

An Analysis of Commuter Bicyclist Route Choice Using a Stated Preference Survey

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TRB 2003: Paper # 03-3301

Final Submission for Publication: April 1, 2003
Word Count: 7,634 (*includes 1 figure and 3 tables*)

ABSTRACT

This paper evaluates the importance of factors affecting commuter bicyclists' route choices. Both route-level (*e.g.*, travel time) and link-level (*e.g.*, pavement quality) factors are examined. Empirical models are estimated using data from a stated preference survey conducted by the authors over the Internet. The models indicate that, for commuter bicyclists, travel time is the most important factor in choosing a route. Presence of a bicycle facility (especially a bike lane or separate path), the level of automobile traffic, pavement or riding surface quality, and presence of a bicycle facility on a bridge are also very important determinants. The paper also discusses the policy implications of these results for bicycle facility planning.

1. INTRODUCTION

This paper presents an analysis of route choice preferences of bicycle commuters using a discrete-choice modeling framework. The current research contributes to the literature on commuter bicyclist route choice preferences through the analysis of eleven determinants of route choice decisions, using data from a stated preference survey.

Examining the determinants of bicycle route choices is important for at least two reasons. First, understanding bicycle route choice determinants can facilitate the design of bicycle facilities that have the potential to increase the share of non-motorized modes and decrease automobile travel. This can help alleviate automobile-related problems of traffic congestion, pollution, sprawl, and noise. Second, because non-motorized trips substitute for short, emission-intensive, motor vehicle trips, increased bicycle mode share may displace a disproportionately high amount of emissions and fuel consumption (1). This is particularly likely to be the case for commuting, since most commute trips are well within bicycling range—in fact, half of all commuters live within about three miles of work (2).

For most people, however, automobiles are generally much more convenient than bicycles even for short distances because the transportation infrastructure is designed primarily to accommodate personal automobiles (3). Creating safe, comfortable, and convenient routes for bicyclists within this automobile-oriented infrastructure is a challenging task. However, providing better bicycle routes is essential for encouraging bicycling.

The planning of transportation facilities for commuter bicyclists entails demand estimation, network evaluation, and future network planning. This research focuses on the latter two steps. Specifically, the goals of this paper are to (a) describe the design and administration of a nationwide stated preference survey conducted by the authors to collect information on bicycle commuting choices and preferences, (b) use the survey results to model route choice preferences for bicycle commuting, and (c) discuss the planning and policy implications of the analysis.

The rest of this paper is structured as follows. The next section discusses earlier studies in the area of bicycle route planning and identifies the scope of the current study. Section 3 describes the survey design and modeling methodology issues. Section 4 presents the empirical results. Section 5 highlights the important findings from the research.

2. EARLIER RESEARCH

The factors influencing bicycle commuting-related decisions can be broadly categorized into link-level factors and route-level factors (in this paper, a “link” is defined as a segment of throughway between two intersections). In addition, individual factors (such as age and sex) can also affect route choice through their interaction with link and route-level factors. For example, older individuals may prefer a flatter terrain compared to younger individuals. The focus in this section is on identifying link and route factors that affect route choice directly, or indirectly through demographic interactions. The section also presents methods/guidelines that have been developed based on the effect of link and route-level factors.

2.1 Link-Level Factors and Associated Methods/Guidelines for Bicycle Facility Planning

The link-level factors influencing route choice may include bicycle facility presence and motor vehicle traffic characteristics (2,4-10), parking characteristics (11-13), riding surface quality (10,13,14) and hilliness (8,15). A substantial amount of previous research on bicycle facilities has focused on examining the impact of link-level factors on route choice and related decisions. In addition, AASHTO and ITE (16,17) have established general guidelines for designing bicycle

facilities on links that form part of a bicycle route. Similarly, the Manual on Uniform Traffic Control Devices (18) and Highway Capacity Manual (19) also include design standards for bicycle facilities.

Most of the research studies and guidelines discussed above provide a broad and qualitative sense of the effect of link-level factors on route preferences and/or provide broad and qualitative guidelines for bicycle facility design. However, some of the studies are more specific and quantitative. These quantitative studies have focused on translating combinations of link-level attributes into a consolidated scalar level of service measure for bicycle travel. The link-level factors considered in these studies have included some or all of the following link-level attributes: (a) geometric configuration (automobile lane width and the number of driveways/side streets providing access to the link), (b) motor vehicle factors (speed, volume, and percentage of heavy vehicles), (c) bicycle facility factors (width of bicycle lane, right hand lane, or separate path), (d) pavement factors (rough, smooth, coarse sand, *etc.*), (e) parking controls, and (f) adjacent land-use attributes. Examples of consolidated level of service measures include the Interaction Hazard Score (20), the Bicycle Stress Level index (11), and the Bicycle Compatibility Index (9, 13). Other related studies that develop level of service measures for bicycling include Landis *et al.* (10), Dixon (12), and Allen *et al.* (21). A bicycle compatibility index that has been developed specifically for rural areas is the CRC Index by GRIMES (22).

The quantitative measures discussed above provide important information to assess the safety, comfort, and level-of-service considerations of bicyclists. However, most of the measures rely on the analyst's "expert" judgment regarding the importance of each link-level factor in bicyclists' evaluation of the desirability of a bicycle facility. Thus, though the measures provide quantitative indices of facility rating and performance, they are developed through qualitative weightings of the various link-level attributes.

2.2 Route-Level Factors and Associated Route-Level Studies

Route-level factors refer to those attributes that are most meaningful when accumulated over the entire route. These factors include travel time, bicycle facility continuity (which accounts for interruptions in bicycle facilities, for example, at highway interchanges), and delays due to traffic controls (such as at stop signs and traffic lights).

Several earlier studies have examined bicyclists' evaluation of facilities at the route-level. There are two broad differences between these studies and those discussed under link-level studies in the previous section. First, the route-level studies have been more quantitative in nature, and have used surveys to obtain information on bicyclist route preferences and choices (though some route-level studies have also used a Delphi approach, as we discuss later). Second, the route-level studies have included both route-level and link-level factors in the analysis, while the link-level studies of the previous section, by their very definition, do not consider route-level factors. Previous route-level studies have used revealed preference (RP) surveys, stated preference (SP) surveys, or the Delphi technique to evaluate bicycle routes.

RP surveys elicit information on actual choices made by individuals. The advantage of using RP data to examine route choice preferences of bicyclists is that such data represent information about preferences in an actual choice environment. The limitation of RP data is that data collection can be rather cumbersome and time consuming, limiting sample size and the geographic scope of data collection. Further, in the context of comparing alternative routes (or, more precisely, comparing alternative combinations of link-level and route-level factors), the analyst needs to impute the routes considered by each respondent. Unfortunately, these imputed

routes may not correspond to the actual routes considered by bicyclists. Earlier commuter bicycle route choice studies using RP surveys include Howard and Burns (7), Shafizadeh and Niemeier (23), Hulse and Shafizadeh (24), Aultman-Hall *et al.* (25), and Hyodo *et al.* (26). These studies have, in general, compared the chosen route with the shortest path. These studies indicate the following: (a) commuter bicyclists prefer directness en route to their work place, but are willing to detour slightly to use bicycle facilities, (b) commuter bicyclists avoid turns, hills, major roads, and off-road routes, and prefer routes with signalized traffic control (compared to other control mechanisms or no control), and (c) higher income and older individuals are less sensitive to route travel time.

Stated preference (SP) surveys present the respondent with a series of hypothetical choice situations, and obtain the respondent's choice responses. The advantages of using SP data are several, including (a) the ability to obtain a large sample size due to the low cost of data collection, (b) the potential to avoid multi-collinearity among attributes, and (c) pre-specification of the choice set (27). A possible limitation of SP data is that the comprehension capability of respondents may limit the number of variables used to characterize route choices. However, this difficulty can be overcome by using several different survey instruments, each with different sets of variables characterizing routes. Earlier bicyclist route choice studies that have used SP surveys include Bovy and Bradley (14) and Abraham *et al.* (27). The study by Bovy and Bradley (14), conducted in Delft, Netherlands, found that travel time is the most important consideration in route evaluation, followed by surface quality, traffic level, and facility type. Older bicyclists were found to be more sensitive to comfort and traffic condition than younger bicyclists. The analysis of Abraham *et al.* (27), conducted in Calgary, Canada, also found that commuter bicyclists were willing to incur additional travel time to use routes with bicycle facilities.

The Delphi technique uses expert opinions to identify the importance, ranking, and relative weights of link-level and route-level factors in route evaluation. Mescher and Souleyrette's (28) study examines 16 different variables relevant to bicycle commuting, ranking and assigning relative weights of importance to these variables. However, the resulting ranking and weighting of variables are not consistent with those obtained in RP and SP surveys. For instance, mountainous topography and frequent high cross-street traffic are the most heavily weighted variables in Mescher and Souleyrette's Delphi study, while travel time is close to the bottom of the list. These relative rankings are quite the reverse of those estimated from RP and SP surveys.

2.3 Summary and Scope of Current Study

Earlier link-level and route-level analyses of bicycle commuter preferences have provided valuable insights into the factors affecting route evaluation and route choice. However, the link-level analyses are either qualitative in nature, or even if quantitative, are mostly based on underlying qualitative weights. The link-level analyses also do not include route-level factors such as travel time and facility continuity. The route-level analyses are more quantitative and include both route-level and link-level factors. But these studies have primarily emphasized travel time as the route-level factor. Other potential route-level attributes such as facility continuity and delays en route have received little (if any) attention [these factors have been hypothesized as potentially important determinants of route choice, but not quantitatively examined; see Howard and Burns (7), Mescher and Souleyrette (28), Smith (29), and Fajans and Curry (30)].

The current study uses a SP survey to obtain information from a large sample of individuals, and includes a comprehensive set of link-level and route-level factors in the analysis. The study employs a quantitative discrete choice methodology to analyze the effect of these factors on route choice. The large sample size in the analysis also enables the estimation of differential sensitivities of demographic subgroups to the link- and route-level factors.

3. DATA SOURCE AND METHODOLOGY

This section discusses the design and administration procedures for the survey undertaken in this study (Section 3.1 and 3.2), presents the data assembly techniques and sample statistics (Section 3.3), and discusses the model structure (Section 3.4).

3.1 Survey Design

The SP survey conducted in this research was designed to obtain information on commuter bicyclist route preferences, using a series of hypothetical route choice questions (such as the one presented in Figure 1). Respondents were asked to imagine that they had just begun a new job and that they would commute by bicycle to this new job. A base route option with certain attributes was then provided to respondents with which they compared several other hypothetical route options. Definitions of route attributes were clearly specified in the survey [further details of the web survey are available in Stinson (31)]. The survey also collected data on individual socio-demographic characteristics such as sex, age, and income, as well as information on individuals' bicycle commuting experience.

The overall survey included nine different instruments, distinguished based on the attributes characterizing routes. Each instrument considered only three or four attributes, so that respondents are able to easily comprehend and evaluate the scenarios presented to them. The hypothetical route choice scenarios within each instrument were generated by varying the levels of the attributes specific to that instrument. Also, by varying the attributes among the nine instruments in a carefully designed experimental procedure, we are able to obtain data to estimate the effects of the full range of attributes affecting route choice.

A total of eleven link and route attributes are considered across the nine different survey instruments. These attributes are listed below (the range of levels considered for each attribute are in parentheses):

Link-level factors: (a) Roadway class (residential, minor arterial, major arterial), (b) Parallel parking permitted (yes/no), (c) Bicycle facility type (none, wide right-hand lane, bike lane, separate path), (d) Bridge type (no bicycling provisions, bike lane provided, barrier-separated riding area provided, no motor vehicles permitted), (e) Hilliness (flat, moderate hills, steep hills), (f) Riding surface (rough pavement, smooth pavement, coarse sand surface).

Route-level factors: (a) Travel time (5 to 40 minutes), (b) Facility continuity (yes/no), (c) Number of stop signs per mile (1, 2, 4), (d) Number of red lights (0 to 5), (e) Number of major cross-streets (0 to 5).

The interpretations of most of the factors listed above are quite straight forward, except for facility continuity. We defined a bicycle facility as being "continuous" if the bike facility was available for the entire route without interruptions. We defined a bicycle facility as "discontinuous" if there was no bicycle facility for at least 25% of the route (*i.e.*, the bicyclist would have to share a 10-12 feet lane with motor vehicles for 25% or more of the route).

The survey was also designed to gather information on the combined effects of several attributes, or second order interaction effects (32). Including secondary effects involves

significantly more data collection and, therefore, only a few second-order effects were selected for this work. These effects include: (a) travel time with terrain, number of stop signs, roadway class, bridge type, and bicycle facility type, (b) bicycle facility type with riding surface, number of stop signs, and parking presence, and (c) continuity with roadway class. The above combinations were chosen for their usefulness in planning and evaluating bicycle routes.

3.2 Survey Administration and Self-Selection Bias

To solicit respondents, an announcement of the survey was sent to about 25 bicycling-related listserves across the U.S. and three non-bicycling-related e-mail lists in Austin. In addition, a link was posted on another bicyclist-oriented website (<http://www.massbike.org>) and announcements were placed in widely read electronic newsletters (Adventure Cycling's Bike Bits and the League of American Bicyclists' BikeLeague [sic] News). Scattered distribution from individuals subscribing to these sources likely occurred as well.

Due to the sampling technique, most of the respondents are avid bicyclists with good access to computers. Since less than one percent of bicyclists in the population are members of a bicycling organization (33), self-selection bias is surely present in the data used for this research. The computerized distribution also does not include bicyclists who don't use computers, a group that is likely to represent the lower income segment of transportation system users.

The use of a self-selected group of respondents (mostly avid bicyclists who use computers) has both disadvantages and advantages. The main disadvantage is that the respondents' perceptions are not necessarily similar to those of the population at large. Therefore, using results based on the opinions of avid bicyclists for designing routes intended to serve all bicyclists or potential bicyclists might result in designing facilities that do not adequately serve the needs of the entire design population. On the other hand, using a self-selected sample has two advantages. First, a larger sample can be obtained due to high response rates of the targeted group, who are interested in anything that promotes bicycling. Second, this sample may contain more "experts" than a broader sample. Their accumulated experiences may actually yield more accurate assessments of potential facilities.

3.3 Data Assembly and Sample Description

The survey was administered on the World Wide Web using server space and software provided by the College of Engineering at The University of Texas at Austin. To obtain a reasonable distribution of responses across the nine different instruments, survey instruments were associated with months of the year and each respondent was asked to complete the survey corresponding to her month of birth. Six of the months had unique links, but the other six shared the three remaining links. (To ensure that each instrument garnered similar numbers of responses, the hyperlink for each month was altered periodically to link the month with a different survey during the three month on-line period.) A total of 3,145 individuals responded to the survey.

The completed surveys were subsequently downloaded from the online software into Microsoft Excel, and then imported into SPSS to code the variables numerically. Finally, the data were imported into LIMDEP to perform discrete choice modeling analysis.

In the final sample, the overwhelming majority of respondents (91%) reported that they have experience in commuting by bicycle, while 9% indicated that they are not experienced in commuting by bicycle. Furthermore, 22% of the respondents are female and 78% are male. This suggests that most bicycle commuters are male. The age distribution is fairly normal, with the

majority of respondents between 25 and 54 years of age. Compared to the U.S. population, annual household income levels are very high, probably because of the computerized distribution method (2000 U.S. Census figures are in parentheses): 19% (compared to 47%) earn less than \$40,000, 20% (18%) earn \$40,000-\$60,000, 14% (10%) earn \$60,000-\$75,000, 21% (11%) earn \$75,000-\$100,000, and 26% (14%) earn over \$100,000. In terms of residential location, 52% lived in the suburbs, 39% lived in an urban or downtown area, and 9% lived in a rural area. The range of geographic/climatic locations also varied, with 26% living in the Northeast U.S. or Alaska (grouped together for weather reasons); 20% living in the Midwest; 14% in the Northwest; 22% in the Southwest; 11% in the South or Hawaii; and 7% in a non-U.S. location.

3.4 Model Structure and Explanatory Variable Specification

The route choice analysis undertaken in this study uses a binary logit model to estimate the main and interaction effects of the variables. The model system is as follows:

$$U_{in} = \beta X_{in} + \varepsilon_{in} \quad (1)$$

where i is an index for route ($i = 1$ or 2 , because each choice scenario comprises two routes), n is an index for individuals, X_{in} represents a vector of explanatory variables specific to individual i and route n , β represents a corresponding vector of parameters to be estimated, and U_{in} is the utility associated with route i by individual n . The random error term, ε_{in} , is assumed to be identically and independently standard Gumbel distributed across routes and observations.¹ The probability that a person chooses route i over route j is then given by:

$$\text{Prob (Individual } n \text{ selects route } i) = \text{Prob } (U_{in} > U_{jn}) = \frac{e^{\beta X_{in}}}{e^{\beta X_{in}} + e^{\beta X_{jn}}} \cdot \quad (2)$$

The variable specification process was pursued in several steps to systematically analyze the effects of variables and their interactions. First, a main effects model was estimated, without interactions of route attributes with demographic characteristics of respondents and without second-order interaction effects of these attributes among themselves. Second, interaction effects between the route variables and sex, age, income, and land-use variables were explored. Third, second-order interactions between the route characteristics themselves were included and analyzed. Finally, the coefficients of related variables with statistically similar effects were combined.

4. EMPIRICAL RESULTS

This section presents the empirical results of the route choice utility model. First, the main effects of the variables are discussed with respect to the directionality of effect and their relative magnitudes. Next, the full model with main effects and interaction effects is discussed.

¹ The Gumbel distribution is an asymmetric distribution with a long right tail. The density function of the standard Gumbel distribution is as follows: $f(\varepsilon_{in}) = e^{-e^{-\varepsilon_{in}}} \cdot e^{-\varepsilon_{in}}$.

4.1 Main Effects

The main effects model (Table 1) serves as an important reference point for analyzing the importance of each link-level and route-level variable relative to one another. The results of the main effects model are discussed in the next two subsections: Section 4.1.1 discusses the effects of link-level factors, while Section 4.1.2 presents the effects of route-level factors.

4.1.1 Link-Level Variable Effects

Six link-level factors were considered in our analysis. All of these factors have a statistically significant effect on route choice (see Table 1).

The effect of roadway class is introduced with the residential street class as the base. The negative signs on the non-residential street classes indicate that commuter bicyclists prefer residential streets to non-residential streets. Further, the larger magnitude of the coefficient on major arterials indicates that bicyclists prefer minor arterials to major arterials. Overall, bicyclists prefer routes with low-volume motorized traffic.

The negative sign on the parking variable indicates that bicyclists avoid routes with links on which parking is permitted. This result is intuitive, since parked cars can pose a safety threat to bicyclists: parked cars can reduce sight distance at intersections, and bicyclists can be severely injured by motorists opening their car doors.

The effect of bicycle facility type is as expected. The positive effects on the variables representing the presence of some type of a bicycle facility (compared to the base condition of no bicycle facility) indicate that bicyclists have a clear preference for routes designed for bicycle use. The relative magnitudes of the facility type variables also suggest that a bicycle lane is the most preferred facility type, followed by a separate path. In summary, bicyclists generally prefer routes that offer some or total lateral separation from motorized traffic.

Many bridges in the U.S. have narrow automobile lanes and narrow sidewalks, both of which are unsafe for riding bicycles (2). The parameter estimates on the bridge type variables in Table 1 indicate that bicyclists prefer an environment in which no motorized traffic is allowed on bridges, or bridges that feature a riding area separated from auto traffic by a sturdy barrier.

The variables associated with the riding terrain indicate a preference for flat ground rather than a mountainous environment. Surprisingly, however, the results suggest a preference for hilly (moderately uphill and downhill) terrain compared to flat terrain. This may be related to the more visual and scenic views offered by hills. In addition, hilly terrain may be preferred to flat terrain because they are not as strenuous as mountainous terrain, but also provide a higher level of exercise benefits compared to flat ground. Downhills also offer a rest period while bicycling – therefore, despite encountering uphills in addition to downhills, a bicyclist may prefer occasional extra exertion in hilliness to a more constant level of effort on flat ground.

Finally, in the group of link-level factors, the impact of the pavement type variables clearly reveal a preference among bicyclists for a smooth pavement riding surface over a rough riding surface, and for a rough surface over a coarse sand surface.

4.1.2 Route-Level Variable Effects

Four route-level factors were included in the analysis, corresponding to travel time, bicycle facility continuity, delays due to traffic controls, and disruptions due to cross-streets.

The coefficient on the travel time variable in Table 1 is negative and highly significant, reflecting a preference for shorter travel times. The effect of the other route-level variables show (a) a clear preference for continuous (as opposed to discontinuous) bicycle facilities, (b) a

tendency to avoid routes with traffic controls, especially stop sign-controlled intersections, and (c) a preference for bicycle routes without many major cross streets.

4.1.3 Relative Impacts of Variables

The parameter effects in Table 1 show the directionality of impact of link-level and route-level variables. However, the relative impacts of variables are not directly comparable because of the different ranges of the variables. One simple approach to assess the relative importance of each variable is to compute the contribution to utility of each variable at its average value when the feature represented by the variable is present in a route. The results of such an exercise are presented in Table 2. For example, the average value of travel time across all routes presented to respondents is 21 minutes, and the contribution to (dis-) utility of each additional minute of travel time is -0.11 from the model in Table 1. Thus, the average contribution to utility of travel time is computed as 21×-0.11 utilities/minute = -2.31. Other values are computed similarly.

Table 2 indicates that travel time is the most important route characteristic for bicycle commuters, followed by presence (or absence) of a bicycle lane, whether the bicycle route is along a major arterial, and whether the route is completely separated from motorized vehicles. Other important attributes include riding surface, bridge type, number of major cross streets, whether the route is in a mountainous terrain, and facility continuity. On the other hand, delays caused by traffic controls (stop signs per mile and number of red lights), whether the route is along a minor arterial or not, presence (or absence) of parking on route, and whether the route is in a hilly terrain are among the least important attributes in commuter cyclists' evaluation of routes.

4.2 Full Model Results with Interaction Effects

This section presents the best specification obtained from a comprehensive exploration of route attributes, interactions among the route-related attributes, and interactions of the route attributes with bicyclist characteristics (including bicyclist demographics, residential location, and experience in bicycling).

In addition to the characteristics listed above, the respondent's income was also examined for possible effects on perceived route utility. Income was found to have no significant effects on route attribute preferences. This suggests that the relatively high incomes of the respondents do not affect the interpretation of the results.

The results are presented in Table 3. The log-likelihood of the model with interactions can be compared to that of the main effect model using a log-likelihood ratio test. The statistic is $-2 \times (-21300.4 + 21053.3) = 494.2$, which is higher than the corresponding chi-squared table value with 18 degrees of freedom at any reasonable level of significance. This is a strong indication that the model with interactions is better than the model with only the main effects.

The focus in the remainder of this section will be on interpreting the interaction effects, since the main effects are similar to Table 2 and have already been discussed earlier.

4.2.1 Interactions Associated with Link-Level Factors

The interaction effects specific to roadway class indicate that older individuals do not differentiate between bikeways on minor arterials and on residential streets as much as younger individuals (who have a higher preference for residential streets). However, the magnitude of this effect is 0.008, compared to the main effect of minor arterial (-0.77). Thus, for practical purposes, the differential preference for residential streets (compared to minor arterials) is a non-

issue (even for a bicyclist who is 100 years old, the magnitude on the minor arterial coefficient drops just from -0.77 to -0.69; note that we attempted non-linear effects of age, but the linear effect turned out to be adequate).

The parking presence-related interactions suggest that parking presence is less of a concern in urban/suburban regions than in rural regions. This may be associated with more exposure to routes with parking in urban and suburban regions, leading to a de-sensitization to this attribute among urban and suburban bicyclists. The influence of age suggests that older respondents, who are probably more safety conscious and experienced than younger cyclists, associate a higher disutility for routes with parking; however, as in the case of roadway class, the impact of age is rather small.

The bicycle facility type interactions indicate a higher preference associated with separate paths and bicycle lanes in urban areas (compared to rural and suburban areas), though this increased preference is rather marginal. The interaction effect of parking presence with bicycle lane is, however, quite substantial. The results suggests that, while bicycle lanes with permitted parking are still preferred to routes with no bicycle facilities, the value of a bicycle lane is substantially lowered if parking is permitted. This is rather intuitive, because parking can intrude into the movement space of bicyclists in bicycle lanes. Finally, older individuals have a marginally higher preference for wide right-hand lanes.

There are no interactions associated with bridge type. The interactions of the “extent of hilliness” variables indicate that the undesirability of mountainous terrain is accentuated in urban areas, perhaps because of safety considerations in urban areas with substantial motorized traffic. A similar interpretation could explain the indifference between hilly and flat terrain in urban areas (though hilly terrain is preferred over flat terrain in suburban/rural areas). Finally, in the class of link-level factors, the results suggest that older individuals, who are likely to be more comfort-conscious, have a stronger preference for smooth riding surfaces.

4.2.2 Interactions Associated With Route-Level Factors

The travel time variable has several interactions, including those with urban dwelling, roadway class, age, and bridge facility type. The negative effect of travel time is heightened for urban residents, perhaps because urban areas are busier and/or more hazardous than suburban and rural areas. Similarly, the higher sensitivity to travel time on bicycle routes along major/minor arterials (relative to residential streets) can be attributed to busier and more hazardous conditions on arterials. On the other hand, older individuals have a lower sensitivity to travel time, perhaps reflecting more time availability in general. Further, travel time is less onerous on bridges with bicycle facilities of some kind (be it a bicycle lane, a barrier separation, or a non-motorized bridge) than on bridges with no bicycle facilities. The magnitude of the coefficients on the travel time interaction with the major/minor arterials (-0.016) and with bridge bicycle facility presence (0.016), when compared with the magnitude of the main travel time effect (-0.15), indicate that bicyclists are willing to endure about 10% additional travel times to use routes in residential streets and routes with a bicycle facility at bridge locations rather than routes on minor/major arterial and with no bicycle facility at bridge locations, respectively.

The interactions effects associated with other route-level factors indicate the following: (a) presence of a continuous bicycle facility is much more valued on minor/major arterials compared to residential streets, possibly because facility interruptions can present a higher safety risk on roadways with high levels of traffic, (b) bicyclists in urban areas are more sensitive to the number of red lights on routes than bicyclists in suburban/rural areas, (c) bicyclists in urban and

suburban areas are less averse to routes with several major cross streets, perhaps reflecting the futility of finding bicycle routes without many major cross streets in urban/suburban settings, and (d) older individuals dislike major cross streets more than younger individuals.

5. SUMMARY AND CONCLUSIONS

This paper has presented models for evaluating bicycle commuting routes. The main purpose of this paper was to include both link-level and route-level variables in the model specification. The final specification utilizes a standard binary logit model, including several route factors, their interactions with each other, and their interactions with sociodemographic and land use characteristics. The analysis uses data collected from over 3,000 Internet respondents using a stated preference survey.

The results of the effects of the explanatory variable in the study are quite intuitive. In order of importance, bicycle commuters generally prefer:

- lower travel times,
- residential roads to major or minor arterials,
- bicycle lanes, separate paths, and wide right-hand lanes to roads with no bicycle facilities,
- bridges with no motor vehicles or with a barrier between motorized- and non-motorized users, and bridges with bicycle lanes to bridges with no special provisions for bicycle riders,
- smoother pavement and rough pavement over a coarse sand riding surface,
- streets with no parallel parking to streets with parallel parking,
- fewer major cross streets,
- flat ground and moderate hills over very steep hills, and moderate hills to flat ground,
- continuous bicycle facilities to interrupted ones, especially on major or minor arterials,
- fewer stop signs, and
- fewer red lights.

The commuter's age and residential location affect the perceived utility associated with some variables. (The commuter's income had no noticeable effects.) In the overall, however, the variations in sensitivity to the link-level and route-level factors across individuals are rather marginal compared to the main effects of these factors.

This research complements existing studies in two important ways. First, while most of the variables in this research have been analyzed and found to be important in various other studies, this paper examines all of these variables together. Therefore, route-level and link-level variables can be compared side-by-side to determine their relative importance. Second, this study examines variables that have received little (if any) quantitative assessment: these variables include bicycle facility continuity and bicycle facility availability on bridges.

In conclusion, the paper provides a model that can be used to evaluate the effectiveness of new bicycle routes or of changing existing ones. Calculating and comparing route utilities can help planners decide where to implement a new route, or how to improve an existing route. The results also suggest that certain attributes should be emphasized in bicycle facility planning. Providing bicycle facilities that are direct and have light to moderate traffic should be a priority in bicycle planning.

In addition, the high significance of the many variables in the model illustrate that bicycle planners should consider as many of these factors as possible when evaluating routes. Furthermore, the complexity of route decisions (demonstrated by the number of significant variables) indicates that adequate funding and training is important for developing effective bicycle planning programs and departments.

ACKNOWLEDGEMENTS

Lisa Barden and Gus Castellanos of The University of Texas at Austin College of Engineering provided invaluable assistance in developing and tailoring the online survey software, Survey on the Spot, used in this research. The survey was administered online on a CoE website. The authors are grateful to Lisa Weyant for her help in typesetting and formatting this document. Four anonymous reviewers provided valuable comments on an earlier version of this paper.

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FIGURE 1 Sample route choice question.

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Question 3-1.Route 1

Minor arterial
Wide (14') right-hand lane
Continuous
1 or 2 red lights

Route 2

Residential street
Wide (14') right-hand lane
Discontinuous
No red lights

Which route would you choose?

Route 1
Route 2

FIGURE 1 Sample route choice question.

TABLE 1 Simple Main Effects Model

Variable Types	Variable Class	Variable Level	Coefficient	t-ratio
Link-Level	Roadway Class (base: residential street)	Major arterial Minor arterial	-1.78 -0.57	-33.92 -16.67
	Parking (base: parking not permitted)	Parallel parking permitted	-0.47	-13.03
	Bicycle Facility Type (base: no facility)	Separate path	1.59	32.14
		Bicycle lane	1.86	39.28
		Wide right-hand lane	1.09	31.10
	Bridge Type (base: no bicycle facility)	Bicycle lane	1.01	19.57
		Barrier separation	1.28	17.59
Non-motorized bridge		1.46	22.02	
Terrain (base: flat ground)	Mountainous Hilly	-0.78 0.20	-11.66 4.31	
Pavement Type (base: rough pavement)	Smooth Pavement	1.35	31.20	
	Coarse Sand Surface	-1.47	-22.61	
Route-Level	Travel time	Travel time (minutes)	-0.11	-33.09
	Continuity	Continuous facility	0.71	18.58
	Delays	Stop signs per mile	-0.35	-18.67
		#Red lights	-0.10	-5.42
Cross-streets	#Major cross streets	-0.44	-17.13	
Log-likelihood value at equal shares			-23,885.16	
Log-likelihood value at convergence			-21,300.40	
Number of parameters			18	
Number of route choice observations			34,459	

TABLE 2 Approximate Rank Ordering of the Variables According to Effect on Utility

Variable Class	Variable Level	Average Value When Present	Parameter Estimate	Average Contribution to Utility
Travel Time	Travel time (minutes)	21	-0.11	-2.40
Bike Facility	Bike lane	1	1.86	1.86
Roadway Class	Major arterial	1	-1.78	-1.78
Bike Facility	Separate path	1	1.59	1.59
Riding Surface	Coarse sand surface	1	-1.47	-1.47
Bridge Type	Non-motorized bridge	1	1.46	1.46
Riding Surface	Smooth pavement	1	1.35	1.35
Bridge Type	Barrier separation	1	1.28	1.28
Bike Facility	Wide right-hand lane	1	1.09	1.09
Bridge Type	Bike lane	1	1.01	1.01
Cross Streets	#Major cross streets	2	-0.44	-0.89
Hilliness	Mountainous	1	-0.78	-0.78
Continuity	Continuous facility	1	0.71	0.71
Delays	Stop signs per mile	1.9	-0.35	-0.67
Roadway Class	Minor arterial	1	-0.57	-0.57
Parking	Parallel parking permitted	1	-0.47	-0.47
Delays	#Red lights	2.5	-0.10	-0.26
Hilliness	Hilly	1	0.20	0.20

TABLE 3 Final Route Choice Model Results (Including Interaction Effects)

Variable Types	Variable	Variable Level and Interactions	Coefficient	t-ratio
Link- Level	Roadway Class (base: residential street)	Major arterial	-1.760	-21.46
		Minor arterial	-0.770	-6.66
		Age (years)	0.008	3.49
	Parking Presence (base: none)	Parallel parking permitted	-0.430	-2.67
		Urban/suburban	0.310	2.94
		Age (years)	-0.008	-2.75
	Bicycle Facility Type (base: no facility)	Separate path	1.780	30.31
		Urban	0.260	4.47
		Bicycle lane	2.070	36.63
		Urban	0.140	2.55
		Parallel parking permitted	-0.650	-5.41
	Bridge Type (base: no bicycle facility)	Wide right-hand lane	0.810	9.67
		Age (years)	0.010	5.36
		Bicycle lane	0.980	14.70
Hilliness	Barrier separation or non-motorized bridge	1.370	16.93	
	Mountainous	-0.690	-8.49	
	Urban	-0.540	-4.49	
Pavement Type	Hilly	0.210	3.71	
	Urban	-0.200	-2.37	
	Smooth pavement	0.330	2.47	
	Age (years)	0.027	8.72	
	Coarse sand surface	-0.980	-4.77	
Route-Level	Travel Time	Age (years)	-0.018	-3.84
		Travel time (minutes)	-0.150	-13.18
		Urban	-0.031	-5.37
		Major/minor arterial	-0.016	-5.54
		Age (years)	0.001	4.11
	Continuity (base: discontinuous)	Bridge with bicycle facility	0.016	3.92
		Continuous facility	0.160	1.97
	Delays	Major/minor arterial	0.700	6.85
		Stop signs per mile	-0.400	-20.32
		#Red lights	-0.089	-3.80
Cross-streets	Urban	-0.130	-3.72	
	#Major cross streets	-0.620	-4.78	
	Urban/suburban	0.450	5.06	
	Age (years)	-0.006	-2.71	
Log-likelihood at equal shares		-23,885.16		
Log-likelihood at convergence		-21,053.30		
Number of model parameters		36		
Number of observations		34,459		