INFLUENCES ON BICYCLE USE

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submitted for publication in Transportation
draft only: please use the published version or contact the authors for an updated version

October 2001

ABSTRACT

A stated preference experiment was performed in Edmonton in Canada to both (a) examine the nature of various influences on bicycle use and (b) 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. This forced the respondent to trade off among conditions regarding these attributes. Indications of socioeconomic 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 the approach being used here. A literature review of previous work investigating influences on cycling behaviour is also included.

KEY WORDS

bicycling; bicycle route choice; stated preference; logit choice modelling

1.0 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', which is bicycle use 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 'submodel' 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 in particular.

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.

Section 2 of the paper reviews relevant previous work concerning cycling travel behaviour and the factors that influence it. Section 3 describes the investigation approach used in this work, outlining the modelling framework, survey design and analysis method. Section 4 presents and discusses the results of the analysis. Section 5 offers some conclusions.

2.0 REVIEW OF PREVIOUS WORK

Some work has been done in the past on the factors affecting bicycle use and bicycle route choice behaviour in particular. A brief review of this work is provided below in terms of the factors having influence and the analysis procedures used.

2.1. Factors having influence

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 various modes and all the distributions of land use and socioeconomic 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 appear to have received the most attention, leading to their more frequent identification as behavioural influences. Three broad categories of cycling facility that influence preferences can be identified as follows:

- '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.

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 – either real or perceived – is an emotional issue that has received considerable attention in the literature (Forester 1986; Wilkerson 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 '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.

Very little of the previous work considers route length or the directness of the trip as influential factors. This is surprising given that time and directness are seen to play such pivotal roles in route choice behaviour for other modes (Ortúzar and Willumsen 1994). There has been very little evaluation of the tradeoffs that cyclists might be making between the relative directness and ‘pleasantness’ of different routes. It is possible that efforts to make cycling safer or more pleasant would lead to longer trips and greater delays for both cyclists and motorists (Forester 1996). More importantly, if special accommodations are provided 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 tradeoffs 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 and significant variable (Axhausen and Smith 1986; Aultman-Hall 1996).

2.2. Analysis procedure

A number of alternative methods of analysis involving different model forms and statistical techniques have been used with various kinds of observations of cycling behaviour in order to obtain indications of the relative influence of various factors on cycling behaviour. These are reviewed below.

Location Case Studies

Some studies consider a particular location or city, and relate its attributes to aspects of the cycling behaviour of its population relative to other locations. Typically, certain characteristics of an area are identified as responsible for the comparatively high rates of cycle use in the area. This has been done for the City of Davis in California (Copley and Pelz 1995), for European regions (Wynne 1992) and for North American cities generally (Clarke 1992).

This approach uses an 'aggregate' perspective, where aggregate mode shares are related to aggregate measures of the factors thought to have influence. Such studies suffer from all the problems of aggregate-level analysis of travel behaviour, the primary ones being the loss of information and the loss of a direct behavioural basis with the use of zonal averages (Richards 1974). Furthermore, cause and effect can be difficult to separate with this approach; for example: did the cycling priority at certain traffic signals in the area give rise to the high volume of cycling or vice versa?

Validated Expert Opinion

Some studies attempt to gather expert opinions (understanding, knowledge and experience) and use it to develop formal methods for rating cycling facilities that indicate the influences of different factors (Epperson 1994; Landis 1996). The accuracy of these methods as indications of actual cyclist behaviour is an obvious concern. In response to this concern, some work has been done to compare the ratings from such formal methods with the indications from surveys of cyclists (Davis 1995; Landis and Vattikuti 1996; Sorton 1995; Sorton and Walsh 1994). In one case, 150 cyclists were asked to evaluate the perceived safety of 30 different roadway segments and a model explaining the evaluations was developed using regression (Landis and Vattikuti 1996) – but the focus on perceived safety in this case ignores many of the other influences on cycling behaviour (Sacks 1994).

Polls of Cyclists

A number of cyclist surveys have been undertaken to determine what things influence cycle use, what concerns cyclists have and what is important to cyclists. Antonakos (1994) asked members of a cycling club to indicate the route characteristics they felt were most important and the corridor types they preferred. Mars and Kyriakides (1986) asked cyclists open-ended questions about riding conditions and cycling concerns. Denver (1993) and Calgary (1993) had respondents rate factors according to importance in making it easier to commute by bicycle. Sacks (1994) asked users of a multi-use pathway various questions about their preferences. This included some rudimentary 'stated preference' components (see below) where respondents were to indicate whether they would rather ride further on the pathway or on a roadway in mixed traffic and how they would travel if the pathway did not exist.

While this approach has considerable 'face-value', it can suffer from problems. When respondents are able to present wish-lists without any 'costs' they are encouraged to identify as much as possible. Rating different factors on their own is a somewhat abstract process, which can lead to some inaccuracies. Any sort of introspection concerning motivations has various problems, including the tendency towards ex post rationalisation and even memory loss regarding decisions made in the past.

Non-cyclists could also be asked about their tendency to cycle under different conditions, but this has been highly criticized for facility planning since non-cyclists have no experience with which to gauge different types of cycling facilities. For long term planning it matters little what causes people to *try* cycling; what matters is what keeps them cycling once they have tried it. As they learn the advantages and disadvantages of different facilities their attitudes towards them will develop, and in the absence of longitudinal data showing how these attitudes develop it is probably best to assume that their relative preferences will evolve in the same way that current cyclists relative preferences evolved. Note, however, that this does not apply to their *absolute preferences* regarding whether to cycle or not, but only applies to their relative preferences for different types of infrastructure.

Discrete Choice Analysis

Some studies have sought to learn about cycling preferences and the influences of various factors on cycling behaviour by analysing the cycling-related choices people make. This analysis typically uses 'disaggregate logit model estimation', where one or more logit choice models are estimated using observations of the choices made by individual cyclists in specific cycling-related situations. 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 (Axhausen and Smith 1986; Aultman-Hall 1996; Bradley and Bovy 1984; Parajuli 1996; Parajuli et al 1996; Taylor and Mahmassani 1997). This technique of analysis and model development is widely used and accepted, which is not surprising given its advantages in terms of relevance, sophistication, and ease of use.

There are two basic types of disaggregate choice observation that can be used to estimate logit models, and both of these forms have been used in previous studies of cycling behaviour.

One form of observation is 'revealed preference' (RP), which indicates the actual choices made regarding cycling (Aultman-Hall 1996). Such observations have a high degree of validity in that they represent actual behaviour. However, they suffer from a variety of shortcomings.

RP observations describe the compromises travellers make, not their true preferences. Various constraints that exist regarding bicycle use may inhibit travellers from realising their strongest preferences. In addition, the disequilibrium and habit that affect much of real world travel behaviour may cause travellers to 'stay put' with options that satisfy them sufficiently rather than continue searching for the best possible option at any given moment (Goodwin 1977).

An additional problem with RP observations is the existence of correlations among the attributes. Such correlations can make it difficult to separate the influences of different factors using statistical analysis. For example, in one study using RP data to analyze cyclist route choice (Aultman-Hall 1996), grade-separated railway crossings were found to have a significant negative impact on route desirability, steep gradients were unattractive in the winter only, and only men had a significant aversion to roads that carry buses. The same study also found no preference for shorter routes together with a high preference for collector roadways. As suggested in the description of the study, it may be that these results arise because of correlations in the attributes of the available alternatives. For instance, the collector roadways in the study area may offer more direct routings and the observed selection of more direct routes is incorrectly ascribed to the collector road designation.

Collecting and developing the real-world data used in RP observations is usually very expensive and time consuming (Bates 1983; Louviere et al 1981). This can be especially true when considering route choice, where alternative routes should be independent to roughly the same extent if logit models are to be used and there are an infinite number of possible routes in general (Bradley and Bovy 1984). The same study using RP data to analyze cyclist route choice considered above employed a sophisticated GIS system to identify the set of alternative routes and determine their attributes (Aultman-Hall 1996).

The other form of observation is 'stated preference' (SP), which indicates the choices respondents make regarding hypothetical cycling situations and options (Axhausen and Smith 1986; Sacks 1994; Bradley and Bovy 1984; Taylor and Mahmassani 1997). The descriptions of the hypothetical alternatives include the various attributes or factors of interest to the analyst, allowing the analyst to ascertain the respondent reactions to these attributes.

The 'choice experiment' surveys used to collect SP observations can be comparatively inexpensive. The structure of the data can be controlled to avoid correlations and the individuals taking part in the experiments need not be hindered by real-world constraints. Attention can be focused on the attributes of interest – with the influences of other attributes held constant. All these attributes make use of SP observations attractive when considering cycle route choice behaviour (Bradley and Bovy 1984).

SP observations suffer from a substantial 'face-value' uncertainty: do those playing a hypothetical choice game behave in the same way they do in reality, and thus do the parameter estimates arising with SP observations match actual influences? There is also the possibility that games of this sort lead respondents; and the exhibited choice behaviour can be unrealistic if the respondents find the hypothetical situations too unbelievable. Nevertheless, various studies have found that properly designed experiments can help account for these problems and provide accurate and realistic results in various contexts (Beaton et al 1997; Benjamin and Sen 1982; Kroes and Sheldon 1988; Louviere 1991).

Axhausen and Smith (1986) performed a stated preference survey where respondents chose between pairs of hypothetical cycling links with specified attributes. The consideration of individual links, which do not differ much in length in typical networks, and the apparent lack of any specific trip purpose may help explain why trip length was found to be of no influence. Bradley and Bovy (1984) asked commuters to rank hypothetical route options and found that travel time was significant when the entire journey was considered.

Taylor and Mahmassani (1997) asked respondents to select from among hypothetical multi-mode alternatives with bicycle included as one of the alternative access modes to transit. A nested logit model was estimated using the resulting observations. Bike lockers as secure parking facilities were found to have a strong influence on preferences.

It is possible to estimate logit model parameters using SP and RP observations jointly, thereby combining the benefits of the ability to control the data structure with SP observations together with the 'face-value' of the RP observations (Bradley and Daly 1992; Bradley and Kroes 1990; Daly 1990). This is based on the idea that the differences between the SP and the RP observations can be taken into account appropriately by allowing the scale parameter factoring all the utility function coefficients and the alternative specific constants to differ between the two types of observations (Bradley and Daly, 1982). This has been done in a study of route choice (Abdel-Aty et al 1995) and in a study of mode choice with bicycle included as one of the mode alternatives (Parajuli 1996; Parajuli et al 1996). In general, some hypothesis are made about the weaknesses of each type of data, and some parameters are estimated with only one type of data to eliminate the hypothesized weaknesses. The hypothesis that people are less constrained in hypothetical situations leads to an estimation procedure where the logit scale parameter (or, equivalently in linear utility functions, the scale of the remaining parameters) is determined only by RP data. When SP data are collected using choice based samples, the normal hypothesis is that the relative sensitivity to different attributes can be informed by both types of data, but that the alternative specific constants should only be informed RP data. The hypothesis regarding the weaknesses of RP data (correlations, compromises and limited diversity, as discussed above) could lead to additional changes in joint estimation procedures, but experience suggests that the weaknesses in RP data are picked up by the estimation procedure itself – the maximum likelihood estimation cannot reliably estimate certain parameters (or their relationships) from the RP data and so it relies on the SP data to separate correlations and understand trade-off rates beyond the conditions that exist in reality.

Joint simultaneous estimation from SP and RP data is an excellent way to establish parameters of choice models. But joint simultaneous estimation can be quite difficult, especially when the ultimate purpose is a sophisticated, all-inclusive, transport demand model. Sequential estimation becomes inevitable in such cases, but the analyst can guide the sequential estimation based on the strengths and weaknesses of the different types of data and on previous experience with simultaneous information. For instance, a choice based sample of SP data could be relied on to provide the relative trade-off rates for attributes of an alternative, and RP data in a larger model could be used to establish scale parameters and alternative specific constants.

2.3. Ramifications for this research

Logit model estimation with SP observations was selected for use in this research because of its successful use in previous work considering non-recreational bicycle use and other contexts. RP observations were collected in both the cycling survey and in the representative household survey collecting data for the larger model development project, which meant that estimation using both SP and RP observations would be possible. The SP data alone would be used to establish trade-off rates between attributes of cycling; there would be no effort to establish alternative specific constants or scale parameters from the SP data alone.

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 socioeconomic 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.

3.0 METHOD

Components of the investigation method are described below, including salient aspects of the logit modelling framework and the survey to collect SP observations of selected cycling attributes and personal characteristics.

3.1. Modelling framework and statistics

The logit model is a mathematical model that represents the behaviour of individuals trading off among the attributes of alternatives when selecting one alternative out of a set of available alternatives (McFadden 1974). It has the following form for the choice situation concerning two hypothetical bicycle use alternatives considered in this research:

$$P_a = \frac{e^{U_a}}{e^{U_a} + e^{U_b}}$$

where:

P_a = probability that bicycle use alternative a is preferred

U_a = utility value associated with bicycle use alternative a.

U_b = 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:

$$U_i = \phi_1 * X_{1i} + \phi_2 * X_{2i} + \ldots + \phi_n * X_{ni} + \ldots$$

where:

n = index representing attributes

X_{ni} = value of attribute n for alternative i

ϕ_n = 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. Computer programs that perform this estimation using maximum likelihood are readily available (Daly 1992) and the statistical properties of the resulting estimates are 'well-behaved' (McFadden 1974).

Various goodness-of-fit indicators are available for logit models, but the most accepted is the $\rho^2(0)$ index, which is analogous to the R^2 statistic for linear regression in that it ranges from 0 to 1, with larger values indicating a better fit.

See Ben-Akiva and Lerman (1985) for a thorough review of the method, issues and interpretation of results with logit choice modelling.

3.2. Bicycle attributes and issues considered

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; McMillan et al, 1997). 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 be 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 minutes, rounded to the nearest 5 minutes;
- time spent cycling on designated bike lanes on roads: values selected randomly from 0 to 60 minutes, rounded to the nearest 5 minutes;
- time spent cycling on bike paths shared with pedestrians: values selected randomly from 0 to 60 minutes, rounded to the nearest 5 minutes;
- availability of showers at destination; with 2 values considered: 'showers are available' and 'showers are not available';
- availability of secure parking for bicycles at destination; with 2 values considered: 'secure parking is available' and 'secure parking is not available'.

The total travel time was constrained to be no longer than 60 minutes.

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. 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 minutes on roadways in mixed traffic and 20 minutes on bike paths shared with pedestrians, with showers but no secure parking at the destination. Another might be 30 minutes on bike paths, with secure parking but no showers at the destination. Once two alternatives were selected in this way, the two were compared attribute-by-attribute to ensure that each had at least one attribute value that was better than the corresponding attribute value in the other alternative. This was to ensure that each respondent was forced to make some degree of trade-off in choosing one of the two alternatives.

3.3. Survey instrument

A survey questionnaire form was prepared, fitting on two sides of an 8.5" x 11" sheet. It contained various questions about actual bicycle use and also presented the SP exercise. It was designed for respondents to complete on their own and mail back to the City of Edmonton Transportation Department.

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 Figure 1.

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.

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 kilometres of bicycle paths, for use by cyclists and pedestrians exclusively, called 'Class 1 Routes';
- 3 kilometres of bicycle lanes, where a longitudinal portion of a roadway is designated for use by cyclists exclusively, called 'Class 2 Routes'; and
- 96 kilometres 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 kilometres of multi-use recreational trails in the City 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%. The joint distribution among gender, age and income categories for this sample is indicated in Figure 2. 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 as described in the results section below.

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 2, with the parameter definitions provided in Table 3. These results are discussed below.

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. This is fairly low – although still 'satisfactory' according to Hensher and Johnson (1981) – indicating that there is still considerable unexplained variation in preferences.

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 in other work (Kroll and Ramey 1977; Kroll and Sommer 1976; Lott et al 1978; Guttenplan and Patten 1995) and also consistent with the claims made 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 minutes 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.

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.

Figure 3 shows the coefficient estimates. 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 extent 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.

Function 3 – Comfort and cycling facility preferences

Function 3 is similar to Function 2, except that the attitudes were 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.

The coefficient estimates are shown in Figure 4. 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 values' for the coefficient estimates for both lanes and paths.

The results obtained with Functions 2 and 3 together indicate the following:

- 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.

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.

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.

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.

5.0 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 minute cycling 'in mixed traffic' is as onerous as 4.1 minutes on 'bike lanes' or 2.8 minutes 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 minutes 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 minutes 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 cycling-friendly.

It is uncertain whether the reversals of trends for the 'highly inexperienced' or the 'highly uncomfortable' categories, as shown in Figures 2 and 3, has a basis in actual behaviour or is related to 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 behavior. 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 submodel 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 submodel. 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 submodel 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.

6.0 ACKNOWLEDGEMENTS

Alan Brownlee, Bob Strynadka and Rhonda Toohey of the City of Edmonton provided valuable assistance in the collection and preparation of the data and along with Peter Heppleston of the City of Edmonton offered helpful suggestions on how to improve the work. The cooperation of those cyclists who completed the survey form was an essential component of the work, for which the authors are very thankful.

The City of Edmonton provided financial support for the data collection and analysis work reported here. The Natural Science and Engineering Research Council of Canada also provided financial support for the preparation of this paper.

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Table 1: Summary of factors that have been identified as influences on cycling behaviour and cycle route choice in particular, together 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 1997; 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

Table 1 continued:

cycling treatments at signals, including timing and loop 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; Epperson1994; 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 1995; Sorton and Walsh 1994
pedestrian interaction	Mars and Kyriakides 1986

Table 1 continued:

Individual and Trip Characteristics

gender	Antonakos 1994; Aultman-Hall 1996; Sacks 1994; Taylor and Mahmassani 1997
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
concerns about safety	Antonakos 1994; Kroll and Ramey 1997; Kroll and Sommer 1976; Lott et al 1978; Mars and Kyriakides 1986
concerns about personal security	Sacks 1994
flexibility of work hours	Denver 1993; Sacks 1994
type of bicycle (whether road bike or mountain bike)	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;

Table 1 continued:

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

Table 2: Estimation results for selection of utility functions considered, showing coefficient estimates, absolute values of t-ratios and goodness-of-fit statistics

	Function 1		Function 2		Function 3		Function 4		Function 5	
Parameter	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	

Table 3: Definitions 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
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

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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 minutes**	* total cycling time:	**30 minutes**
which is made up of		which is made up of	
time on bike paths shared with pedestrians	**15 minutes**	time on bike paths shared with pedestrians	**20 minutes**
time on roadways shared with cars	**25 minutes**	time on roadways shared with cars	**10 minutes**

Figure 1: Two randomly generated hypothetical cycling options for a trip to an all-day meeting; respondents were asked to choose between two such options.

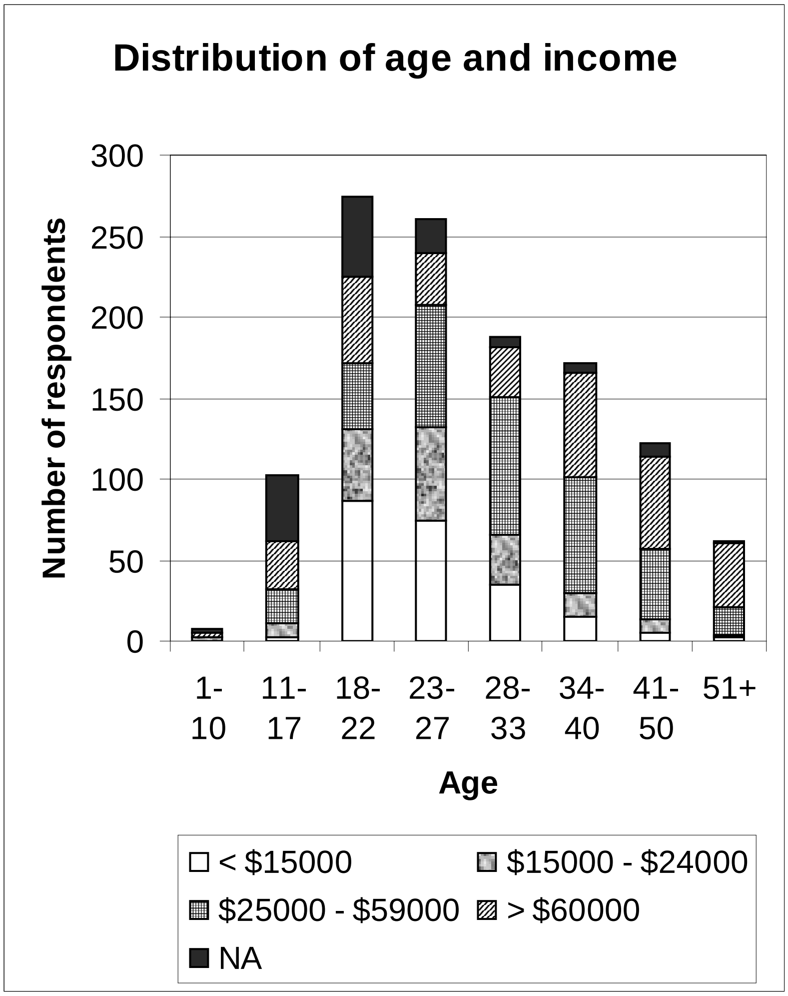

Figure 2: Distribution of age and income in the sample.

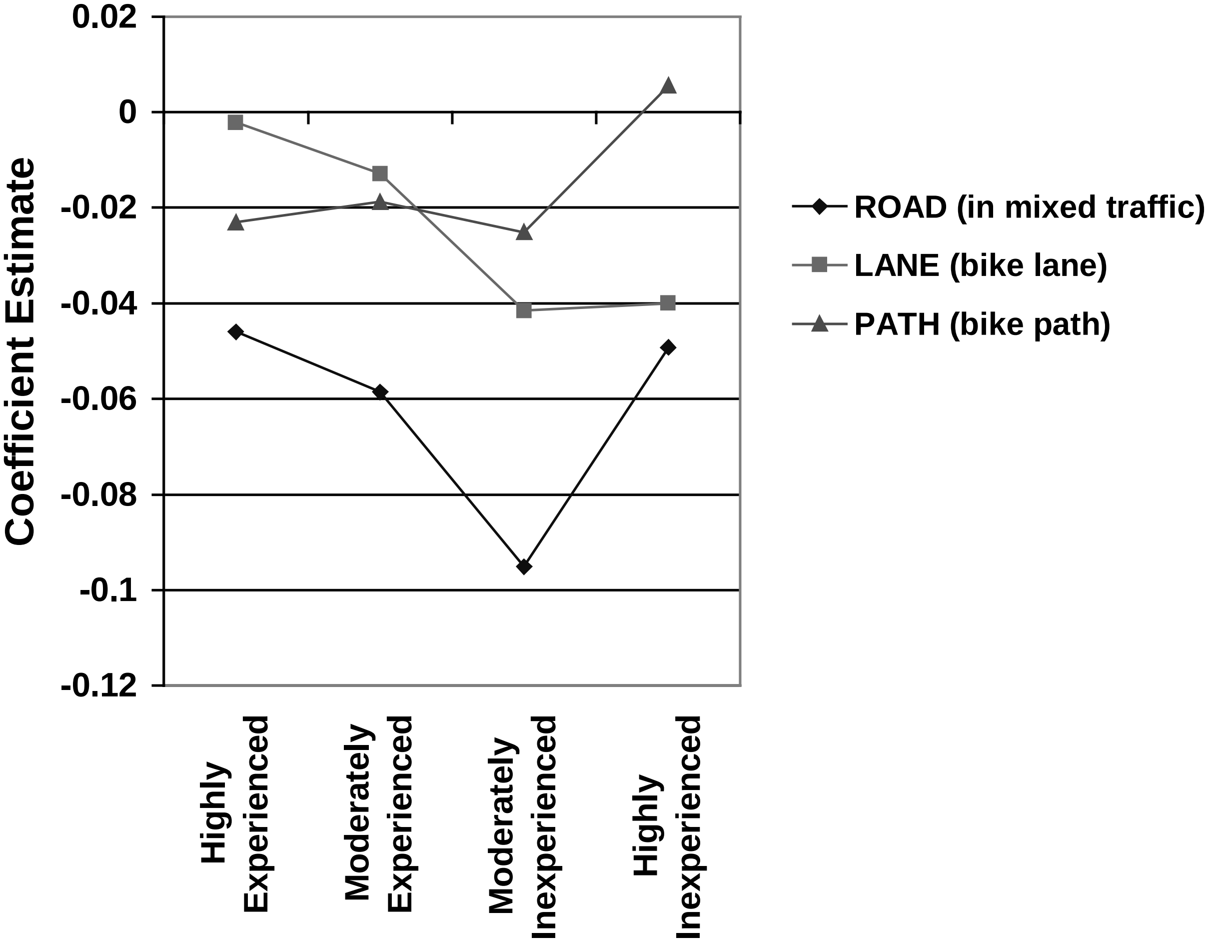

Figure 3: Estimation results for Function 2 - Experience and cycling facilities; a separate coefficient for minutes of ride time was estimated for each cycling facility type and level of experience cycling in mixed traffic

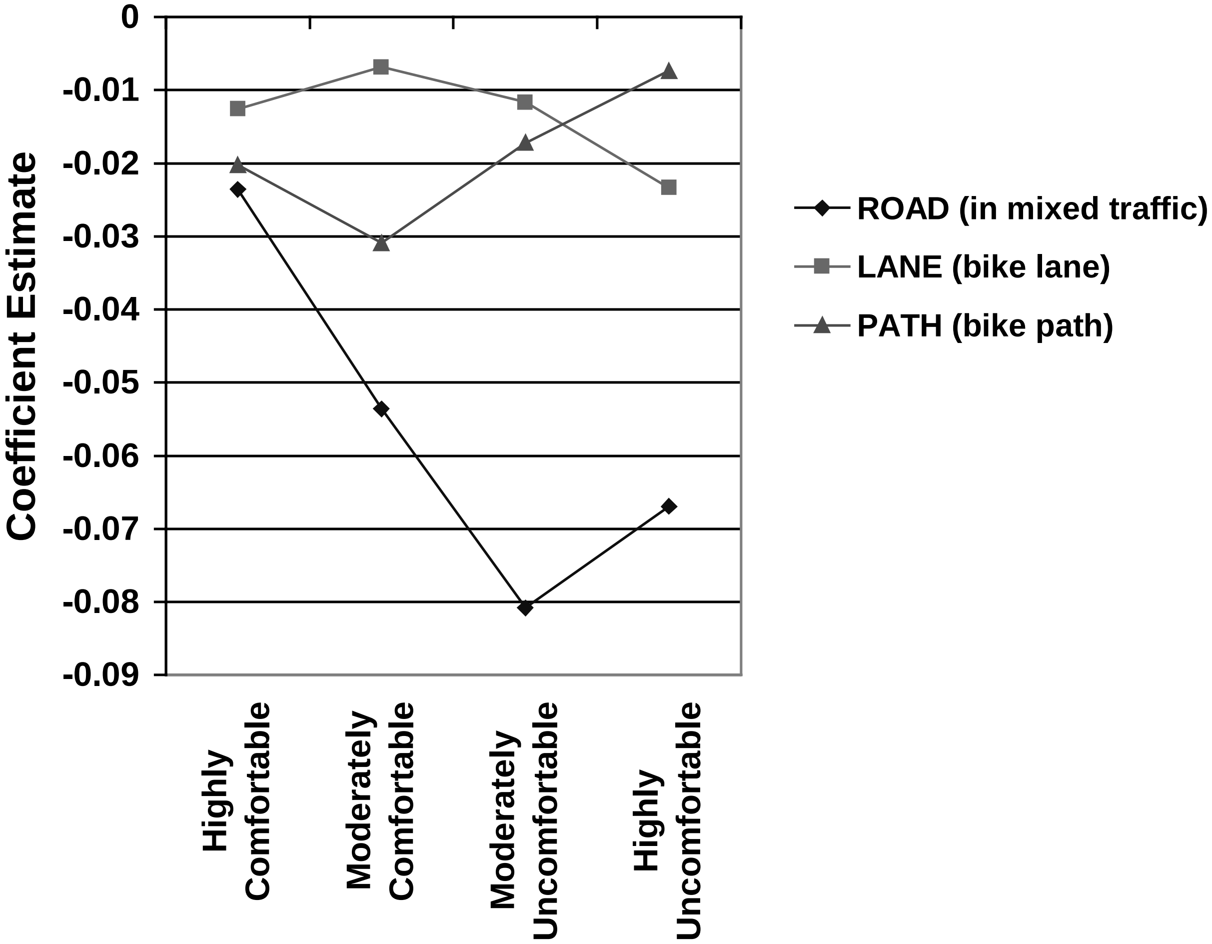

Figure 4: Estimation results for Function 3 - Comfort and cycling facilities; a separate coefficient for minutes of ride time was estimated for each cycling facility type and level of comfort cycling in mixed traffic