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Influences on bicycle use

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Abstract A stated preference experiment was performed in Edmonton in Canada to both examine the nature of various influences on bicycle use and obtain ratios among parameter values to be used in the development of a larger simulation of household travel behaviour. A total of 1128 questionnaires were completed and returned by current cyclists. Each questionnaire presented a pair of possible bicycle use alternatives and asked which was preferred for travel to a hypothetical all-day meeting or gathering (business or social). Alternatives were described by specifying the amounts of time spent on three different types of cycling facility and whether or not showers and/or secure bicycle parking were available at the destination. Indications of socio-economic character and levels of experience and comfort regarding cycling were also collected. The observations thus obtained were used to estimate the parameter values for a range of different utility functions in logit models representing this choice behaviour. The results indicate, among other things, that time spent cycling in mixed traffic is more onerous than time spent cycling on bike lanes or bike paths; that secure parking is more important than showers at the destination; and that cycling times on roadways tend to become less onerous as level of experience increases. Some of these results are novel and others are consistent with findings regarding bicycle use in work done by others, which is seen to add credence to this work. A review of previous findings concerning influences on cycling behaviour is also included.

Keywords Cycling · Bicycle route choice · Stated preference · Logit choice modelling

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1 Introduction

This paper describes an experimental investigation of the influence of various factors on bicycle use for a set of cyclists in Edmonton in Canada. The concern is with non-recreational cycling, for transport to some other activity and not solely for recreation. The investigation was to contribute to a larger modelling effort concerning all passenger travel in Edmonton by obtaining sufficient data regarding cycling behaviour to support the development of a sub-model with acceptable sample errors that could be appropriately grafted to a larger model in a subsequent estimation process. The investigation was also to bring about a more complete understanding of attitudes and behaviour regarding cycling, and thereby inform the design and development of public policy measures intended to improve and encourage cycling as a travel alternative.

Of particular interest here are the roles and influences of different types of bicycle facility, different forms of cycling-related amenities at the destination, level of experience and degree of comfort with cycling in mixed traffic. This reflects a desire to appreciate how public policy alternatives regarding elements of cycling infrastructure might influence the attractiveness of non-recreational cycling for different segments of the travelling public.

2 Review of previous work on factors influencing bicycle use

A wide range of factors have been identified as having an influence on bicycle use in previous studies. These factors are summarised in Table 1 together with corresponding sources. The list in Table 1 draws only from studies with a direct focus on cycling behaviour where some form of empirical approach was used in analysis or verification.

Some travel demand models include bicycle as an explicit alternative (Greenberg 1995; Replogle 1995; Stein 1996). It can be argued that all the input variables in such models—including all the times and costs for each mode and all the distributions of land use and socio-economic characteristics—influence the model outputs concerning bicycle use. But such indications of influence are not included in Table 1, even though they may be empirically based, in part because these indications are somewhat less 'direct' and in part because of the very large amount of modelling work done and the difficulty of assessing the empirical basis of much of this work using available written descriptions.

The type of cycling facility and the nature of the shared roadway and the vehicle traffic using it seem to have received the most attention, leading to their more frequent identification as behavioural influences. Three broad categories of cycling facility that influence preferences are:

- 'in mixed traffic', where cyclists share the full roadway with other traffic without any longitudinal separation;
- 'bike lane', where cyclists use the roadway with other traffic but have a separate lane that is longitudinally separated from the other traffic lanes and is exclusively for cyclists; and
- 'bike path', a separate facility that is typically much narrower than a roadway that cyclists use exclusively or share with other non-motorised traffic.

Table 1 Summary of factors that have been identified as influences on cycling behaviour and cycle route choice in particular, with references where these factors are identified

Factor	References
Facility characteristics	
Type of cycling facility (whether mixed with traffic, bike lane, or bike path)	Antonakos (1994); Aultman-Hall (1996); Axhausen and Smith (1986); Bradley and Bovy (1984); Calgary (1993); Copley and Pelz (1995); Goldsmith (1996); Guttenplan and Patten (1995); Harris and Associates (1991); Kroll and Ramey (1977); Kroll and Sommer (1976); Landis and Vattikuti (1996); Lott et al. (1978); Mars and Kyriakides (1986); Nelson and Allen (1997); Sacks (1994); Taylor and Mahmassani (1997)
Nature of shared roadway, including road class, sight distances, turning radii, lane/median configurations	Aultman-Hall (1996); Calgary (1993); Copley and Pelz (1995); Davis (1995); Denver (1993); Epperson (1994); Landis and Vattikuti (1996); Mars and Kyriakides (1986); Shepherd (1994); Sorton (1995); Sorton and Walsh (1994)
Existence of on-street parking	Davis (1995); Epperson (1994); Mars and Kyriakides (1986)
Pavement surface type and/or quality	Antonakos (1994); Axhausen and Smith (1986); Bradley and Bovy (1984); Davis (1995); Epperson (1994); Landis and Vattikuti (1996)
Grades	Antonakos (1994); Axhausen and Smith (1986); Davis (1995)
Intersection spacing and/or configuration	Aultman-Hall (1996); Davis (1995); Epperson (1994); Teichgraeber (1982)
Cycling treatments at signals, including timing and detection	Copley and Pelz (1995)
Completeness and directness of cycling infrastructure	Ambrosius (1984); Copley and Pelz (1995); Sacks (1994)
Availability of showers at origin and/or destination	Guttenplan and Patten (1995); Sacks (1994); Taylor and Mahmassani (1997)
Availability of secure parking for bicycle at origin and/or destination	Calgary (1993); Copley and Pelz (1995); Denver (1993); Guttenplan and Patten (1995); Mars and Kyriakides (1986 Sacks (1994); Taylor and Mahmassani (1997); Wynne (1992)
Non-cycle traffic characteristics	
Motor vehicle speeds and driver behaviour	Antonakos (1994); Davis (1995); Epperson (1994); Landis and Vattikuti (1996); Mars and Kyriakides (1986); Sorton (1995); Sorton and Walsh (1994)
Volume or mix of motor vehicle types, including proportion trucks	Antonakos (1994); Axhausen and Smith (1986); Bradley and Bovy (1984); Calgary (1993); Davis (1995); Epperson (1994); Landis and Vattikuti (1996); Mars and Kyriakides (1986); Sorton and Walsh (1994)
Pedestrian interaction	Mars and Kyriakides (1986)
Individual and trip characteristics	
Gender	Antonakos (1994); Aultman-Hall (1996); Sacks (1994); Taylor and Mahmassani (1997)

Table 1 continued

Factor	References
Age	Antonakos (1994); Aultman-Hall (1996); Sacks (1994); Taylor and Mahmassani (1997); Treadgold (1996)
Income	Taylor and Mahmassani (1997)
Level of cycling experience	Antonakos (1994); Axhausen and Smith (1986); Sorton and Walsh (1994)
Private vehicle ownership	Sacks (1994)
Safety concerns	Antonakos (1994); Kroll and Ramey (1977); Kroll and Sommer (1976); Lott et al. (1978); Mars and Kyriakides (1986)
Personal security concerns	Sacks (1994)
Flexibility of work hours	Denver (1993); Sacks (1994)
Type of bicycle (road or mountain)	Antonakos (1994); Taylor and Mahmassani (1997)
Bicycle purchase price	Parajuli (1996); Parajuli et al. (1996)
Trip length, by time or distance	Bradley and Bovy (1984); Calgary (1993); Guttenplan and Patten (1995); Parajuli 1996); Parajuli et al. 1996)
Environment/situation characteristics	
Weather	Calgary (1993)
Sweeping/snowplowing	Copley and Pelz (1995)
Nature of abutting land uses	Axhausen and Smith (1986); Davis (1995); Epperson (1994); Landis and Vattikuti (1996)
Aesthetics along route	Antonakos (1994); Sacks (1994)
Degree of political and public support for cycling	Clarke (1992); Copley and Pelz (1995); Wynne (1992)
Level of public assistance for cyclists, including maps, route advice and emergency aid	Denver (1993)
Education and enforcement regarding cycling	Antonakos (1994); Denver (1993); Wynne (1992)
Availability of public transport	Denver (1993); Wynne (1992)
Cost and other disincentives to use other modes	Moritz (1997); Sacks (1994); Taylor and Mahmassani (1997); Wynne (1992)

Some work has been done developing and supporting the idea that there are different types of cyclists with different perceptions and preferences regarding different types of facilities and treatments (Axhausen and Smith 1986; Epperson et al. 1995; Forester 1986; Sorton and Walsh 1994). Income, age, level of cycling experience and trip purpose have all been proposed as the basis for categorisations intended to capture these differences.

Cycling safety—real or perceived—is an emotional issue that has received considerable attention in the literature (Forester 1986; Wilkinson et al. 1992). Various opinions and positions regarding both the influence of different factors on real and perceived safety and the accuracy of generally held perceptions about safety have been forcefully argued. One particular 'lightning-rod' has been the relative accuracies of perceptions regarding safety across different levels of cycling experience and training. Some contend that cycling on bike paths and bike lanes is actually less safe in general than cycling in mixed traffic—at least for cyclists who understand basic driving rules and practice so-called 'effective cycling'—which contradicts conventional perceptions (Forester 1986; St Jacques and DeRobertis 1995). The influence of safety on cycling behaviour, either directly with regard to perceived conditions or via the factors that affect either actual or perceived safety, has also received some attention and been found to influence behaviour.

There has been little consideration of route length or the directness of the trip as influential factors. This is surprising given that time and directness are seen to play pivotal roles in route choice behaviour for other modes (Ortúzar and Willumsen 1994). There has also been very little evaluation of the trade-offs that cyclists might be making between the relative directness and pleasantness of routes. Efforts to make cycling safer or more pleasant might lead to longer trips and greater delays for both cyclists and motorists (Forester 1996). More importantly, if special accommodations are made for cyclists at only some locations or parts of networks then at least some cyclists would have to go out of their way in order to enjoy these accommodations. It follows that an understanding of cyclist attitudes regarding trade-offs between directness and pleasantness would help in the design and evaluation of cycling facilities. Notwithstanding, it should be noted that in some cases where trip length has been considered it has not emerged as an important or significant variable (Axhausen and Smith 1986; Aultman-Hall 1996).

3 Method

Components of the investigation method are described below, including aspects of the analysis approach used and the design and implementation of the survey used to collect the required data.

3.1 Analysis approach

The approach used in this work was to investigate cycling preferences and the influences of various factors on cycling behaviour by estimating relevant logit choice models using stated preference (SP) observations of the cycling-related choices people make. SP observations in this case indicate the choices respondents make regarding hypothetical cycling situations and options. The resulting coefficient estimates and associated statistics form the basis for inferences about the strength and statistical significance of the influences of specific factors on the attractiveness of alternatives.

The logit choice model has the following form for the choice situation concerning two hypothetical bicycle use alternatives considered here:

$$P_{\mathrm{a}} = \exp(U_{\mathrm{a}})/(\exp(U_{\mathrm{a}}) + \exp(U_{\mathrm{b}}))$$

where P_{a} is probability that bicycle use alternative a is preferred, U_{a} is utility value associated with bicycle use alternative a and U_{b} is utility value associated with bicycle use alternative b.

The utility function that ascribes utility values to the bicycle use alternatives has the following general, linear form:

$$U_{\mathrm{i}} = \phi 1 * X_{1\mathrm{i}} + \phi 2 * X_{2\mathrm{i}} + \cdots + n * X_{n\mathrm{i}} + \cdots$$

where n is index representing attributes, $X_{n\mathrm{i}}$ is value of attribute n for alternative i, ϕn is utility function coefficient associated with attribute n.

The logit model and the estimation of the coefficients in the utility function using empirical data are well-known. See Ben-Akiva and Lerman (1985) for a review of the relevant methods, issues and interpretation of results as used here.

3.2 Bicycle attributes and issues considered

The potential importance and policy relevance of trip length, together with the lack of agreement regarding it in previous work led to it being selected as one of the factors to be considered in this work. Different cycling facilities and both showers and secure parking were also selected for consideration because of their policy relevance in Edmonton.

Variations in behaviour across different socio-economic groups and across levels of experience were also included for consideration in response to the indications regarding their relevance obtained in previous work. The role of familiarity or comfort with cycling in mixed traffic, as opposed to level of experience with cycling, was identified as an issue for consideration in this work, as was bicycle purchase price.

The ‘in mixed traffic’, ‘bike lane’ and ‘bike path’ categories for cycling facility were adopted in this work, in part to be consistent with previous work and with designations in Edmonton; but also because it was felt that more detailed categorisations would be too unwieldy given the survey method chosen.

It is important to keep the descriptions of alternatives in stated preference experiments relatively simple, otherwise some respondents may find the task too complicated and thus not try to be accurate (Bates 1988). Accordingly, consideration was limited to those attributes and factors identified to be of specific interest in the light of the literature review. The requirements for combining the results of this work with the aggregate, network-based travel demand model being developed for the larger modelling effort also placed some constraints on the sorts of variable descriptions and categorisations that could be considered.

The result was a set of specific attributes as follows:

- time spent cycling on roads in mixed traffic: values selected randomly from 0 to 60 min, rounded to the nearest 5 min;
- time spent cycling on designated bike lanes on roads: values selected randomly from 0 to 60 min, rounded to the nearest 5 min;
- time spent cycling on bike paths shared with pedestrians: values selected randomly from 0 to 60 min, rounded to the nearest 5 min;
- availability of showers at destination; with two values considered: 'showers are available' and 'showers are not available';
- availability of secure parking for bicycles at destination; with two values considered: 'secure parking is available' and 'secure parking is not available'.

Descriptions of the hypothetical alternatives were developed by randomly selecting values for the attributes listed above (in all cases from uniform distributions) and combining these selected values into a bundle representing a complete bicycle use alternative. For a given alternative, first one of the three types of time was randomly selected for omission, so that the alternative would include only two types of time and thereby be somewhat less complicated. Then the value for the total travel time was selected and split randomly into the other two types of time, with a 60-min maximum value for the total time. After that the values for the facility conditions regarding showers and secure parking were randomly selected as indicated. Thus, one alternative might be to cycle for 15 min on roadways in mixed traffic and 20 min on bike paths shared with pedestrians, with showers but no secure parking at the destination. Another might be 30 min on bike paths, with secure parking but no showers at the destination.

3.3 Survey instrument

A self-completion, mail-back survey questionnaire form was prepared, fitting on two sides of an 8.5″ × 11″ sheet. It contained various questions about actual bicycle use and also presented the SP exercise.

The SP portion of the form occupied about half of one side of the sheet, including instructions and the presentations of two hypothetical alternatives. The instructions guided the respondent through the process, first setting the context by instructing the respondent to imagine that he or she was travelling from home to an all-day meeting by bicycle, then displaying a randomly selected pair of hypothetical bicycle use alternatives and asking the respondent to indicate which of these alternatives was preferred. An example of this portion of the questionnaire form is provided in Table 2.

The questionnaire form also contained questions about personal conditions and attitudes as follows:

- gender;
- age, using specified ranges;
- household income, using specified ranges;
- bicycle purchase price;
- level of experience with cycling in mixed traffic, using a Likhert Scale with a 'highly-moderately-moderately-highly' sequence of adjectives;
- level of comfort with cycling in mixed traffic, using a Likhert Scale with a 'highly-moderately-moderately-highly' sequence of adjectives.

Table 2 Two randomly generated hypothetical cycling options for a trip to an all-day meeting; respondents were asked to choose between two such options

In this section we would like you to play a small game that is designed to indicate how cyclists in Edmonton feel about certain aspects of cycling. Please imagine you have to make a trip by bicycle to an all-day meeting that you must attend. If you are employed, imagine that you must attend this meeting as part of your work responsibilities. Consider the following two options for the trip. They have conditions as indicated and are identical in all other aspects. Please check the box corresponding to the option you most prefer.

Option A: [__]		Option B [__]	
* Showers for cyclists at destination	Yes	* Showers for cyclists at destination	Yes
* Secure bicycle parking at destination	Yes	* Secure bicycle parking at destination	No
* Total cycling time:	40 min	* Total cycling time:	30 min
which is made up of		which is made up of	
Time on bike paths shared with pedestrians	15 min	Time on bike paths shared with pedestrians	20 min
Time on roadways shared with cars	25 min	Time on roadways shared with cars	10 min

3.4 Data collection

Edmonton is the principal metropolitan centre in the central and northern portions of the Province of Alberta in Canada. In 1994 the population of the Edmonton metropolitan (Census) area was approximately 866,000 (Edmonton 1995). Edmonton has a connected network of designated bicycle routes and trails. In 1993 there were (Edmonton 1993):

- 47 km of bicycle paths, for use by cyclists and pedestrians exclusively, called 'Class 1 Routes';
- 3 km of bicycle lanes, where a longitudinal portion of a roadway is designated for use by cyclists exclusively, called 'Class 2 Routes'; and
- 96 km of bicycle routes, where cyclists are provided with a signed route through the roadway network but share the road with motorized vehicles, called 'Class 3 Routes'.

In addition, there were at least 55 km of multi-use recreational trails in the Edmonton river valley park system (Edmonton 1993).

In late September 1994, a total of 3540 questionnaire forms were handed to cyclists or attached to parked bicycles throughout the Edmonton area. A total of 1188 completed questionnaire forms were returned, constituting a response rate of just over 33%. After the removal of unusable and inconsistent forms, the result was a data set of stated preference choice observations for a corresponding sample of 1128 individual cyclists. This data set was used to estimate the coefficients in different utility functions.

4 Results

Various alternate utility functions were considered using different combinations of variables. The estimation results for a selection of some of these utility functions are displayed in Table 3, with the parameter definitions provided in Table 4. These results are discussed below.

Table 3 Estimation results for selection of utility functions considered, showing coefficient estimates, absolute values of *t*-ratios and goodness-of-fit statistics

Parameter	Function 1		Function 2		Function 3		Function 4		Function 5	
	Coeff	*t*-ratio	Coeff	*t*-ratio	Coeff	*t*-ratio	Coeff	*t*-ratio	Coeff	*t*-ratio
SHWR	0.1967	2.10	0.1824	1.90	0.2104	2.20	0.1953	2.00	0.1992	2.10
PARK	1.459	13.60	1.472	13.50	1.495	13.50				
PARK-A1							2.143	4.80		
PARK-A2							1.596	10.30		
PARK-A3							1.244	7.30		
PARK-A4							1.288	5.40		
PARK-C1									1.253	8.90
PARK-C2									1.684	9.60
PARK-C3									1.803	4.70
PARK-C4									1.518	4.70
ROAD	–0.05507	10.40					–0.05541	10.40	–0.05573	10.50
ROAD-HE			–0.04594	3.50						
ROAD-ME			–0.05857	7.80						
ROAD-MI			–0.09511	4.90						
ROAD-HI			–0.04924	1.80						
ROAD-HC					–0.02354	2.00				
ROAD-MC					–0.05356	6.80				
ROAD-MU					–0.08081	7.20				
ROAD-HU					–0.06694	5.20				
LANE	–0.01347	3.10					–0.01374	3.10	–0.01348	3.10
LANE-HE			–0.00218	0.30						
LANE-ME			–0.01288	2.00						
LANE-MI			–0.04153	3.50						
LANE-HI			–0.03998	1.90						
LANE-HC					–0.01256	2.00				
LANE-MC					–0.00682	0.90				
LANE-MU					–0.01166	1.50				
LANE-HU					–0.02333	2.40				
PATH	–0.01952	4.50					–0.01977	4.50	–0.01986	4.50
PATH-HE			–0.02305	3.40						
PATH-ME			–0.01877	2.90						
PATH-MI			–0.02516	1.90						
PATH-HI			–0.00557	0.30						
PATH-HC					–0.02021	1.70				
PATH-MC					–0.03091	4.30				
PATH-MU					–0.01721	2.20				
PATH-HU					–0.00737	0.80				
$\rho^2(0)$	0.200		0.201		0.206		0.200		0.200	

4.1 Function 1—Baseline

Function 1 is the simplest and most direct representation of the preferences of the sample. For each attribute the overall average attitude for the entire sample is captured in one coefficient.

All the coefficient estimates are statistically significant and have signs consistent with expectations. For example, the coefficient for ROAD is negative, consistent with the notion that an increase in riding time on roadways would make the corresponding alternative less attractive. The value for $\rho^2(0)$ is 0.200, which is fairly low but still satisfactory—indicating that there is still considerable unexplained variation in preferences.

Table 4 Definition of variables

Parameter	Definition
SHWR	Availability of showers at destination—1 if showers available, 0 otherwise
PARK	Availability of secure parking at destination—1 if showers available, 0 otherwise
PARK-A1	1 when secure parking is available and respondent is less than 18-years-old, 0 otherwise
PARK-A2	1 when secure parking is available and respondent is between 18 and 27-years-old, 0 otherwise
PARK-A3	1 when secure parking is available and respondent is between 28 and 40-years-old, 0 otherwise
PARK-A4	1 when secure parking is available and respondent is more than 40-years-old, 0 otherwise
PARK-C1	1 when secure parking is available and bicycle cost is less than C$400, 0 otherwise
PARK-C2	1 when secure parking is available and bicycle cost is between C$400 and $900, 0 otherwise
PARK-C3	1 when secure parking is available and bicycle cost is between C$900 and $1300, 0 otherwise
PARK-C4	1 when secure parking is available and bicycle cost is more than $1300, 0 otherwise
ROAD	Minutes riding on roadways in mixed traffic
ROAD-HE	Minutes riding on roadways in mixed traffic when ‘‘highly experienced’’, 0 otherwise
ROAD-ME	Minutes riding on roadways in mixed traffic when ‘‘moderately experienced’’, 0 otherwise
ROAD-MI	Minutes riding on roadways in mixed traffic when ‘‘moderately inexperienced’’, 0 otherwise
ROAD-HI	Minutes riding on roadways in mixed traffic when ‘‘highly inexperienced’’, 0 otherwise
ROAD-HC	Minutes riding on roadways in mixed traffic when ‘‘highly comfortable’’, 0 otherwise
ROAD-MC	Minutes riding on roadways in mixed traffic when ‘‘moderately comfortable’’, 0 otherwise
ROAD-MU	Minutes riding on roadways in mixed traffic when ‘‘moderately uncomfortable’’, 0 otherwise
ROAD-HU	Minutes riding on roadways in mixed traffic when ‘‘highly uncomfortable’’, 0 otherwise
LANE	Minutes riding on designated bike lanes on roadways
LANE-HE	Minutes riding on designated bike lanes on roadways when ‘‘highly experienced’’, 0 otherwise
LANE-ME	Minutes riding on designated bike lanes on roadways when ‘‘moderately experienced’’, 0 otherwise
LANE-MI	Minutes riding on designated bike lanes on roadways when ‘‘moderately inexperienced’’, 0 otherwise
LANE-HI	Minutes riding on designated bike lanes on roadways when ‘‘highly inexperienced’’, 0 otherwise
LANE-HC	Minutes riding on designated bike lanes on roadways when ‘‘highly comfortable’’, 0 otherwise
LANE-MC	Minutes riding on designated bike lanes on roadways when ‘‘moderately comfortable’’, 0 otherwise
LANE-MU	Minutes riding on designated bike lanes on roadways when ‘‘moderately uncomfortable’’, 0 otherwise
LANE-HU	Minutes riding on designated bike lanes on roadways when ‘‘highly uncomfortable’’, 0 otherwise

Table 4 continued

Parameter	Definition
PATH	Minutes riding on bike paths shared with pedestrians
PATH-HE	Minutes riding on bike paths shared with pedestrians when "highly experienced", 0 otherwise
PATH-ME	Minutes riding on bike paths shared with pedestrians when "moderately experienced", 0 otherwise
PATH-MI	Minutes riding on bike paths shared with pedestrians when "moderately inexperienced", 0 otherwise
PATH-HI	Minutes riding on bike paths shared with pedestrians when "highly inexperienced", 0 otherwise
PATH-HC	Minutes riding on bike paths shared with pedestrians when "highly comfortable", 0 otherwise
PATH-MC	Minutes riding on bike paths shared with pedestrians when "moderately comfortable", 0 otherwise
PATH-MU	Minutes riding on bike paths shared with pedestrians when "moderately uncomfortable", 0 otherwise
PATH-HU	Minutes riding on bike paths shared with pedestrians when "highly uncomfortable", 0 otherwise

The coefficient estimates for ROAD and LANE together imply that a minute spent on a roadway in mixed traffic is 4.1 times as onerous as a minute spent on a designated bike lane. This suggests there is a general feeling that riding on a roadway in mixed traffic is much less desirable than riding in a designated bike lane. It is expected that this feeling is in part due to the perception that riding in mixed traffic is more dangerous, which is consistent with the evidence of safety effects found elsewhere (Kroll and Ramey 1977; Kroll and Sommer 1976; Lott et al. 1978; Guttenplan and Patten 1995) and also with the claims regarding 'effective cycling' (Forester 1986).

The coefficient estimates for PATH and LANE together imply that a minute spent on a pathway with pedestrians is 1.4 times as onerous as a minute spent on a designated bike lane. This may be in part the result of a general perception that mixing with pedestrians is seen to be more dangerous than using a designated bike lane. It may also be partly due to concerns about the possibility of being confined to slower speeds when mixing with pedestrians. The *t*-statistic is only 1.1 for the difference between the coefficient estimates for PATH and LANE, indicating that this difference is not highly significant in a statistical sense. Nevertheless, it was judged appropriate to keep two separate coefficients for these two variables in subsequent utility functions given their central role in the analysis overall.

Consistent with the findings of previous work, both the availability of secure bicycle parking and the availability of showers at the destination have significant influences. The coefficient estimates for SHWR and PARK indicate that secure parking is much more important than showers. The coefficient estimates for ROAD and PARK together imply that the addition of secure parking has the same effect on utility as a decrease of 26.5 min in the time spent on a roadway in mixed traffic. Such a large amount of time as an equivalent is rather surprising and is felt to reflect both a relatively large degree of concern about bicycle security overall together with a relatively small degree of concern about cycling time generally.

4.2 Function 2—Experience and cycling facility preferences

Function 2 is designed to test the hypothesis that attitudes to different cycling facility types vary according to the level of experience cycling in mixed traffic. The function splits the sensitivity to time on each facility type into four values, one for each indicated level of experience. The value for $\rho^2(0)$ is only slightly higher than it is for Function 1, indicating only a slight improvement in model fit.

For the lanes and roads categories, there is a modest trend where the ride time becomes more onerous in going from the 'highly experienced' to 'moderately experienced' to 'moderately inexperienced' categories. This is consistent with expectations in that the more experienced will tend to perceive less risk for a given amount of exposure time (Forester 1986) and may also tend to be in better physical shape for longer rides in general. The trend does not extend to the highly inexperienced group. This may be due to sample error—only 31 cyclists rated themselves highly inexperienced. This could also reflect some genuine differences in attitudes 'bucking' the weak trends across the other groups. For example, with regard to bike paths in particular, the parameter estimate for PATH-HI is positive but not significantly different from 0, which may be partly due to the existence of some very positive feelings about bike paths and pedestrian speeds among cyclists in this group specifically.

4.3 Function 3—Comfort and cycling facility preferences

Function 3 is similar to Function 2, except that the attitudes are split according to the self-assessed level of comfort riding on main roads in traffic. The $\rho^2(0)$ shows an improvement in model fit.

Overall, the results do not display simple trends across comfort groups. For the highly comfortable category, the sensitivities to times on different facilities are fairly similar. For all other comfort groups, the sensitivities to times in mixed traffic are relatively much more negative. This is hardly surprising: those less than completely comfortable cycling in mixed traffic view time in mixed traffic as more onerous. This is seen to be a fairly strong confirmation that the stated preference process was able to elicit realistic behaviour, thereby adding credence to the results obtained.

Time on paths appears to be more onerous than time on lanes for the moderately comfortable category; and yet the reverse appears to be true for the highly uncomfortable category. It may be that these results reflect different perceptions and relative concerns within these groups: the moderately comfortable are more concerned about potential pedestrian–cycle conflicts and being restricted downwards to pedestrian speeds whereas the highly uncomfortable are more concerned about potential vehicle–cycle conflicts and being pressured upwards to relatively faster cycling speeds. The moderately uncomfortable category possibly contains a mix of these different perceptions and concerns, resulting in the middle-range values for the coefficient estimates for both lanes and paths.

The results obtained with Functions 2 and 3 together indicate:

- the relative unattractiveness of cycling in mixed traffic decreases in much the same way with both increasing levels of comfort and increasing levels of experience in mixed traffic, with an upward swing for the highly inexperienced group;

- those who are highly comfortable in mixed traffic are relatively indifferent to cycling facility type;
- the relative attractiveness of bike lanes tends to increase as level of experience and level of comfort in mixed traffic increases; and
- the relative attractiveness of bike paths tends to increase with decreasing level of comfort in mixed traffic but does not vary much with level of experience.

4.4 Function 4—Age and parking sensitivities

The results for Function 1 showed the importance of secure parking. Functions 4 and 5 were formulated to investigate how attitudes towards parking vary across different categories of cyclists.

Function 4 considers the variation in attitudes towards parking with age. The results indicate that the youngest age groups value secure parking much more highly (and with greater statistical significance) than do the two oldest age groups. It may be that this arises because of differences in the expected cost of having a bicycle stolen. The bicycle may tend to be a more significant possession, representing a larger proportion of the total set of possessions, for those in the younger age groups. For those under 16-years-old in particular, the bicycle is likely to be a much more important means of transportation given the restrictions on automobile driving. In addition, those in the younger age groups tend to go more often to places where the incidence of cycle theft may be more prevalent, such as playgrounds, schools and universities.

4.5 Function 5—Bicycle price and parking sensitivities

Function 5 considers the variation in attitudes towards secure parking with bicycle purchase price. The results for Function 4 seem to suggest that sensitivities to secure parking would be strongly influenced by bicycle price; but the results for Function 5 provide only partial support. For the lowest three cost groups secure parking becomes relatively more attractive as price increases. The result for the highest price group does not follow this trend. Furthermore, the *t*-statistics for the differences between the coefficient estimates for secure parking for the highest three highest price groups are all close to 0, indicating that these estimates are not significantly different. Thus, it would appear that money cost is only part of what determines the strength of concern about secure parking.

4.6 Other functions

A variety of other functions were considered. Expanding the relationship between self-assessment of experience and attitudes to showers did not produce a model with a better goodness-of-fit, but it did provide some indication that those with a higher level of cycling experience place a higher value on showers. No relationship was found between experience and attitudes towards parking. There were indications that older people had less of an aversion to riding in mixed traffic and that the very young had less of an aversion to riding on paths, but these indications were weak statistically and the corresponding models did not display any better goodness-of-fit.

5 Conclusions

Various attributes related to cycling and personal characteristics have been shown to have significant influences on attitudes to non-recreational cycle use, including the type of cycling facility and the length of time spent on it, the availability of showers and secure parking at the destination, cyclist age, levels of experience and comfort cycling in mixed traffic and cycle purchase price. Several trade-off rates among these attributes have been identified and these seem plausible and at least broadly consistent with the findings of other work. All this adds credence to the results, particularly those results that are most novel.

Some of the specific findings arising from the work are as follows:

- Increasing trip length represented as a greater trip time has an important and significant negative effect on the attractiveness of cycling. This is consistent with expectations, but does contradict the findings of some previous work.
- The sensitivity to cycling trip time varies substantially with cycling facility type. For the typical cyclist, 1-min cycling in mixed traffic is as onerous as 4.1 min on bike lanes or 2.8 min on bike paths.
- The sensitivities to cycling times on different cycling facility types varies with levels of experience and comfort in mixed traffic, with general trends where times on roadways become less onerous as level of experience or comfort increases.
- The provision of secure parking at the destination has a very large and significant positive effect on the attractiveness of cycling, equivalent to a reduction of 26.5-min cycling in mixed traffic.
- The provision of showers at the destination has a more modest but still significant positive effect on the attractiveness of cycling, equivalent to a reduction of 3.6-min cycling in mixed traffic.
- Taking into account variations in attitudes across different segments of cyclists did not bring about dramatic increases in the explanation provided by models of cycling choice behaviour.

Because 'wide curb lanes' were not included as a facility type as distinct from 'in mixed traffic', this work does not contribute much to the debate over the relative merits of bike lanes versus wide curb lanes (St Jacques and DeRobertis 1995). But this work does show that cyclists tend to place a high value on engineering improvements to roadways that make these roadways more cycle-friendly.

It is uncertain whether the reversals of trends for the highly inexperienced and the highly uncomfortable categories—as obtained with Functions 2 and 3–have any basis in actual behaviour or are the results of the small number of observations in these specific categories. With hindsight, perhaps it should have been anticipated that there would be relatively few observations in these categories for two reasons: (1) there is a selection bias where it is less likely to encounter and attach questionnaires to cycles being used by highly inexperienced cyclists simply because these cyclists are not out cycling as much; and (2) human nature might tend to make it difficult for some respondents to make a self-assessment–or admission—of highly inexperienced or highly uncomfortable. Accordingly, some sort of stratified sampling could have been used; although this would have required an alternative survey design and would have added complexity.

It is important to provide the caveat at this point that SP observations and models developed using them do suffer from some limitations—both generally and in this case specifically. In particular, the magnitudes of the individual parameter estimates on their own and the aggregate elasticities implied by them must be viewed with caution: it is to be expected that the nature of the SP process itself will influence the scale parameter factoring the entire set of parameter estimates in the model (the dispersion in the error term) and thus cause the entire set of parameter estimates to be different from those estimated using RP observations (Morikawa 1994). But the relative magnitudes among the parameter estimates developed using SP observations, as expressed in the ratios between them, do not suffer from the same difficulties—which means that they are much more reliable indicators of the corresponding relative magnitudes of the influences in the RP observations and thus of real-world choice behaviour. This is why the ratios among the parameter estimates and not the magnitudes of individual parameters have been used to draw inferences in the discussions included here.

The results obtained in here were also used in the development of the network-based travel demand model of Edmonton as intended. The ratios among the coefficient estimates for the riding times for the three categories of cycling facility in Function 1 were used to develop a utility function for cycling in the mode choice sub-model of the larger model. Specifically, the utility function for the cycling alternative in the larger model was formed by factoring the portion concerning these three riding times in Function 1 by a scale parameter and adding a mode specific constant. Values for the scale parameter and the mode specific constant were then estimated as part of the estimation of the rest of the parameters for the mode choice sub-model. This amounts to a form of joint estimation using both SP and RP data, using a sequential rather than a simultaneous process, but still drawing on the strengths of both types of data—and in particular using just the ratio indications provided by the SP data consistent with the caveat indicated above.

One further implication of the use of the sequential form of joint estimation outlined above is that the relative sensitivities among the riding times in the mode choice sub-model for all travellers are based on observations collected from just cyclists. There is therefore an implicit assumption made in the development of the mode choice sub-model that the perceptions indicated by current cyclists regarding different types of cycling facility are indicative of the corresponding perceptions of future cyclists who may currently be non-cyclists. A significant advantage of stated preference survey data (as opposed to revealed preference data) is that trade-off rates regarding attributes of a mode can be estimated from the choices made by individuals who currently have no experience with the mode being considered. Practically, however, this requires explaining the attributes of the mode in detail to survey respondents, to "teach" them about how a mode works. This is expensive, adds complexity to the survey, and the exact words and visual aids used to describe the attributes can bias the survey results. Such an approach is usually only applied to forecast the use of a "new" mode, where current users are non-existent (Kroes and Sheldon 1988). In this work a less expensive, less complex, and more standard approach was taken to understand the attitudes of non-cyclists towards cycling: the revealed preference data regarding the choice not to cycle was considered in the larger model building exercise, and influenced the resulting scale parameter and mode specific constant.

The interactions among facility type, perceived safety, level of experience and preferences are still only partly appreciated despite their importance, and they remains the subject of much debate. This work has provided some further insight, but has left out any empirical consideration of perceived safety. Future work should include an examination of perceived safety as an important part of the causal–behavioural link between facility type and preferences.

The specific context for the choice games—where the respondent is to imagine going to an all-day meeting—may have influenced sensitivities. Sensitivities to auto driving time and money costs have been found to vary depending on trip purpose, so the influence of cycling time may be different for travel to other than an all-day meeting or gathering. Thus, in the strictest sense, the indications obtained do not necessarily apply for all non-recreational cycling generally—and their application for other purposes other than travel to an all-day meeting is speculative. The desire for exercise may also be an important influence (Moritz 1997). Cycling in other contexts and to other activities should be considered in future work in order to test empirically for such differences.

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References

Ambrosius, P: Nachfrage im Fahrradverkehr – Ansätze zur Quantifizierung des Einflusses von Radverkehrsanlagen. Ph.D. Thesis, Ruhr Universität Bochum, Germany (in German) (1984)

Antonakos, C.L.: Environmental and travel preferences of cyclists. Transport. Res. Record **1438,** 25–33 (1994)

Aultman-Hall, L.M.: Commuter bicycle route choice: analysis of major determinants and safety implications. Ph.D. Thesis, McMaster University, Hamilton, ON (1996)

Axhausen, K.W., Smith, R.L.: Bicyclist link evaluation: a stated-preference approach. Transport. Res. Record **1085**, 7–15 (1986)

Bates , J.J.: Stated preference techniques and the analysis of consumer choice. In: Wrigley, N. (ed.) Store Choice, Store Location and Market Analysis, pp. 187–202. Routledge Chapman and Hall, New York (1988)

Ben-Akiva, M.E., Lerman, S.R.: Discrete Choice Analysis: Theory and Application to Travel Demand. MIT Press, Cambridge, USA (1985)

Bradley, M.A., Bovy, P.H.L.: A stated preference analysis of bicyclist route choice. Presented at the Planning and Transport Research and Computation Summer Annual Meeting, Brighton, UK (1984)

Calgary: Calgary Commuter Cyclist Survey, 1992/1993; Final Results. City of Calgary Transportation Department, Calgary, AB (1993)

Clarke, A: Bicycle-friendly cities: key ingredients for success. Transport. Res. Record **1372**, 71–75 (1992)

Copley, J.D., Pelz, D.B.: The City of Davis experience—what works. Am. Soc. Civil. Eng. Transport. Congr. **2**, 1116–1125 (1995)

Davis, W.J.: Bicycle test route evaluation for urban road conditions. Am. Soc. Civil. Eng. Transport. Congr. **2**, 1063–1076 (1995)

Denver: Denver Bicycle Master Plan. City and County of Denver, Denver, CO (1993)

Edmonton: Economic Forecasts for Edmonton City and CMA 1995–2020. Planning Department, City of Edmonton, May 1995 (1995)
Edmonton: Five Year Transportation Capital Program 1993–1997. Transportation Department, City of Edmonton, May 1993 (1993)
Epperson, B.: Evaluating suitability of roadways for bicycle use: towards a cycling level-of-service standard. Transport. Res. Record **1438**, 9-16 (1994)
Epperson , B., Hendricks, S.J., York, M.: Estimation of bicycle transportation demand from limited data. In: Compendium of Technical Papers from the Institute of Transportation Engineers 65th Annual Meeting, pp. 436–440 (1995)
Forester, J.: How to make biking a real alternative. Transport. Environ. **21**, 59–61 (1996)
Forester, J.: Effective Cycling. MIT Press, Cambridge, MA (1986)
Goldsmith, S.: Estimating the Effect of Bicycle Facilities on VMT and Emissions. City of Seattle Engineering Department, Seattle, WA (1996)
Greenberg, A: (1995) Bicycle travel forecasting. Bicycle USA **July/August**
Guttenplan, M., Patten, R.: Off-road but on track. Transport. Res. News **178**(3), 7–11 (1995)
Harris and Associates: Pathways for people. Rodale Press Survey, Emmaus, PA (1991)
Kroes, E.P., Sheldon, R.J.: Stated preference methods: an introduction. J. Transport Econ. Policy **22**, 11–25 (1988)
Kroll, B., Ramey, M.: Effect of bike lanes on driver and bicyclist behavior. J. Transport. Eng. Div., Am. Soc. Civil. Eng. **103**(TE2), 243–256 (1977)
Kroll, B., Sommer, R.: Bicyclist response to urban bikeways. J. Am. Inst. Planners **42**, 42–51 (1976)
Landis, B.W., Vattikuti, V.R.: Real-time human perceptions: towards a bicycle level of service. Presented at the 1997 Transportation Research Board Annual Conference, Washington DC, January, 1997
Lott, D.Y., Tardiff, T., Lott, D.F.: Evaluation by experienced riders of a new bicycle lane in an established bikeway system. Transport. Res. Record **683**, 40–46 (1978)
Mars, J.H., Kyriakides, M.I.: Riders, Reasons and Recommendations: A Profile of Adult Cyclists in Toronto. City of Toronto Planning and Development Department, Toronto ON (1986)
Morikawa, T.: Correcting State Dependence and Serial Correlation in RPSP Combined Estimation Method. Transportation **21**, 153–165 (1994)
Moritz, W.E.: A survey of North American bicycle commuters—design and aggregate results. Presented at the 1997 Transportation Research Board Annual Conference, Washington DC, January, 1997
Nelson, A.C., Allen, D.: If you build them, commuters will use them: the association between bicycle facilities and bicycle commuting. Presented at the 1997 Transportation Research Board Annual Conference, Washington DC, January, 1997
Ortúzar, J. de D., Willumsen, L.G.: Modelling Transport, 2nd edn. Wiley, New York, NY (1994)
Parajuli, P.: Analysis of Line Haul Transit Systems with Low Cost Feeder Modes. Ph.D. Thesis, University of Calgary, Calgary, AB (1996)
Parajuli, P., Wirasinghe, S.C., Hunt J.D.: Line haul transit system planning for low cost access modes. Transportation System Analysis and Policy Studies, Proceedings of the 4th National Conference on Transportation System Studies, NCOTSS-96, Mumbai, India, December 1996, pp. 145–168 (1996)
Replogle, M.: Integrating Pedestrian and Bicycle Factors into Regional Transportation Planning Models – Summary of the State of the Art and Suggested Steps Forward. Environmental Defence Fund, Washington DC (1995)
Sacks, D.W.: Greenways as Alternative Transportation Routes: A Case Study of Selected Greenways in the Baltimore, Washington Area. M.Sc. Thesis, Towson State University, Towson, MD (1994)
Shepherd, R.: Road and path quality for cyclists. Conf. Aust. Road Res. Board **17**(5), 133–147 (1994)
Sorton, A.: Measuring the bicyclist stress level of streets. Am. Soc. Civil Eng. Transport. Congr. **2**, 1077–1088 (1995)
Sorton, A., Walsh, T. Bicycle stress level as a tool to evaluate urban and sub-urban bicycle compatibility. Transport. Res. Record **1438**, 17–24 (1994)
St Jacques, K.R., DeRobertis, M.: Bike lanes versus wide curb lanes: applications and observations. Am. Soc. Civil Eng. Transport. Congr. **2**, 1126–1136 (1995)
Stein, W.R.: Pedestrian and bicycle modeling in North America's urban areas: a survey of emerging methodologies and MPO practices. M.Sc. Project Document, Georgia Institute of Technology, Atlanta, GA (1996)

Taylor, D., Mahmassani H.: Analysis of stated preferences for intermodal bicycle-transit interfaces. Transport. Res. Record **1556**, 86–95 (1997)
Teichgraeber, B.: Wegewhal von Radfahrern. M.Sc. Thesis, Universität Karlsruhe, Germany (in German) (1982)
Treadgold, P.: The future for cycling. Meeting report. In: Proceeding of the Institute of Civil Engineers, Vol. 117, pp. 231–233 (1996)
Wilkinson, W.C., Clarke, A., Epperson, B., Knoblauch, R.: The effects of bicycle accommodations on bicycle/motor vehicle safety and traffic operations. United States Department of Transportation, Washington DC (1992)
Wynne, G.G.: National Bicycling and Walking Study; Case Study 16: A Study of Bicycle and Pedestrian Programs in European Countries. FHWA-PD-92–037, United States Government Printing Office, Washington DC (1992)

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