are the fitness/health benefits and the pleasure/enjoyment gained (Stinson and Bhat, 2004; Goldsmith, 1992; Hope, 1994). It is noted by some that the very low cycling rates in many contexts suggests that most travelers do not view cycling in this way, or at least do not put enough value on these perceived benefits to outweigh the perceived costs (Goldsmith, 1992). Unpleasant weather almost certainly reduces the pleasure/enjoyment and increases the perceived costs for most people. Nevertheless, there is still a small cadre with measurable “bicycling inclination” characteristics and attitudes that keep them cycling all year, even right through the severe depths of Canadian winters (Shirgaokar and Habib, 2017). Research considering the nature of changing attitudes to cycling has identified a further group of current non-cyclists who would like to cycle and who could be persuaded to cycle under the right circumstances (Gatersleben and Appleton, 2007).

A survey of cyclists in Amsterdam found savings in travel time the most frequently indicated reason for cycling (Beck and Immers, 1994). Another survey of cyclists in Shanghai found more than 80 percent of respondents used bicycles because of convenience and reliability (Tanaboriboon and Ying, 1993). These findings establish it is possible for cycling in certain contexts to draw on other than health/exercise, pleasure/enjoyment and environmental responsibility motivations, to go beyond the “bicycling inclination”, and to complete successfully with other modes in terms of time and components of utility. It follows that savings in cycling ride time have positive benefit, and that the attractiveness of cycling-friendly facilities and good maintenance can be evaluated using equivalent savings in ride time.

“Winter conditions” is of course a relative term. It means different things to different people in different contexts. A bit of cool wind and rain makes cycling less pleasant, more than enough to dissuade some. A -40 °C cold snap makes cycling an extreme sport, but not enough to dissuade some. In this work, the “winter conditions” associated with winter cycling are those of a Calgary winter. A summary of the monthly pattern of weather conditions in Calgary is provided in Figure 01, with the basis for calling October or November through to March Calgary's the "winter months".

It is hardly surprising that weather impacts cycling. There are inherent characteristics of cycling that simply do not mix with adverse weather conditions, specifically:

- the direct exposure to the elements;
- the physical vulnerability and the potential traumatic consequences of error; and
- the reliance on human effort to overcome all impediments to movement as they are encountered.

Accordingly, a wide range of studies have variously found that cycling (rates, instances, flows, probabilities) for all purposes (utilitarian, commuting, recreational) is reduced because of a decrease in cycling utility (attractiveness, appeal, enjoyment) caused by components of bad weather, including:

- cold temperatures (Parkin *et al*, 2008; Saneinejad, 2010; Hanson and Hanson, 1977; Winters *et al*, 2007; Stinson and Bhat, 2004; Bergström and Magnusson, 2003; Brandenburg *et al*, 2007; Flynn *et al*, 2012; Gebhart and Noland, 2014; Ahmed *et al*, 2010; Nankervis, 1999; Motoaki and Daziano, 2015; Miranda-Moreno and Nosal, 2011; Spencer *et al*, 2013; Helbich *et al*, 2014; Thomas *et al*, 2013; Nosal and Miranda-Moreno, 2014; Sabir, 2011; Böcker *et al*, 2015; Böcker and Thorsson, 2014; Liu *et al*, 2015; Heinen *et al*, 2011; Phung and Rose, 2008; Richardson, 2000);
- hot temperatures (Stinson and Bhat, 2004; Gebhart and Noland, 2014; Ahmed *et al*, 2010; Nankervis, 1999; Motoaki and Daziano, 2015; Miranda-Moreno and Nosal, 2011; Meng *et al*, 2016; Sabir, 2011; Clifton *et al*, 2011; Richardson, 2000);
- strong sunshine (Ahmed *et al*, 2010);
- humidity (Gebhart and Noland, 2014; Nosal and Miranda-Moreno, 2014; Miranda-Moreno and Nosal, 2011; Meng *et al*, 2016; Phung and Rose, 2008; Liu *et al*, 2017; Gallop *et al*, 2012);
- wind (Saneinejad, 2010; Flynn *et al*, 2012; Ahmed *et al*, 2010; Nankervis, 1999; Spencer *et al*, 2013; Helbich *et al*, 2014; Thomas *et al*, 2013; Sabir, 2011; Böcker *et al*, 2015; Heinen *et al*, 2011; Phung and Rose, 2008; Tin *et al*, 2012);
- precipitation (Pucher and Buehler, 2006; Winters *et al*, 2007; Bergström and Magnusson, 2003; Brandenburg *et al*, 2007; Gebhart and Noland, 2014; Miranda-Moreno and Nosal, 2011; Spencer *et al*, 2013; Helbich *et al*, 2014; Thomas *et al*, 2013; Sabir, 2011; Böcker *et al*, 2015; Liu *et al*, 2015; Heinen *et al*, 2011);
- rain (Parkin *et al*, 2008; Saneinejad, 2010; Flynn *et al*, 2012; Ahmed *et al*, 2010; Nankervis, 1999; Goldsmith, 1992; Ashley and Banister, 1989; Motoaki and Daziano, 2015; Meng *et al*, 2016; Nosal and Miranda-Moreno, 2014; Phung and Rose, 2008; Dill and Carr, 2003; Emmerson *et al*, 1998);
- snow (Saneinejad, 2010; Stinson and Bhat, 2004; Flynn *et al*, 2012; Motoaki and Daziano, 2015; Sabir, 2011; Liu *et al*, 2015);
- ice (Stinson and Bhat, 2004);
- cloud cover (Hanson and Hanson, 1977; Gallop *et al*, 2012);
- poor visibility (Sabir, 2011);
- darkness (Stinson and Bhat, 2004; Gebhart and Noland, 2014; Spencer *et al*, 2013; Thomas *et al*, 2013; Heinen *et al*, 2011; Phung and Rose, 2008); and
- poor surface conditions (Parkin *et al*, 2008; Bergström and Magnusson, 2003; Spencer *et al*, 2013; Agarwal and North, 2012; Miranda-Moreno *et al*, 2013).

Each of these weather effects is working along causal links associated with one or more of the inherent characteristics identified above. To the extent that these causal links can be weakened, this should help mitigate the negative impacts of adverse weather conditions. In particular, cycle-friendly facilities that help separate bicycles from vehicles and thereby reduce the consequences of error should help, even if they merely reduce perceived risk rather than actual collision rates (Mulvaney *et al*, 2015; Sanders, 2013; Amiri and Sadeghpour, 2013; Klassen *et al*, 2014). Increased cover and shielding from the elements, providing some respite, should help. Efforts to maintain good surface conditions, permitting better control, should also help (Bergström and Magnusson, 2003; Amiri and Sadeghpour, 2013; Agarwal and North, 2012; Miranda-Moreno *et al*, 2013).

Various studies have found that cycling facilities – such as bike lanes, cycle tracks and separate paths –have strong positive effects on the utility of cycling (Lott et al, 1978; Abraham *et al*, 2002; Hunt and Abraham, 2007; Stuckless, 2010; Stinson and Bhat, 2004; Pucher and Dijkstra, 2003; Broach et al, 2012; Fraser and Lock, 2011; Motoaki and Daziano, 2015; Pucher *et al*, 2011). There is some evidence that cycling-friendly infrastructure can compensate for some weather impacts. Cycling rates are higher in Canada than the United States despite the weather, with better infrastructure identified as one of the likely reasons (Pucher and Buehler, 2006). But Canadian weather can be very harsh at times, and have influence, in that the probability of cycling is reduced by both the number of days below 0 °C and number of days with precipitation (Winters *et al*, 2007).

A summary of research and practice indicated two main factors influencing winter cycling rates in Northern European cities are (a) the quality of the cycling infrastructure (extent of protected bike lanes) and (b) the degree of winter maintenance (Jaffe, 2016). It cited examples of good practice and its beneficial impacts, largely anecdotal, including:

- Linköping, Sweden: has more than 60 miles of prioritized bike routes with year-round maintenance, clearing as little as 1 cm of snow accumulation; indicates that 3 cm of snow cover can discourage riding.
- Umea, Sweden: with more than 130 snow days annually, has an aggressive maintenance program and maintains a 24% bike share among commuters all year.
- Copenhagen, Denmark: salts bike lanes before it snows and clears them before the general roadways for car traffic; sees only a slight decline in cycling mode-share in winter (noting that winter conditions are much less severe than in the other examples included here).
- Oulu, Finland: with more than 100 snow days annually, has network of bike lanes with good winter maintenance, where "overwhelming" heavy snowfall is sometimes packed and layered with gravel to provide extra traction; cycling rates are relatively steady down to temperatures as low as -20°C (Swanson, 2016; Pratte, 2011; Perälä, 2003).

The intention in this work is to obtain numerical indications of the potential positive impacts of different facility types and maintenance operations on the utility of winter cycling in the Calgary context. The facility types concern alternative treatments for elements of the cycling network in Calgary. The maintenance operations relate to different surface conditions and how these conditions impact cycling utility in Calgary.

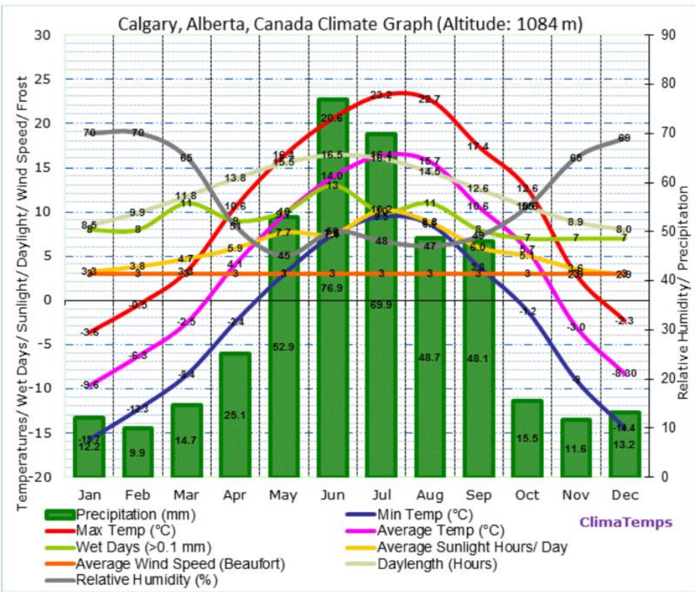

Figure 01. Climate and Temperature Plot for Calgary: The average temperature is below 0°C for the months of November through March and the average minimum is also below 0°C for October and April. Daylength is lower in October and higher in April. On this basis, a working definition of the "winter months" in Calgary is the five months from November to March inclusive, but with October a potential addition on the merits of its darkness, bare trees and common multiple snowfalls, particularly at its end. Source: http://www.calgary.climatemps.com

3. Calgary Cycling Survey

Over the period from October 2014 to March 2015 a survey was conducted where Calgarians were interviewed face-to-face about their behavior and attitudes related to cycling. Respondents were asked to provide specific information about their socio-economic conditions, their attitudes towards cycling, and their current and potential future use of cycling, including:

- year born;
- gender;
- household size;
- household annual before-tax income;
- household auto holdings;
- household adult and child bicycle holdings;
- months of year when cycling;
- whether a student at University of Calgary;
- comfort and willingness to cycle in mixed traffic; and
- interest in cycling more.

The survey included a stated preference (SP) experiment where respondents were asked to indicate their preferences among hypothetical alternatives for the route for a winter cycling journey. Respondents were instructed to imagine a situation where they were cycling, in the weather conditions prevalent at around noon on the day of the interview, to a destination that could be reached using any one of four hypothetical alternative routes. These hypothetical alternative routes were described in terms of their specific states (or conditions) for three specific attributes: cycle ride time, cycle facility type, and winder-related surface condition – with the further indication they were identical in all other aspects. Respondents were asked to indicate their order of preference for these four hypothetical alternatives for the journey, from most preferred to least preferred, along with provide a 0 to 10 rating score for each alternative. This was repeated up to four times with each respondent, with different (randomly selected) combinations of four hypothetical alternative routes considered in each of these up to four trials.

The intent with this experiment is to have respondents consider how they are influenced by the relatively good and bad conditions for the attributes, and how they would tradeoff among them, and on this basis provide responses that are used to estimate the function parameters of discrete choice (logit) models representing this behavior. These estimation results provide numerical indications of the impacts of the attributes on the attractiveness of cycling, and how they interact to influence the preferences of the respondents, which can be used to evaluate the user benefits arising with potential designs and policy actions. Respondents are asked to consider their preferences within the context of a specific choice situation, where tradeoffs may be necessary, which is felt to be a more natural and familiar process for respondents that is more likely to provide reliable indications, than one where respondents are asked to provide direct (and much more abstract) evaluations of the states for attributes.

The attributes included in the descriptions of the hypothetical alternatives are set out in Table 01, together with the possible states for each attribute.

Table 01. Attributes and their possible states for the hypothetical cycle routes.

Attribute	Possible States
cycle ride time (in minutes)	10
	15
	25
	45
cycling facility type	Mixed with Traffic
	Mixed with Traffic with Bike Signs
	Bike Lane (separated by paint)
	Cycle Track (physical barrier)
	Bike Path Shared with Pedestrians
	Bike Path without Pedestrians

surface condition	Clear and No Gravel
	Clear with Gravel
	Fresh Snow (but No Ice)
	Fresh Snow on Existing Ice
	Snow and Ice from Previous Day
	Ice (but No Snow)
	Some Snow Piles from Snow Clearing

Cycle ride time was included because it provides a reasonably understandable equivalence measure for interpreting results and because (typically mode specific) ride time is often included in studies of transportation behavior such that including it here facilitates translation, comparison and combination of the findings obtained here with those of other studies. Cycling facility type was included to obtain indications of the relative attractiveness of alternative facility types for new facility planning. Surface condition was included to get indications of the relative benefits of alternative snow removal and maintenance policies. The possible states (values in minutes) for cycle ride time are staggered with varying intervals because the statistical estimation process uses these intervals and variation in them provides more useful information for estimation.

Descriptions of the hypothetical alternatives were developed by combining one possible state for each attribute into a bundle indicating the ride time, facility type and surface condition for the alternative. With 4, 6 and 7 possible states, the total number of different alternatives is 4·6·7=168. Each of these different alternatives was printed on a separate 12 x 8 cm card, and full 'decks' of cards covering the full 168 different alternatives were prepared for use in the interviews with respondents. One of the cards is shown as an example in Figure 02.

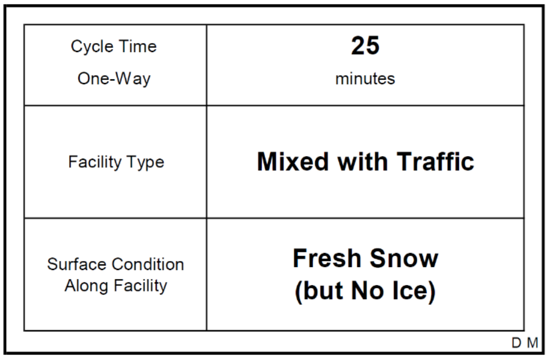

Figure 02. Example card presenting a hypothetical cycle route alternative: The alternative is a bundle of specific states for the three attributes under consideration. The specific states are printed in bold in order to make them more prevalent. Indications of the units used ("minutes") and specific clarifications (cycle time is "one-way", surface condition is "along facility") are included. The two-letter code in the lower right corner is unique to each alternative and is used to record responses in the survey interviews.

After cleaning and checking the data for internal consistencies, useful observations were obtained for a total of 1797 respondents and 4077 SP trials. The analysis methods and the results for this dataset are covered in Sections 04 and 05 below.

4. Preliminary Preparation and Analysis of Calgary Cycling Survey Data

4.1. Survey data expansion

The respondents in the dataset sample were assigned weights determined using iterative proportional fitting such that the distributions in the sample matched the corresponding population distributions for the following demographic attributes:

- age and gender;
- household size;

- household before-tax income; and
- whether or not a student at The University of Calgary (UofC).

The population distributions were taken from Statistics Canada tables for the City of Calgary in 2016 (Statistics Canada, 2017) and from materials posted by The University of Calgary regarding full-time and part-time students in the Fall of 2014 (University of Calgary, 2017).

The resulting weighted sample distributions and their matches to the population distributions are shown in Figure 03 (Parts a through d). The distribution of sample weights is shown in Figure 04. These weights were used in the estimations described here to help make the results more representative of the target City of Calgary population.

Individuals under the age of 18 years were not included in the survey and accordingly are not included in the target population, as shown in Figure 03 Part c.

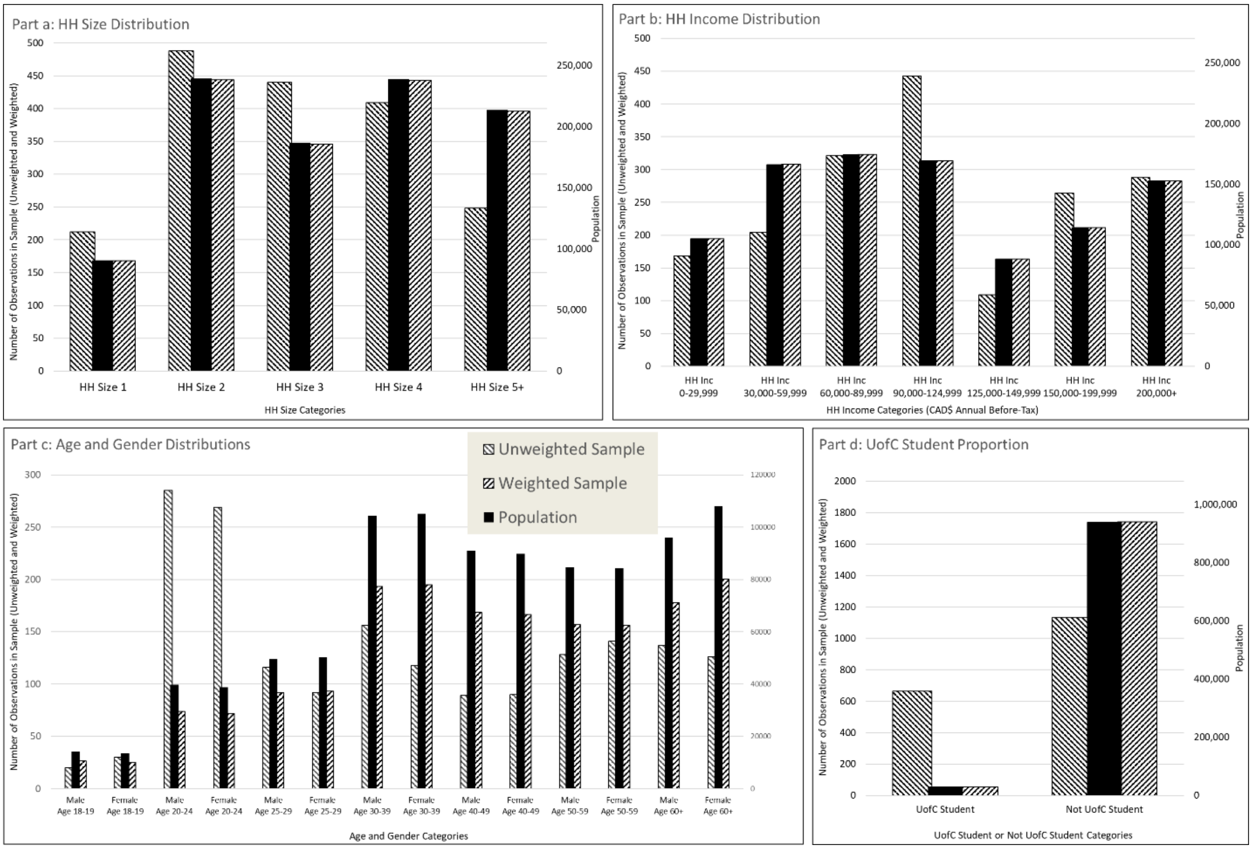

Figure 03. Unweighted and weighted sample distributions and corresponding population distributions for dimensions matched using weights, shown in four parts.

Perhaps not surprisingly, the sample included a substantial proportion of UofC students. The interviewers, themselves UofC students, were encouraged to seek non-student respondents in the first instance, and only to "*fall-back*" on the readily-available pool of fellow students (excluding other interviewers) when "*necessary*". The sample weights were used to help adjust for the disproportionately high number of UofC students that were included notwithstanding these encouragements, to help counter any bias introduced beyond what is accounted for with the age, gender, household size and household income adjustments.

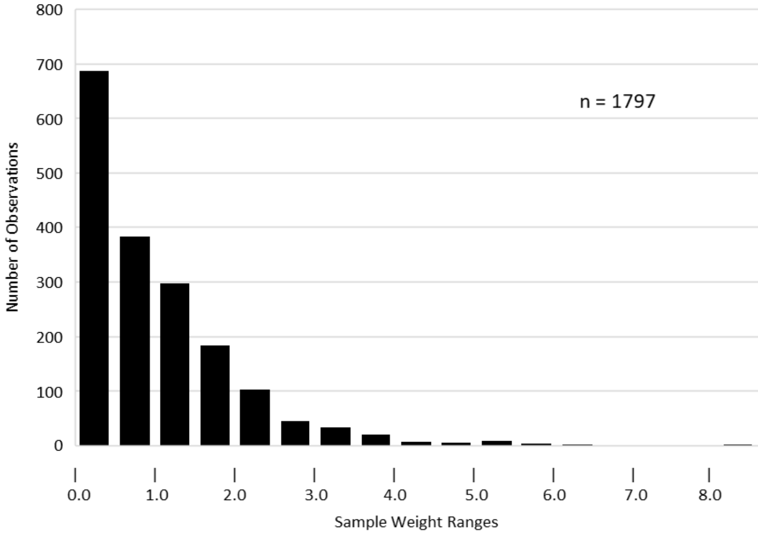

Figure 04. Distribution of sample weight values: This shows the weighting process did not rely excessively on any specific observation and that the sample overall provided a reasonably complete coverage across the dimensions considered. It also shows that a substantial portion of the observations were assigned weights less than 0.5, which was required in order to adjust for the disproportionately high number of UofC students.

4.2. Survey Initial Analysis

Respondents were asked to indicate the months of the year they were willing to cycle. The age and gender distributions of those indicating they were willing in the month of July (termed "fair-weather cycling") and the month of January (termed "winter cycling") are shown in Figure 05, along with the corresponding population distributions.

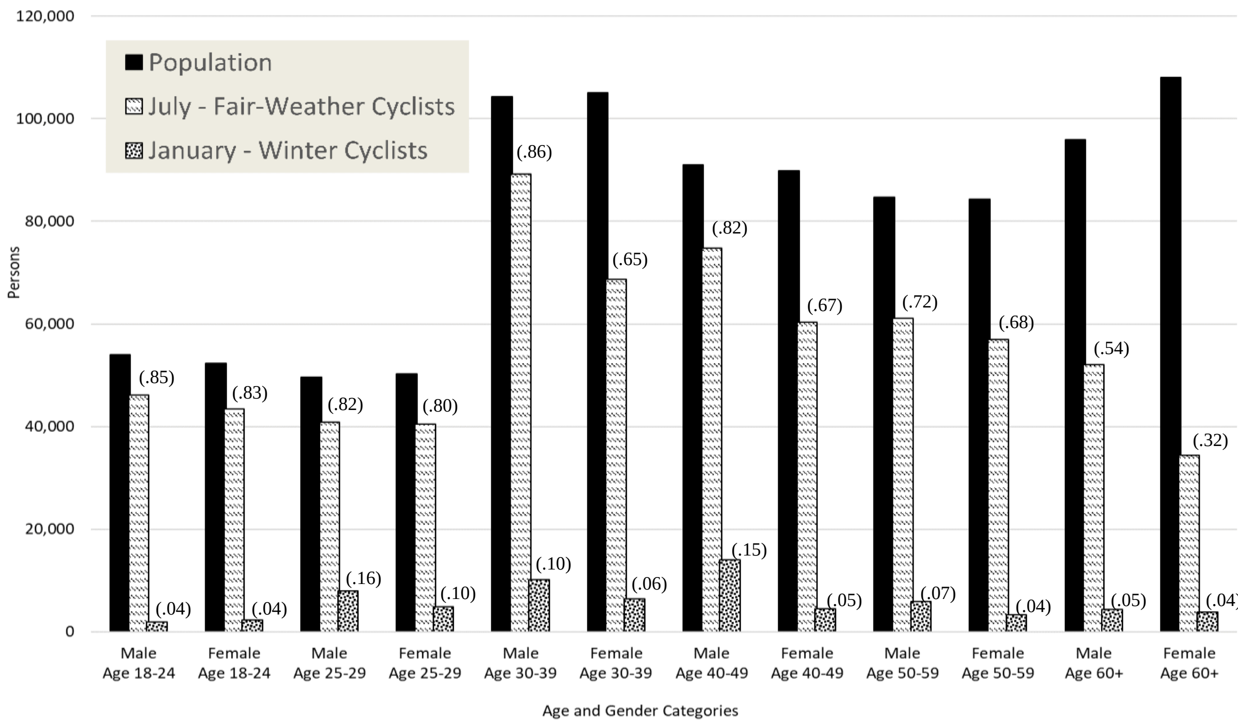

Figure 05. Numbers of persons indicating willingness to cycle in July and January by age and gender categories: The numbers in brackets are the proportions of the total persons in the category indicating willingness.

Overall, there is much less willingness to cycle in January than July. Generally, males and females show similar very low willingness rates. The exception are males aged 25 to 49 years, who show rates roughly twice as high as the others (but still never more than 0.16). There is a similar pattern in the variation in willingness to cycle in July, but at much higher rates generally. These patterns are consistent with the findings reported from other studies of winter cycling, as discussed in the review of previous research included above.

A consistent overall pattern is displayed in the responses to questions about bicycle ownership as shown in Figure 06 below: Males display higher bicycle ownership rates for all age ranges above 25 years, but the differences decrease with increasing age and the rates for both men and women drop off substantially for age above 60 years.

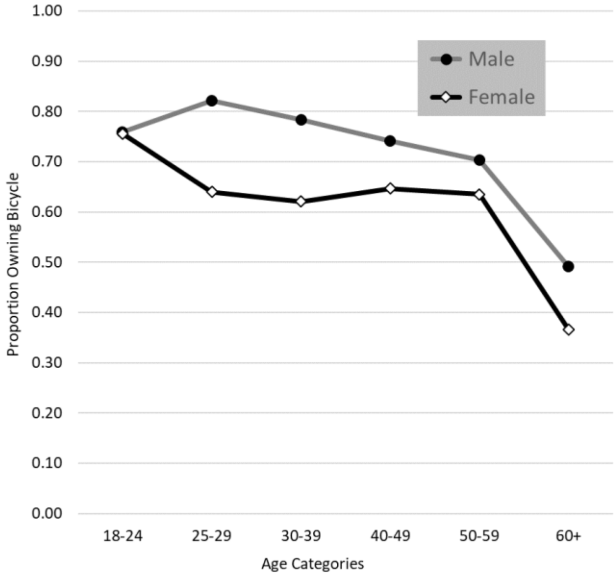

Figure 06. Bicycle ownership rates by age and gender.

5. Stated Preference Analysis of Calgary Cycling Survey Data

In the stated preference (SP) component of the survey, respondents were asked to indicate their preferences among four hypothetical alternative routes described in terms of their specific states for three specific attributes: cycle ride time, cycle facility type, and winder-related surface condition. This indication of preferences is equivalent to a series of three indications of the most preferred alternative, the first among all four alternatives, the second among the three alternatives that remain after the most preferred is removed, and the third among the two alternatives that remain after the two most preferred are removed. The determination of the most preferred among a set of alternatives in this context is represented by a logit choice model with a utility function and general form shown in Equations 01 and 02 below.

$$\mathrm{U}_a = \beta_r \cdot \mathrm{RT}_a + \sum_{m \in M} \delta^F_{a,m} \cdot k^F_m + \sum_{w \in W} \delta^S_{a,w} \cdot k^S_w \quad (01)$$

$$\mathrm{P}_{a^*} = \exp(\mathrm{U}_{a^*}) \ / \ [\ \sum_{a \in A} \exp(\mathrm{U}_a)\ ] \quad (02)$$

where:

a = index for alternative hypothetical cycle routes, with A = the full set of routes considered by a respondent

m = index for cycling facility types, with M = the full set of all cycling facility types considered by all respondents

w = index for surface conditions, with W = the full set of all surface conditions considered by all respondents

U_a = utility for alternative a (utils)

RT_a = ride time for alternative a (minutes)

β_r = utility sensitivity to ride time (utils/minute)
k_m^F = utility for facility type *m* (utils)
k_w^S = utility for surface condition *w* (utils)
$\delta_{a,m}^F = 1$ when alternative a has facility type m and $= 0$ otherwise
$\delta_{a,w}^S = 1$ when alternative a has surface condition *w* and $= 0$ otherwise
P_{a^*} = selection probability assigned alternative a^*, any specific one of the alternatives in A.

Maximum likelihood techniques can be used with these SP data providing these indications of preferences to establish estimates of the parameters in Equation 01: β_r , the k_m^F , and the k_w^S . Unbiased and efficient statistical estimators are available, with means providing the point estimates and standard deviations providing the standard errors for these estimates (Ben-Akiva and Lerman, 1985; Chapman and Staelin, 1982). Software that performs these techniques are commonly available. In this work the ALOGIT software was used (Daly, *undated*).

For each parameter estimate, the point estimate and both the absolute value of the t-ratio and the equivalent ride time are reported. The t-ratio is the ratio of the point estimate over the standard error of the estimate. Under the hypothesis that the true parameter is 0, the t-ratio is standard normal distributed, which can be used in formal hypothesis testing. Less formally, a t-ratio with a higher absolute magnitude can be taken to indicate a more confident estimate and therefore a greater confidence that the associated attribute state has a real impact on utility. The equivalent ride time is the ratio of the point estimate over the estimated value for β_r, the utility sensitivity to ride time. It is the change in cycle ride time that has the same impact on utility as the associated attribute state, which provides a consistent and intuitive basis for comparing estimation results both within and across contexts.

In order to obtain estimates for the k_m^F and k_w^S parameters, one of each must be fixed to act as a reference. The estimates for the others are then the differences in utility from the one that is fixed. For the k_m^F parameters, concerning facility types, the reference is always "Mixed with Traffic" and its value is fixed at 0. This means the estimate for each of the other k_m^F is the difference in utility arising with the corresponding facility type rather than "Mixed with Traffic". For the k_w^S parameters, concerning surface conditions, the reference is always "Clear and No Gravel" with its value fixed at 0, so the estimate for each of the other k_w^S is the difference in utility arising with the corresponding surface condition rather than "Clear and No Gravel".

Variations in the influences on utility for different sub-populations are examined by estimating the parameters in alternative forms of the utility function with different splits of the parameters. The results for a series of these alternative forms are presented and discussed below. In all cases the fit statistics indicate the overall model fit is reasonable such that the parameter estimates provide valid indications of the impacts of the corresponding attributes.

5.1. Full population

In the first case, the entire population is considered altogether, with no splits of the parameters and no sub-populations. The estimation results for this first case are shown in Table 02.

Table 02. Estimation results for full population including all cyclists and non-cyclists.

Parameter	Parameter Description	(Sub-)Population		Estimated Value	| t -ratio |	Equivalent Ride Time (minutes)
β_r	utility sensitivity to ride time	all		-0.05398	27.6	1.0
$k_{m=0}^F$	utility for Mixed with Traffic	all	*fixed*	0		
$k_{m=1}^F$	utility for Mixed with Traffic with Bike Signs	all		0.19673	2.6	-3.6
$k_{m=2}^F$	utility for Bike Lane	all		0.74216	9.5	-13.7
$k_{m=3}^F$	utility for Cycle Track	all		1.11472	14.1	-20.6
$k_{m=4}^F$	utility for Bike Path Shared with Pedestrians	all		0.83931	10.5	-15.5
$k_{m=5}^F$	utility for Bike Path without Pedestrians	all		0.98986	12.3	-18.3
$k_{p=0}^S$	utility for Clear and No Gravel	all	*fixed*	0		

$k^S_{p=1}$	utility for Clear with Gravel	all	-0.09705	1.2	1.8
$k^S_{p=2}$	utility for Fresh Snow (but No Ice)	all	-1.04998	12.7	19.5
$k^S_{p=3}$	utility for Fresh Snow on Existing Ice	all	-2.13960	23.6	39.6
$k^S_{p=4}$	utility for Snow and Ice from Previous Day	all	-1.79895	20.4	33.3
$k^S_{p=5}$	utility for Ice (but No Snow)	all	-2.13393	23.2	39.5
$k^S_{p=6}$	utility for Some Snow Piles from Clearing	all	-1.16115	13.9	21.5

Fit Statistic	Value
number of observations	4077
number of parameters	12
0 coefficients likelihood	-4620.11
final likelihood	-3490.09
$\rho^2(0)$	0.2446

Regarding the results in Table 02, for the full population:

- The signs and relative magnitudes of the estimates are consistent with expectations generally based on the review of previous work.
- An increase in cycle ride time has a negative impact on utility. Some cyclists may enjoy cycling to the point where each additional minute brings more enjoyment, but overall there is a desire to spend less time cycling. It follows that plans and actions to reduce cycling time will generate benefits overall.
- “Cycle Track” is the most attractive facility type. Switching to it from “Mixed with Traffic” has the same impact on utility as a reduction in ride time of more than 20 minutes. “Bike Path without Pedestrians” is the next most attractive facility type, with an impact that is similar to that of “Cycle Track”. That these two most exclusive treatments for cycling have the greatest and similar impacts on utility adds credence to these results and to the process used to obtain them.
- “Bike Lane” has similar impact to “Bike Path with Pedestrians”, switching “Mixed with Traffic” to either one has the same impact as a reduction in ride time of about 10 minutes.
- “Mixed with Traffic with Bike Signs” is only a little more attractive than “Mixed with Traffic”. The value of the t-ratio is still reasonably high – so the null hypothesis that there is no difference can be rejected with more than 95% confidence – but the impact is equivalent to a reduction in ride time of less than 4 minutes. This indicates the population has the opinion overall that merely adding bike signs to a normal road with traffic, just calling it a “Bike Route”, results in only a slight improvement in the attractiveness of using it for cycling.
- “Fresh Snow on Existing Ice” and “Ice (but No Snow)” are surface conditions with the greatest negative impacts on cycling utility. The presence of ice, with or without snow, is the worst. “Fresh Snow (but No Ice)” has only half the impact in a switch from “Clear with No Gravel”, equivalent to a nearly 20 minute reduction in ride time compared to a nearly 40 minute reduction in ride time for the two others with ice.
- “Snow and Ice from Previous Day” has an impact in between the two with ice and snow without ice. Switching from “Clear with No Gravel” is equivalent to a 33 minute reduction in ride time. It may be that some respondents think the elapsed day allows time for the ice to become less treacherous because of melting or breaking, or the result of some form of maintenance work, but this is speculation.
- Going from “Clear with No Gravel” to “Clear with Gravel”, which is merely the addition of gravel, has a small negative impact on cycling utility. The t-ratio is only 1.2 and the equivalent reduction in ride time is less than 2 minutes, so any indications are fairly weak. But this suggests that gravel on an otherwise clear surface is viewed negatively overall. Certainly, some gravel can make a clear surface more slippery and difficult for cycling. This indicates that gravel added as part of some maintenance work to help with snow and/or ice, if remaining after the snow and/or ice is gone, then has a slight negative impact on cycling utility for the entire population.

5.2. All cyclists

In this case, the sub-population of all cyclists is considered, including those in the survey who expressed an interest in cycling or cycling more and who owned at least one bicycle, with no splits of the parameters. The estimation results for this case are shown in Table 03.

Table 03. Estimation results for all cyclists.

Parameter	Parameter Description	(Sub-)Population		Estimated Value	| t -ratio |	Equivalent Ride Time (minutes)
β_r	utility sensitivity to ride time	all cyclists		-0.05148	20.0	1.0
$k^F_{m=0}$	utility for mixed with traffic	all cyclists	*fixed*	0		
$k^F_{m=1}$	utility for Mixed with Traffic with Bike Signs	all cyclists		0.04783	0.5	-0.9
$k^F_{m=2}$	utility for Bike Lane	all cyclists		0.43609	4.2	-8.5
$k^F_{m=3}$	utility for Cycle Track	all cyclists		0.82455	8.2	-16.0
$k^F_{m=4}$	utility for Bike Path Shared with Pedestrians	all cyclists		0.71536	6.7	-13.9
$k^F_{m=5}$	utility for Bike Path without Pedestrians	all cyclists		0.85935	8.5	-16.7
$k^S_{p=0}$	utility for Clear and No Gravel	all cyclists	*fixed*	0		
$k^S_{p=1}$	utility for Clear with Gravel	all cyclists		-0.07021	0.7	1.4
$k^S_{p=2}$	utility for Fresh Snow (but No Ice)	all cyclists		-0.97376	9.2	18.9
$k^S_{p=3}$	utility for Fresh Snow on Existing Ice	all cyclists		-1.81465	15.6	35.3
$k^S_{p=4}$	utility for Snow and Ice from Previous Day	all cyclists		-1.62835	14.7	31.6
$k^S_{p=5}$	utility for Ice (but No Snow)	all cyclists		-1.92166	16.4	37.3
$k^S_{p=6}$	utility for Some Snow Piles from Clearing	all cyclists		-1.03582	9.9	20.1

Fit Statistic	Value
number of observations	3530
number of parameters	12
0 coefficients likelihood	-2656.34
final likelihood	-2083.03
$\rho^2(0)$	0.2158

Regarding the results in Table 03, for the sub-population of all cyclists:

- The signs and relative magnitudes of the estimates are broadly similar to those obtained for the full population.
- All facility types other than "Mixed with Traffic" have somewhat lower impacts on utility. They follow a similar relative pattern, but the equivalent ride time reductions are 20 to 40 percent lower.
- The impact of adding signs to "Mixed with Traffic" has the same impact on utility as a reduction in ride time of 1 minute, with a corresponding t-ratio value of only 0.5. This indicates that bike route signs are of even less concern to cyclists than they are to the full population.
- The pattern of impacts for switching to surface conditions other than "Clear and No Gravel" for all cyclists is very similar to the pattern for full population, just a bit lower. This suggests cyclists and non-cyclists are in very close agreement overall regarding surface conditions, but with non-cyclists utilities impacted just slightly more. The one exception is for switching to "Clear with Gravel", where the impact on utility for cyclists is even smaller and less certain than it is for the full population.

5.3. Facility type and surface condition utility split between winter cyclists and fair-weather cyclists

In this case, the sub-population of all cyclists is considered, with separate parameters for facility types and surface conditions for winter cyclists (who continue to cycle in one or more of the months October through March) and fair-weather cyclists (who only cycle in months other than October through March). The estimation results for this case are shown in Table 04.

Table 04. Estimation results for facility type and surface condition utility split between winter cyclists and fair-weather cyclists.

Parameter	Parameter Description	(Sub-)Population	Estimated Value	| t -ratio |	Equivalent Ride Time (minutes)
β_r	utility sensitivity to ride time	all cyclists	-0.05448	20.7	1.0

$k^F_{m=0}$	utility for Mixed with Traffic	all cyclists	*fixed*	0		
$k^F_{m=1}$	utility for Mixed with Traffic with Bike Signs	winter cyclists		0.09371	0.6	-1.7
$k^F_{m=2}$	utility for Bike Lane	winter cyclists		0.08405	0.5	-1.5
$k^F_{m=3}$	utility for Cycle Track	winter cyclists		0.51273	3.2	-9.4
$k^F_{m=4}$	utility for Bike Path Shared with Pedestrians	winter cyclists		0.47711	2.8	-8.8
$k^F_{m=5}$	utility for Bike Path without Pedestrians	winter cyclists		0.34579	2.2	-6.3
$k^F_{m=1}$	utility for Mixed with Traffic with Bike Signs	fair-weather cyclists		-0.00670	0.1	0.1
$k^F_{m=2}$	utility for Bike Lane	fair-weather cyclists		0.66401	4.7	-12.2
$k^F_{m=3}$	utility for Cycle Track	fair-weather cyclists		1.01896	7.6	-18.7
$k^F_{m=4}$	utility for Bike Path Shared with Pedestrians	fair-weather cyclists		0.87775	6.3	-16.1
$k^F_{m=5}$	utility for Bike Path without Pedestrians	fair-weather cyclists		1.15432	8.5	-21.2
$k^S_{p=0}$	utility for Clear and No Gravel	all cyclists	*fixed*	0		
$k^{S1}_{p=1}$	utility for Clear with Gravel	winter cyclists		-0.74189	4.7	13.6
$k^{S1}_{p=2}$	utility for Fresh Snow (but No Ice)	winter cyclists		-1.45141	8.9	26.6
$k^{S1}_{p=3}$	utility for Fresh Snow on Existing Ice	winter cyclists		-2.73626	13.9	50.2
$k^{S1}_{p=4}$	utility for Snow and Ice from Previous Day	winter cyclists		-2.09838	12.4	38.5
$k^{S1}_{p=5}$	utility for Ice (but No Snow)	winter cyclists		-2.43120	13.1	44.6
$k^{S1}_{p=6}$	utility for Some Snow Piles from Clearing	winter cyclists		-1.10119	7.0	20.2
$k^{S2}_{p=1}$	utility for Clear with Gravel	fair-weather cyclists		0.46507	3.3	-8.5
$k^{S2}_{p=2}$	utility for Fresh Snow (but No Ice)	fair-weather cyclists		-0.64106	4.5	11.8
$k^{S2}_{p=3}$	utility for Fresh Snow on Existing Ice	fair-weather cyclists		-1.28165	8.5	23.5
$k^{S2}_{p=4}$	utility for Snow and Ice from Previous Day	fair-weather cyclists		-1.28525	8.6	23.6
$k^{S2}_{p=5}$	utility for Ice (but No Snow)	fair-weather cyclists		-1.63128	10.7	29.9
$k^{S2}_{p=6}$	utility for Some Snow Piles from Clearing	fair-weather cyclists		-0.95665	6.7	17.6

Fit Statistic	Value
number of observations	3530
number of parameters	18
0 coefficients likelihood	-2656.34
final likelihood	-2035.63
$\rho^2(0)$	0.2337

Regarding the results in Table 04, for the sub-population of all cyclists, with separate parameters for facility types and surface conditions for winter cyclists and fair-weather cyclists:

- Fair-weather cyclists are much more influenced by facility type. Switching from “Mixed with Traffic” to any other facility type (except “Mixed with Traffic with Bike Signs”) has much greater equivalent reductions in ride time for fair-weather cyclists compared to winter cyclists. The impact of the switch to “Mixed with Traffic with Bike Signs” has t-ratios of only 0.6 and 0.1, so the null hypothesis that this impact is 0 for both groups cannot be rejected. The impact of the switch to “Bike Lanes” is similarly indistinguishable from 0 for winter cyclists. However, for fair-weather cyclists, this impact is strong, equivalent to a reduction of 12 minutes in ride time with a respectable value of 4.7 for the t-ratio. These two groups of cyclists overall have very different reactions to bike lane facilities. Switching to “Cycle Track” has broadly similar impacts on utility for the two groups: equivalent to a reduction in ride time of more than 9 minutes for winter cyclists and more than 12 minutes for fair-weather cyclists. Switching to a bike path has a much greater impact on utility for fair-weather cyclists, particularly when there are no pedestrians. There is also a difference in relative impacts in that for fair-weather cyclists “Bike Path without Pedestrians” has more impact that “Bike Path Shared with Pedestrians” whereas for winter cyclists “Bike Path Shared with Pedestrians” has more impact that “Bike Path without Pedestrians”.
- Winter cyclists and fair-weather cyclists display markedly different reactions to the switch from “Clear and No Gravel” to “Clear with Gravel”: For winter cyclists it decreases utility by an amount equivalent to an increase in ride time of more than 13 minutes, with a solid value of 4.7 for the t-ratio, whereas for fair-weather cyclists it increases utility by an amount equivalent to a decrease in ride time of 8.5 minutes, with a still solid value of 3.3 for the t-ratio. The reasons for this difference in reactions are not clear.

- Winter cyclists are much more influenced by surface conditions. Switching from “Clear and No Gravel to other surface conditions (except “Clear with Gravel”) has much greater equivalent increases in ride time for winter cyclists compared to fair-weather cyclists. This is presumably a result of real-world experience. Fair-weather cyclists will have had virtually no experience with snow and ice by definition. For winter cyclists, switching to conditions with ice is equivalent to increases in ride time of 38.5 to 50 minutes, which is likely to exceed the actual ride time of most cycle trips in Calgary. The worst case is “Fresh Snow on Existing Ice”, which presumably is because it seems to be both the most slippery and the best at hiding its bad spots.
- Switching to “Fresh snow (but No Ice)” and to “Some Snow Piles from Clearing” have similar impacts on utility for winter cyclists, with the former equivalent to an increase in ride time of 26 minutes and the latter equivalent to an increase in ride time of 20 minutes. The impact of the latter is fairly similar to the impact of switching to “Clear with Gravel” for winter cyclists, which brings together these two surface conditions related to the results of maintenance actions.
- The utility for fair-weather cyclists is impacted comparatively more by “Ice (but No Snow)” and comparatively less by “Fresh Snow on Existing Ice” and “Some Snow Piles from Clearing”, which could reflect their lack of real-world experience.

5.4. Facility type and surface condition utility for all cyclists split by gender

In this case, the sub-population of all cyclists is considered, with separate parameters for facility types and surface conditions for male and female cyclists. The estimation results for this case are shown in Table 05.

Table 05. Estimation results for facility type and surface condition utility for cyclists split by gender.

Parameter	Parameter Description	(Sub-)Population		Estimated Value	| t -ratio |	Equivalent Ride Time (minutes)
β_r	utility sensitivity to ride time	all cyclists		-0.05330	20.4	1.0
$k^F_{m=0}$	utility for Mixed with Traffic	all cyclists	*fixed*	0		
$k^F_{m=1}$	utility for Mixed with Traffic with Bike Signs	male cyclists		0.04220	0.3	-0.8
$k^F_{m=2}$	utility for Bike Lane	male cyclists		0.38047	2.8	-7.1
$k^F_{m=3}$	utility for Cycle Track	male cyclists		0.87226	6.6	-16.4
$k^F_{m=4}$	utility for Bike Path Shared with Pedestrians	male cyclists		0.89640	6.5	-16.8
$k^F_{m=5}$	utility for Bike Path without Pedestrians	male cyclists		0.88566	6.6	-16.6
$k^F_{m=1}$	utility for Mixed with Traffic with Bike Signs	female cyclists		0.15572	1.0	-2.9
$k^F_{m=2}$	utility for Bike Lane	female cyclists		0.56887	3.5	-10.7
$k^F_{m=3}$	utility for Cycle Track	female cyclists		0.84091	5.2	-15.8
$k^F_{m=4}$	utility for Bike Path Shared with Pedestrians	female cyclists		0.56742	3.2	-10.6
$k^F_{m=5}$	utility for Bike Path without Pedestrians	female cyclists		0.90206	5.7	-16.9
$k^S_{p=0}$	utility for Clear and No Gravel	all cyclists	*fixed*	0		
$k^{S1}_{p=1}$	utility for Clear with Gravel	male cyclists		0.32048	2.3	-6.0
$k^{S1}_{p=2}$	utility for Fresh Snow (but No Ice)	male cyclists		-0.94248	6.7	17.7
$k^{S1}_{p=3}$	utility for Fresh Snow on Existing Ice	male cyclists		-1.53506	10.1	28.8
$k^{S1}_{p=4}$	utility for Snow and Ice from Previous Day	male cyclists		-1.37873	9.2	25.9
$k^{S1}_{p=5}$	utility for Ice (but No Snow)	male cyclists		-1.75481	11.3	32.9
$k^{S1}_{p=6}$	utility for Some Snow Piles from Clearing	male cyclists		-0.95376	6.9	17.9
$k^{S2}_{p=1}$	utility for Clear with Gravel	female cyclists		-0.60518	3.7	11.4
$k^{S2}_{p=2}$	utility for Fresh Snow (but No Ice)	female cyclists		-1.00969	6.3	18.9
$k^{S2}_{p=3}$	utility for Fresh Snow on Existing Ice	female cyclists		-2.19798	11.9	41.2
$k^{S2}_{p=4}$	utility for Snow and Ice from Previous Day	female cyclists		-1.93495	11.6	36.3
$k^{S2}_{p=5}$	utility for Ice (but No Snow)	female cyclists		-2.17955	12.3	40.9
$k^{S2}_{p=6}$	utility for Some Snow Piles from Clearing	female cyclists		-1.16607	7.2	21.9

Fit Statistic	Value
number of observations	3530
number of parameters	18
0 coefficients likelihood	-4620.11
final likelihood	-3447.98
$\rho^2(0)$	0.2484

Regarding the results in Table 05, for the sub-population of all cyclists, with separate parameters for facility types and surface conditions for male and female cyclists:

- Male and female cyclists display broadly similar influences on cycling utility. But there are a few substantive differences.
- Switching from "Clear and No Gravel" to "Clear with Gravel" increases utility for males, equivalent to a decrease of 6 minutes in riding time, and decreases utility for females, equivalent to an increase of more than 11 minutes in ride time. In this regard, male cyclists are like fair-weather cyclists and female cyclists are like winter cyclists.
- Females also display a greater reaction to ice in surface conditions, which is also like winter cyclists.
- The addition of bike signs to a "mixed with traffic" facility has slightly more impact on utility for female cyclists, again like winter cyclists, but the t-ratios are low and so there is little confidence in this indication.

5.5 Facility type and surface condition utility for full population split by gender

In this case, the full population is considered, with separate parameters for facility types and surface conditions for males and females. The estimation results for this case are shown in Table 06.

Table 06. Estimation results for facility type and surface condition utility for population split by gender.

Parameter	Parameter Description	(Sub-)Population		Estimated Value	| t -ratio |	Equivalent Ride Time (minutes)
β_r	utility sensitivity to ride time	all		-0.05471	27.7	1.0
$k^F_{m=0}$	utility for Mixed with Traffic	all	*fixed*	0		
$k^F_{m=1}$	utility for Mixed with Traffic with Bike Signs	males		0.18956	1.8	-3.5
$k^F_{m=2}$	utility for Bike Lane	males		0.70229	6.4	-12.8
$k^F_{m=3}$	utility for Cycle Track	males		1.08346	9.9	-19.8
$k^F_{m=4}$	utility for Bike Path Shared with Pedestrians	males		0.89165	8.0	-16.3
$k^F_{m=5}$	utility for Bike Path without Pedestrians	males		0.89884	8.1	-16.4
$k^F_{m=1}$	utility for Mixed with Traffic with Bike Signs	females		0.23881	2.1	-4.4
$k^F_{m=2}$	utility for Bike Lane	females		0.81459	7.2	-14.9
$k^F_{m=3}$	utility for Cycle Track	females		1.18151	10.3	-21.6
$k^F_{m=4}$	utility for Bike Path Shared with Pedestrians	females		0.80974	7.0	-14.8
$k^F_{m=5}$	utility for Bike Path without Pedestrians	females		1.11683	9.5	-20.4
$k^S_{p=0}$	utility for Clear and No Gravel	all	*fixed*	0		
$k^{S1}_{p=1}$	utility for Clear with Gravel	males		0.22470	2.0	-4.1
$k^{S1}_{p=2}$	utility for Fresh Snow (but No Ice)	males		-1.00345	8.8	18.3
$k^{S1}_{p=3}$	utility for Fresh Snow on Existing Ice	males		-1.78881	14.7	32.7
$k^{S1}_{p=4}$	utility for Snow and Ice from Previous Day	males		-1.54075	12.6	28.2
$k^{S1}_{p=5}$	utility for Ice (but No Snow)	males		-1.92970	15.5	35.3
$k^{S1}_{p=6}$	utility for Some Snow Piles from Clearing	males		-1.00122	8.7	18.3
$k^{S2}_{p=1}$	utility for Clear with Gravel	females		-0.44916	3.8	8.2
$k^{S2}_{p=2}$	utility for Fresh Snow (but No Ice)	females		-1.11822	9.3	20.4
$k^{S2}_{p=3}$	utility for Fresh Snow on Existing Ice	females		-2.53974	18.9	46.4
$k^{S2}_{p=4}$	utility for Snow and Ice from Previous Day	females		-2.08755	16.4	38.2

$k^{S2}_{p=5}$	utility for Ice (but No Snow)	females	-2.40249	17.8	43.9
$k^{S2}_{p=6}$	utility for Some Snow Piles from Clearing	females	-1.37432	11.1	25.1

Fit Statistic	Value
number of observations	4077
number of parameters	18
0 coefficients likelihood	-4620.11
final likelihood	-3447.98
$\rho^2(0)$	0.2484

Regarding the results in Table 06, for the full population, with separate parameters for facility types and surface conditions for males and females:

- These results mirror fairly closely those obtained for the sub-population of cyclists split by gender. The t-ratios are higher, with only a couple of exceptions, presumably at least in part as a result of the larger sample used in estimation.
- The impact of adding bike signs to a "mixed with traffic" facility is a bit greater, for both males and females, and the t-ratios are higher, adding more confidence to this indication and to the rejection of the null hypothesis that bike signs have no impact. It appears that cyclists are not influenced by bike signs, but non-cyclists are. This may arise because non-cyclists who are drivers have noted bike signs while driving and have an awareness that cyclists have learned to discount, but this is speculation.

6. Conclusions

6.1. A clarification

This work considers impacts on the utility of cycling for groups of people. Of course, the impacts can vary dramatically across the individuals in a group. The results reported here are for the group overall or for a "typical member" of a group, and not for each and every member of the group as an individual.

6.2. Principal findings

A principal finding of this work is that the various cycle-friendly facilities considered here act to make cycling more attractive for the Calgary population overall and for its sub-populations of cyclists, winter cyclists and fair-weather cyclists as groups. The term "cycle-friendly" is apt in this context. The magnitude of the positive impact on the utility of cycling varies by type of facility. For groups considered, with just one minor exception noted below, the order from least positive to most positive impact is:

- Mixed with Traffic
- Mixed with Traffic with Bike Signs, with a small and uncertain positive impact relative to the previous
- Bike Lane
- Bike Path Shared with Pedestrians
- Bike Path without Pedestrians
- Cycle Track, with the greatest positive impact (except for fair-weather cyclists, where "Bike Path without Pedestrians" has an impact that is greater than the impact of "Cycle Track" by a small and uncertain amount).

Overall, these impacts are much greater for fair-weather cyclists than they are for winter cyclists and are somewhat greater for the full population than they are for cyclists generally. As an indication of the upper bound of these impacts: the introduction of a cycle track facility where the operation was previously cycling mixed with traffic has about the same impact on cycling utility for fair-weather cyclists as a reduction in ride time of about 20 minutes.

Another principal finding of this work is that the various types of poor, winter-related surface conditions considered here act to make cycling less attractive for the Calgary population overall and for its sub-populations of cyclists, winter cyclists and fair-weather cyclists as groups. The magnitude of the negative impact on the utility of cycling varies by the surface condition. For groups considered, with some exceptions noted below, the order from least negative to most negative impact is:

- Clear with Gravel, with an impact compared to "Clear with No Gravel" that is sometimes positive (fair-weather cyclists, male cyclists, all males), sometimes positive with little certainty (full population, all cyclists), sometimes negative (winter cyclists, female cyclists, all females), and sometimes negative with little certainty (female cyclists)
- Fresh Snow (but No Ice)
- Some Snow Piles from Clearing, with an impact that is sometimes lower than the impact of (Fresh Snow (but No Ice)" (winter cyclists)
- Snow and Ice from Previous Day
- Ice (but No Snow)
- Fresh Snow on Existing Ice, with an impact that is sometimes lower than the impact of "Ice (but No Snow)" (fair-weather cyclists) and sometimes lower with less certainty (male cyclists, all males, all cyclists).

Overall, these impacts are substantially greater for winter cyclists than they are for fair-weather cyclists, sometimes double the amount, and are somewhat greater for females and for female cyclists than they are for males and for male cyclists. As an indication of the upper bound of these impacts: "Fresh Snow on Existing Ice" rather than "Clear and No Gravel" has about the same impact on cycling utility for winter cyclists as an increase in ride time of about 50 minutes.

Generally, the negative impacts of very poor surface conditions (particularly those involving ice) are greater than the positive impacts of the most attractive facilities (cycle tracks and bike paths without pedestrians.

Broadly, fair-weather cyclists are influenced more by facility type and winter cyclists are more influenced by surface conditions. It follows that upgrading facility types will generate more benefits for fair-weather cyclists whereas better winter maintenance will generate more benefits for winter cyclists. More broadly, it does not seem to be an aversion to the bad surface conditions in winter that keeps fair-weather cyclists from becoming winter cyclists. Winter cyclists are much more impacted by them than are fair-weather cyclists. In this regard, females and female cyclists are more like winter cyclists whereas males and male cyclists are more like fair-weather cyclists, which contradicts the idea that winter cyclist attitudes are mostly male attitudes and fair-weather cyclist attitudes are mostly female attitudes. Something else is acting to compensate winter cyclists when they decide to endure the bad surface conditions. The other factors influencing winter cyclists identified in the review of previous work are acting, including desire for exercise, a sense of enjoyment, and a "bicycling inclination" and related set of attitudes. Improving the maintenance of surfaces in the winter will almost certainly help encourage some fair-weather cyclists at the margin to switch over, but it will do much more to generate benefits for winter cyclists. Of course, when fair-weather cyclists switch over, they become winter cyclists, and presumably their new real-world experience will draw them towards the sensitivities of winter cyclists as found here.

6.3. Implications for Policy and Planning

If the City of Calgary is contemplating actions to increase bicycle use year-round, the results obtained here provide some relevant indications:

- Adding bike signs to mixed with traffic operations adds little benefit and will do very little to attract more cyclists
- Installing bike lanes will add benefits and attract users, but much more for fair-weather cyclists than for winter cyclists
- Bike paths shared with pedestrians will do more than bike lanes and cycle tracks and bike paths without pedestrians will do even more, again much more for fair-weather cyclists than for winter cyclists.

If the City of Calgary is focusing more on actions to increase bicycle use in winter, the results obtained here indicate:

- Installing cycle-friendly facilities will add some benefit and will attract some more cyclists.
- Improvements in surface conditions will be much more effective than installing cycle-friendly facilities, adding much greater benefits and potentially many more cyclists. Maintenance operations that mitigate the effects of ice would be most effective. Next most effective would be operations that clear the snow, especially if it is fresh snow on ice, and complete removal would be more effective than leaving piles at the side of the facility.

- Substantial increases in winter cycling will only occur if the attitudes and perceptions to winter cycling become more positive for a larger segment of the population beyond the small cadre of current winter cyclists. There are of course some people at the margin, and it may take little encouragement for them. Such encouragements in combination with improvements in surface conditions would be more effective.

These discussions have only considered the relative attractiveness of potential upgrades in facility types and maintenance operations. The corresponding costs are beyond the scope of this paper, but would of course need to be considered in the assessment and development of alternative potential plans.

6.4. Potential further application

The approach used in this work successfully provided indications of the factors influencing cycling in Calgary, and winter cycling in particular. These indications can be used to help guide policy and planning, to make it more effective at achieving the intended goals. It follows that use of this approach could contribute in the consideration of other aspects of cycling, transportation, and policy and planning generally, for the City of Calgary and other jurisdictions.

Acknowledgements

The survey was successful because of the kind cooperation of the respondents who participated, for which the authors express their thanks. Financial support was provided by the Natural Sciences and Engineering Research Council of Canada.

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