PREDICTING BICYCLE TRAVEL SPEEDS ALONG DIFFERENT FACILITIES USING GPS DATA: A PROOF OF CONCEPT MODEL

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Word Count: 3,381 + 6 Figures + 4 Tables

ABSTRACT

Improvements to transportation networks to facilitate travel by non-motorized modes, such as bicycling and walking, are quickly becoming a pursued strategy to maintain levels of accessibility in congested urban areas. However, transportation planners and engineers lack many of the tools to properly predict and evaluate the effects of changes to bicycle or pedestrian networks. This paper seeks to address part of this problem by developing a model to predict travel speeds by bicyclists on various types of facilities (on-street, off-street, and mixed traffic). Using real-time GPS data collected from a small sample of bicyclists traveling on various types of facilities in Minneapolis, MN, regression models are estimated with bicycle speeds as the dependent variable. Trip characteristics, gender, the presence of an off-street facility, and an individual's comfort level with traveling in heavy traffic are shown to influence travel speeds by bicycle. The estimated speed model is seen as a potential input to measures of bicycle accessibility, as well as improving the ability to model and forecast bicycle use, including the choice of route, on existing and planned transportation networks.

Keywords: Bicycling Speed, GPS, Bicycle, Non-Auto Travel Modes

INTRODUCTION

With increasing congestion levels in major U.S. cities, transportation planners and engineers are continually seeking ways to promote non-motorized travel modes as an alternative to congested, peak period auto travel. A key to promoting such modes in the planning process relates to the success in developing similar tools, measures, and planning techniques to those currently available for more prevalent modes such as auto or transit.

For example, improving accessibility is a common element in the goals section of almost all transportation plans in the U.S. *(1)*. Traditional transportation planning models that rely on measures of accessibility typically require a measure to record the distance (or other impedance) between origins and destinations. The most common accessibility measures depend mostly on travel time, impedances, and attractiveness of the land use activity (cumulative apportioning and gravity based) *(2-4)*. Being able to model and predict bicycle speeds on various facilities can help generate accurate accessibility measures by providing estimates of travel time using bicycles. Speeds can be obtained from field data collected along various bicycling facilities. While the methodology for generating travel speeds and accessibility measures is refined for travel by transit and auto, the literature is barren when it comes to describing methods to do so for walking or cycling.

This research application focuses on predicting travel times and speeds by bicycle along different types of facilities and cycling conditions along a transportation network. The model generated by this study provides an example of how it is possible to calculate bicycle travel time and impedances, which can then be used in generating accessibility measures specific to cycling.

BACKGROUND

The available work on travel time and speed of cyclists reports only sporadic attempts to capture such phenomena. The cost and difficulty of collecting speed data for bicycle trips or facilities has meant that primary data collection efforts are uncommon. Bicycle speed data are often collected as a secondary consideration, or as inputs for other related types of studies (e.g. level of service determination or bicycle traffic flow modeling). A comprehensive review by Allen et al. examines bicycling speed in general *(5)*. They conclude that bicycle free-flow speed lies between 6.2 mph (10 km/h) and 17.4 mph (28 km/h) with a majority of the reported speeds in the literature being between 7.5 mph (12 km/h) and 12.4 mph (20 km/h). A study by Botma *(6)* of bicycle facilities in the Netherlands used mean speeds of 11.2 mph (18.0 km/h) to develop service flow rates for bicycles. Another study conducted by Thompson et al. *(7)* used radar guns to detect speeds of adults and children while cycling along a closed road during a recreational event. In their study they found that the mean speed of all ages was around 9.2 mph (14.8 km/h). Khan and Raksuntorn *(8)* used video image data collection and analysis techniques. They report speeds ranging from 10.7 to 22.3 mph (17.2 to 35.9 km/h) with a mean of 15.4 mph (24.8 km/h) on an exclusive bicycle path in Denver, CO. Virkler and Balasubramanian *(9)* collected speed data on bicyclists, along with hikers and joggers, as part of a study of flow on shared-use trail facilities in Columbia, Missouri and Brisbane, Australia. Data in each location were collected manually by an observer with a stopwatch. Reported mean bicycle speeds in Columbia were 13.3 mph (21.4 km/h), while the Brisbane data indicated slightly lower speeds of 12.9 mph (20.7 km/h). As part of a study of urban greenway trails, Lindsey and Doan *(10)* report mean speeds of 13 mph (20.9 km/h) for users of an urban greenway trail in Indianapolis, IN. Other researchers concentrating on bicycle speed were mainly interested in speed at crossings and intersection points between trails and other types of networks *(11, 12)*

Most of the studies being used to derive numbers from the above report were prior the widespread of the global positing systems (GPS). In 2000 the U.S. government stopped its intentional degradation of the civilian GPS signal, called Selective Availability (SA), which was used to protect military operations. SA used to distort the accuracy of any GPS system, making it difficult to use a GPS to accurately locate a moving object such as vehicles on a road *(13)*. Currently, off-the-shelf GPS systems have an accuracy range from three to ten meters that can be used to collect more accurate speed data. It is important to note that bicycle speed varies based on the type of facility being used (transportation network), characteristics of the route (e.g., traffic signals, number of streets) and characteristics of the user (e.g., age, experience).

RESEARCH DESIGN

The aim of this research is to develop a model to predict the speed at which different types of users travel along different types of facilities. To generate a reliable model speed data should be collected along the various transportation facilities. In many urban areas there are three types of environments for cyclists. The first is an off-street facility. An off-street facility is a dedicated path for bicycling only (although sometimes for bicycling *and* walking), where interaction with traffic is minor or non-existent. The Twin Cities region boasts a system of off-street bike paths unparalleled among major metropolitan areas in the U.S., totaling over 2,722 kilometers (1,692 miles). While not nearly as extensive, the second type of environment—a striped on-street bike lane—are common as well. Cyclists travel along these facilities to the side of regular traffic, yet in a dedicated lane where they have the right of way. These types of facilities have higher levels of interaction with traffic compared with off-street ones. The last type of environment that cyclists use are regular streets. Regular streets have the highest level of interaction between cyclists and traffic. Cyclists must travel in mixed traffic. Figure 1 shows example images of the first two types of bicycling facilities.

Figure 1: Types of bicycling facilities

We expect travel characteristics along each of the three types of facilities to differ. We therefore treat travel along each type of facility separately and predict a speed along each, while allowing riders to choose freely among available routes. For example, Figure 2 shows a typical trip from point A to B where the person has passed through three different facilities to reach his destination. Accordingly, this trip should be divided into three different sections. The first is Seg 1 when he/she was cycling along an on-street facility, then Seg 2 when he/she was cycling along an off-street facility, and finally Seg 3 when he/she was cycling along regular local streets. A trip segment will be used as our main unit of analysis for the study. Any trip segment can include only one type of facility.

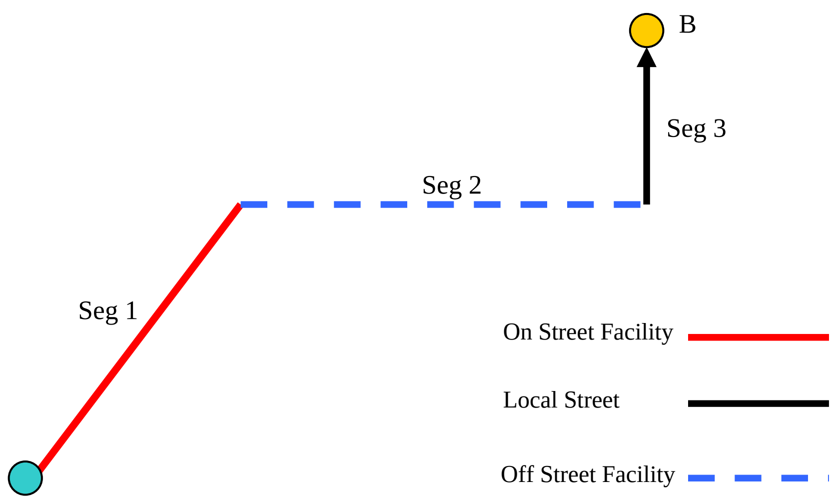

Figure 2: Unit of analysis

Speed along each type of facility can be related mainly to the length and type of segment. The speed, however, is also based on personal, segment-specific and/or trip characteristics. The personal factors are due to differences between individual-level characteristics, which include gender, age, and comfort with traveling in various types of traffic. Trip characteristics include how far this segment is from the starting point and how far it is from the ending one. It also includes the time of day when the trip was made. Segment characteristics that might be affecting travel speed include the number of signalized intersections and the average daily traffic along the segment. The generalized relationship that can measure speed along a segment is represented as follows:

Speed along segment = f (type of facility, segment length, trip length, number of signalized intersections, average daily traffic, time of day, personal characteristics)

The main policy-relevant variable we focused on in this application is the type of facility (or environment). The segment length variable will provide a generalized average speed while controlling for other factors affecting bicycling speed at its mean value. The type of facility is also a key variable since it will provide us with estimates of the effects of specialized facilities on bicycling speed.

DATA

In order to develop an accurate bicycle travel speed model, primary data collection is an important first step. In October 2005 the Active Communities Research Group (ACT) at the University of Minnesota conducted a pilot study to measure the effects of route choice on cyclists. This study required recruiting cyclists and equipping them with GPS units to monitor their travel patterns and speed. Eight cyclists who both live and work in Minneapolis were recruited into the study. None of the cyclists knew that a speed model will be generated from the data they are collecting. Table 1 includes information related to each respondent volunteer showing the age, gender, and frequency of cycling per week for each participant.

TABLE 1: Characteristics of Respondents

ID	Age	Gender	Frequency of Cycling Per Week
1	50	Male	3.67
2	43	Male	5.00
3	60	Female	2.33
4	28	Male	6.00
5	55	Female	3.75
6	47	Female	0.50
7	58	Male	3.25
8	30	Female	1.75

A GPS unit was attached to each respondent's handlebar to collect his/ her location every two seconds. The GPS units were attached to the handlebar of each cyclist for three weeks. GPS data were collected on a weekly basis from each participant. It is important to note that participants were asked to vary their path and to use various facilities during their daily trips. An abundant number of GPS points were collected during the study period. Due to the high level of resolution that the GPS points were collected at, the data had to pass through a cleaning process. For example, Figure 3 shows a snapshot of GPS data collected at the origin of a trip. It is notable that many points exist at the beginning when the person was not moving or when he was starting his trip. Such information had to be removed from the dataset. Also, it is clear from the figure that transitional points between the different types of facilities can be hardly associated to any of them. Accordingly, all transitional points were also removed from the data. Each of the GPS points were then snapped to a transportation facility center line. It is important to note that as observed in Figure 3, some travel occurred in small alleys. Since these alleys are not part of the general transportation network, these observations were also removed from the data for simplification and to avoid conflicts. In this application, we cleaned the data manually to decrease the amount of error and to be sure that all points were to be assigned to one type facility and to the segment that it was actually using. More advanced applications would be able to do this automatically. Figure 4 shows the distribution of the study routes. Study segments are defined based on observing the continuation of the GPS points along a facility, while controlling for the type of facility these points were observed along. A total of 315 study segments were identified as clean and ready to use (81 on street facility segments, 102 off street facility segments, and 132 local street segments).

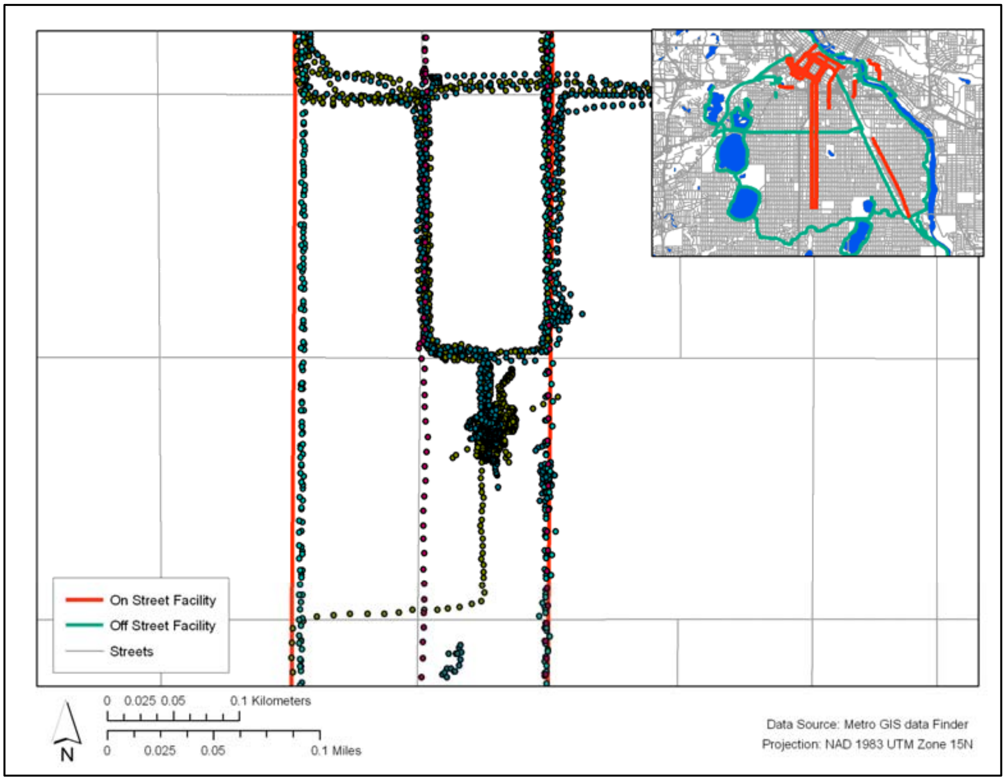

Figure 3: Snapshot of GPS collected data at the origin of a trip

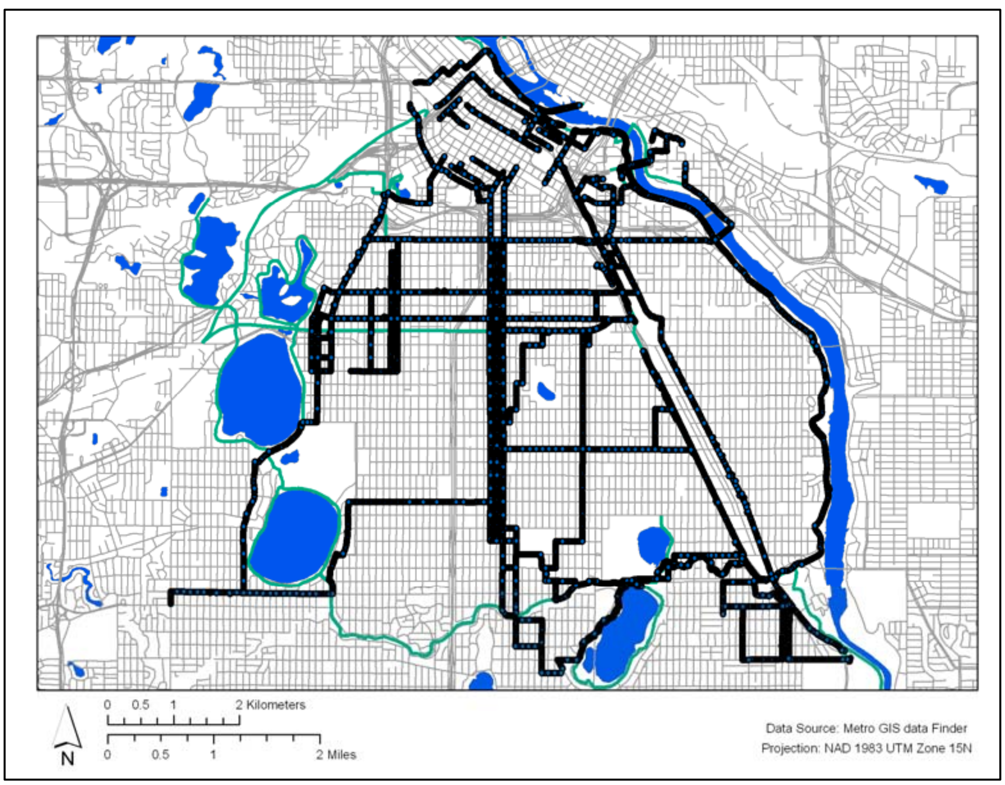

Figure 4: Study routes

After defining route segments and assigning GPS points, the various calculations were made. GPS points are used to derive several variables related to the trip and the segment such as speed, segment length, total trip length, distance traveled to the starting point of the segment, and characteristics of the trip and the cyclist. All of these data were then assigned to the segments. Meanwhile, other segment characteristics including type of facility, number of signalized intersections, and average daily traffic were obtained from secondary data sources including the Metropolitan Council geographic information system (GIS) database, Minnesota Department of Transportation, and the City of Minneapolis. All respondents had to complete a survey at the end of the data collection process. This survey includes various questions that can help in controlling for the variation along the volunteers. Table 2 includes a summary of the descriptive statistics of each variable being calculated.

TABLE 2: Descriptive Statistics

Variable	Min	Max	Mean	SD
On Street Facility (1 or zero)	0.00	1.00	0.26	0.44
Off Street Facility (1 or zero)	0.00	1.00	0.32	0.47
Distance Traveled Till Segment (Miles)	0.00	10.12	2.61	2.30
Total Trip Length (Miles)	0.08	10.62	5.51	1.82
Segment Length	0.05	6.29	1.20	1.40
Average Daily Traffic (Vehicles/ Day)	0.00	28174.68	4497.52	5474.38
Number of Signalized Intersections	0.00	17.00	0.78	1.89
Morning Commute (1 or zero)	0.00	1.00	0.63	0.48
Speed (Miles/Hour)	0.00	20.74	10.02	2.87
Age	28.00	60.00	47.92	11.86
Male (1 male or zero female)	0.00	1.00	0.53	0.50
Comfort in traveling in light Traffic (1 or zero)	0.00	1.00	0.54	0.50
Comfort in traveling in heavy Traffic (1 or zero)	0.00	1.00	0.41	0.49

ANALYSIS

Controlling for the variation in the cyclists themselves is an important factor towards developing a reliable speed model. First, an ordinary least squares regression model is developed. Speed is used as the dependent variable in the model, while the set of independent variables included the type of facility, trip and segment characteristics. Seven different dummy variables are included to control for the variation between the cyclists and their experience in using bicycling facilities. The reference level user was the average in terms of age and frequency of bicycling. The output of the model is reported in Table 3.

Observing the first key variables (type of facility) which are represented as dummy variables, it is clear that speed along off-street bicycling facilities shows a positive and statistically significant effect on bicycling speed along the segments relative to the reference variable (regular streets). A person cycling along an off-street bicycling facility is expected to be faster by 0.71 mph (1.14 km/h), holding all other variables at their mean values. No statistical difference was found between the speed along on-street bicycling facilities and regular streets. The distance traveled to the segment did appear to have a negative effect on the general speed (-0.08 mph). Meanwhile, the total trip length did appear to have a statistically significant and positive effect on speed. For each mile added to the total trip length the cyclist is expected to be around 0.24 mph (0.38 km/h) faster while keeping all other variables at their mean value. This can be related to the experience of the cyclist. The second key variable, segment length, has a positively and statistically significant effect on average speed. For each mile of increase in the segment length cyclists tend to travel faster by around 0.32 mph (0.51 km/h) while keeping all other variables at their mean values. Surprisingly, the effects of average daily traffic, morning commute, and number of signalized intersections did not appear to have a clear effect on speed. The signs of these variables follow an expected trend. For example, the increase in the number of signalized intersections leads to a decrease in the average speed along the segment by 0.14 mph (0.22 km/h) while keeping all the other variables at their mean value. This effect follows the expected hypothesis in term of the sign. Signalized intersections add some delay to cyclists and accordingly, decrease their speed along the segments.

Observing the seven dummy variables representing the cyclist, it is clear that only two of the respondents, 3 and 6, are slower than the reference category (cyclist 2). From Table 1 it can be observed that cyclist 3 was a 60 year old female that tended to travel by bicycle around 2.3 times per week. Cyclist 3 travels slower than cyclist 2 by 1.99 mph (3.2 km/h). Meanwhile, cyclist 6 is a 47 year old female with the least level of frequency in cycling. Cyclist 6 tends to be slower than cyclist 2 by 2.05 mph (3.30 km/h).

TABLE 3: OLS Model Predicting Bicycle Speed

	Coefficients	t-stat	Sig
Constant	**9.38**	**12.84**	**0.00**
On Street Facility (1 or zero)	-0.35	-0.93	0.35
Off Street Facility (1 or zero)	**0.71**	**1.69**	**0.09**
Distance Traveled To Segment (Miles)	-0.08	-1.18	0.24
Total Trip Length (Miles)	**0.24**	2.54	0.01
Segment Length (Miles)	**0.32**	**2.55**	**0.01**
Average Daily Traffic (Vehicles/ Day)	0.00	0.43	0.67
Number of Signalized Intersections	-0.14	-1.5	0.13
Morning Commute (1 or zero)	-0.15	-0.48	0.63
Traveler 1 relative to Traveler 2 (1 or zero)	-0.36	-0.67	0.50
Traveler 3 relative to Traveler 2 (1 or zero)	**-1.99**	**-4.04**	**0.00**
Traveler 4 relative to Traveler 2 (1 or zero)	-0.94	-1.71	0.09
Traveler 5 relative to Traveler 2 (1 or zero)	0.5	0.44	0.66
Traveler 6 relative to Traveler 2 (1 or zero)	**-2.05**	**-2.6**	**0.01**
Traveler 7 relative to Traveler 2 (1 or zero)	0.78	0.92	0.36
Traveler 8 relative to Traveler 2 (1 or zero)	0.95	1.31	0.19

Adjusted R^2 = 0.25
N = 315
Variables in bold significant at the 0.10 level

We developed a second model using the same variables but excluding the seven dummy variables. The dummies were replaced with other independent variables to control for the variance among the travelers. Such variables include age, gender, and a couple of variables describing whether the traveler feels comfortable when traveling along light or heavy traffic relative to no traffic (the reference variable). Table 4 includes the output of the generalized speed model. It is clear from the table that most variables from the previous model maintain their statistical significance and explanatory power in the model.

Among the variables controlling for the variance in travelers, gender has a positive and statistically significant effect on bicycle speed. Being male increases the speed along the segment by 0.67 mph (1.07 km/h) while keeping all the other factors at their mean value. Age is found to have a small, positive effect on the speed measured along the segments. Evidence from the eight study participants suggests that cyclists comfortable with traveling in heavy traffic tend to have statistically significantly higher speeds than people who are only comfortable traveling in no traffic. People who are comfortable cycling on streets with higher traffic cycle faster than those more comfortable traveling along off-street facilities by 1.41 mph (2.26 km/h).

DISCUSSION

Observing the two models we see that travel speed hovers around 10 mph (16 km/h), though there are statistically significant differences in each cycling environment. Cyclists traveling on off-street facilities move faster than all the other facilities when keeping all other variables at their mean values. On average, speed along off-street facilities is observed to be around 10.1 mph (16.25 km/h) (this may in part be influenced by the marked speed limit along such facilities to be 10 mph (16.25 km/h). Speed along on-street facilities is slightly lower at 9.71 mph (15.62 km/h). Finally, when the eight participants rode on regular streets, their average speed was observed to be 9.79 mph (15.75 km/h). Figure 5 shows the predicted speed along each type of facility with all variables held at the mean values. Similarly, Figure 6 shows the predicted speed compared to comfort with all variables held at the mean. The study participants who reported being more comfortable riding in heavy traffic tended to have higher average speeds than cyclists who reported being less comfortable in heavy traffic. They tend to travel on average around 10.79 mph (17.36 km/h).

TABLE 4: Generalized speed model

	Coefficients	t-stat	Sig
Constant	**6.48**	**4.65**	**0.00**
On Street Facility (1 or zero)	-0.32	-0.84	0.40
Off Street Facility (1 or zero)	**0.94**	**2.22**	**0.03**
Distance Traveled To Segment (Miles)	-0.09	-1.31	0.19
Total Trip Length (Miles)	**0.31**	**3.37**	**0.00**
Segment Length (Miles)	**0.23**	**1.85**	**0.07**
Average Daily Traffic (Vehicles/ Day)	0.00	0.37	0.71
Number of Signalized Intersections	-0.01	-0.08	0.94
Morning Commute (1 or zero)	-0.33	-1.05	0.30
Age	0.01	0.66	0.51
Male	**0.67**	**1.83**	**0.07**
Comfort in traveling in light Traffic (1 or zero)	0.16	0.21	0.84
Comfort in traveling in heavy Traffic (1 or zero)	**1.41**	**1.83**	**0.07**

Adjusted R^2 = 0.17
N = 315
Variables in bold significant at the 0.10 levels

Two key variables when interpreted together can help in better understanding cyclist's behavior and how they distribute their efforts along the trip. The first is the trip length and the second is the distance traveled to the segment starting point. These two variables indicate that cyclists making longer trips tend to be faster than others, and that their speeds tend to decline toward the end of their trips, which is expected.

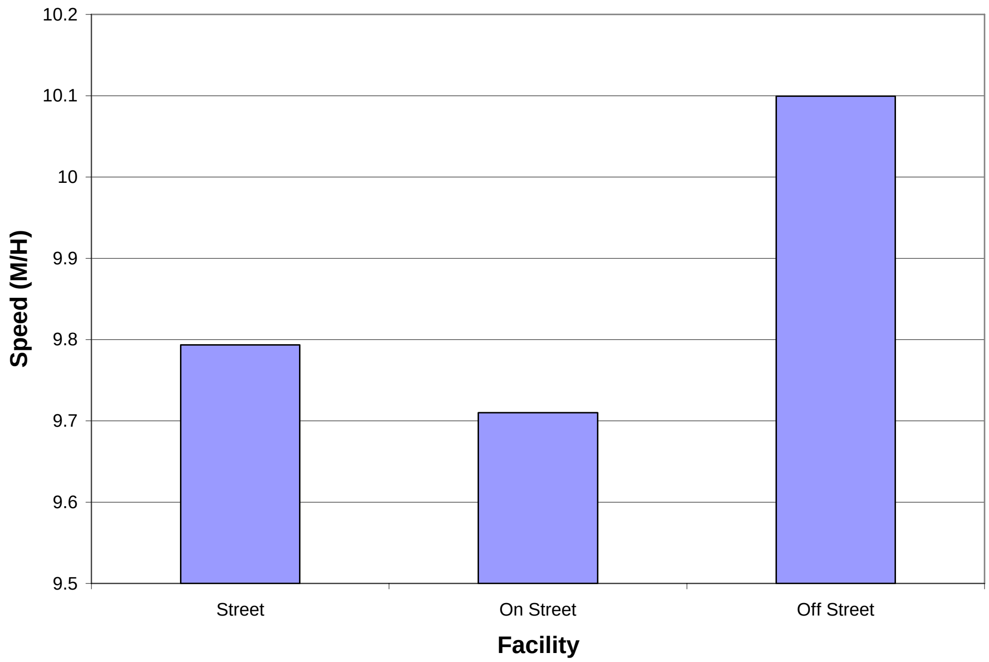

Figure 5: Predicted speed along each type of facility with all variables held at the mean

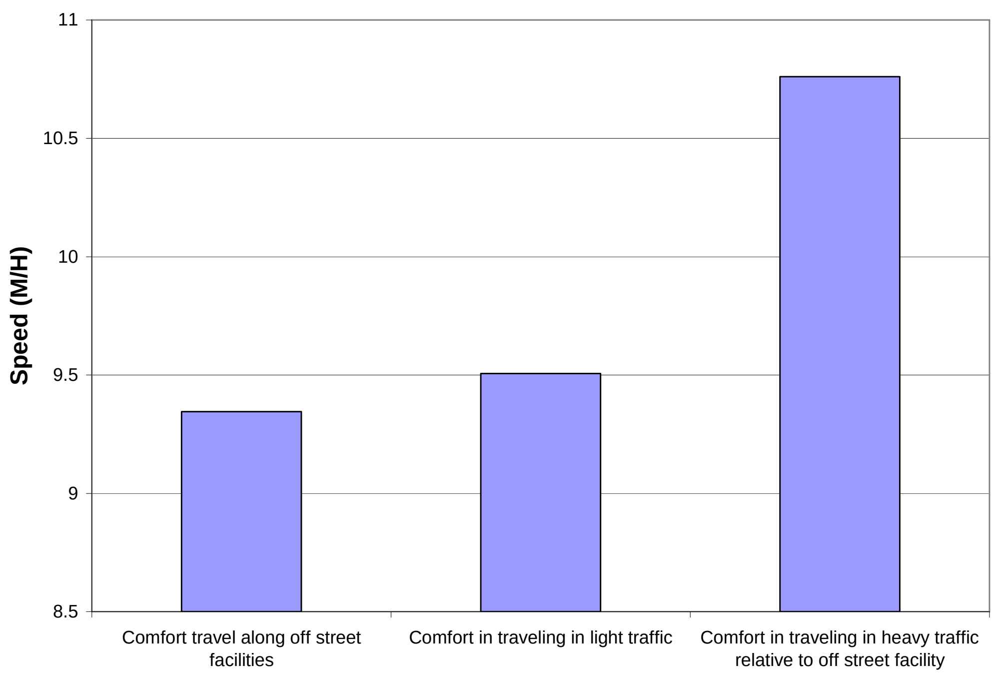

Figure 6: Predicted speed compared to comfort with all variables held at the mean

CONCLUSION

This research presents a proof-of-concept method to model bicycle travel speed in different types of environments found in urban areas. Using primary data collected with commercially available GPS technology, regression models were estimated to predict travel speeds on on-street, off-street, and mixed traffic facilities. Results showed that, all else equal, cyclists tend to travel along various types of facilities at different speeds. On average, their speed ranges between 9.71 mph and 10.8 mph (15.62 km/h and 16.25 km/h) while keeping all other variables at their mean values. Predicted travel speeds on off-street facilities are slightly higher than those for on-street and mixed traffic facilities. However, it is difficult to determine whether the slower observed speeds on on-street facilities were due to congestion, or other factors such as fatigue or pavement conditions. While these average speeds ignore a number of individual-specific factors, they can be considered acceptable for basic planning and modeling purposes. While trip characteristics and gender were also shown to influence travel speeds, an important predictor appears to be a cyclist's level of comfort with traveling in heavy traffic.

An important outgrowth of this study is that the findings of the estimated models can be used to apply impedances to each type of facility to generate more accurate accessibility measures. Understanding the impedances faced by cyclists in the form of travel speeds allows planners to better estimate the range of destinations that might reasonably be reached by bicycle travel in a given amount of time.

The findings of this study are tempered by the limitations inherent the research design. While a large number of observations were collected in order to estimate the models, they were generated from relatively few respondents. An important aspect of the study was to isolate the effects of specific facility types on travel speeds, apart from individual and sociodemographic factors. Beginning with a larger sample of individuals would allow greater confidence in the effects of factors such as age, gender, and skill or comfort level, and would make the results more generalizable. Such extensive data collection efforts are often costly.

An additional measurement concern involves the effect of the GPS units on the research subjects, themselves. One might hypothesize that the mere presence of the GPS unit and the knowledge that the individual is being continually monitored would have an effect on the individual's cycling behavior.

With the amount of attention and resources now being directed towards improving the quality of bicycle and pedestrian facilities, improved research and data collection methods should become more of a priority. Methods such as the one described above can be refined in order to produce more robust results and help development measures of accessibility that are consistent with those being developed for other modes. This paper provides a starting point for addressing what the authors believe is one of the gaps in existing knowledge regarding bicycle facilities and travel.

ACKNOWLEDGEMENTS

The authors thank Francis Harvey and Reuben Collins for their help in recruiting the volunteers and administering the data collection process. This study was made possible by funding from the Minnesota Department of Transportation.

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