Bicycle Level of Service for Arterials

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ABSTRACT

This paper documents a Florida Department of Transportation (FDOT) sponsored study to create a model that predicts how bicyclists perceive the arterial roadway environment. It builds upon their highly successful adopted segment and intersection bicycling level of service (LOS) models. Data for the new Bicycle LOS for Arterials model were obtained from the FDOT's innovative "Ride for Science" field data collection event and video simulations. The data consist of participants' perceptions of how well roadways met their needs as they rode selected arterial roadways and/or viewed simulations of those and other roadways.

The Bicycle LOS for Arterials model is based upon Pearson correlation analyses, stepwise regression, and PROBIT modeling of approximately 700 combined real-time perceptions (observations) from bicyclists riding a course along arterial roadways. An additional 700 combined perceptions obtained from the participants viewing a video simulation (discussed in another paper) were used to refine the model for arterial roadways. The study participants represented a cross section of age, gender, riding experience, and residency. The Bicycle LOS for Arterials model provides a measure of the bicyclist's perspective on how well an arterial roadway's geometric and operational characteristics meets his/her needs. Although further hypothesis testing may be conducted in a future study, this model is highly reliable, has a high correlation coefficient (R^2=0.74) with the average observations, and is transferable to the vast majority of metropolitan areas in the United States.

BACKGROUND

Efforts to measure the accommodation-based Level of Service (LOS) for non-motorized transportation modes have increased in recent years. Predictive models are often used to create such measures. The most dependable method of providing data for these models has been real-time data collection events staged on the roadways of major metropolitan areas. Volunteer or paid participants rate various roadway environments along a course based on their perceived level of how well each environment meets their needs. Using the varying geometric and traffic characteristics of the different facilities along the course, it is possible to determine what factors people view as significantly important when evaluating their LOS.

One such real-time field data collection event was recently conducted for the Florida Department of Transportation (FDOT). Previously, Landis *et al.* developed field validated methods for measuring bicycle and pedestrian LOS along roadway segments (between intersections) and at intersections (*1,2,3,4*). FDOT has adopted these LOS methodologies in its *Quality/Level of Service Handbook* (*5*). The objective of this most recent research was to create a method which could be used to rate entire arterial sections for the bicycle mode. The latest real time event included two major studies: the development of a model of LOS along arterial roadways for the bicycle mode (the focus of this paper), and the creation, testing, and calibration of a corresponding video simulation (discussed in another paper).

RIDE FOR SCIENCE 2005

The *Ride for Science 2005*, a research event sponsored by FDOT District 7, was held in Tampa, Florida on Saturday, November 12, 2005. The event captured how arterial roadways accommodated bicyclists by eliciting their perceived level of safety, comfort, and travel efficiency (*i.e.*, delay) provided by the bicycling environment. During the event, participants completed two primary activities: (1) they experienced a video simulation and (2) they rode a marked course through the surrounding metropolitan area. In the process, individuals rated the varying geometric and operational environments on a pseudo-academic (“A” to “F,” representing “best” to “worst”) scale. This paper documents the real time event used to obtain actual data from cyclists riding on the arterial roadway course. The development and use of the video simulation is addressed in another paper.

Participants

The study team recruited volunteers through a broad media outreach to participate in this data collection event. The researchers solicited participation from all types of individuals ranging from recreational cyclists, to high-end cyclists to those who use bicycles as their sole means of transportation. Participants completed registration forms, either in advance or on the day of the event. The registration forms generated background information about the participants – age, gender, years living in the metro area, and miles ridden per week for various purposes.

THE BICYCLING COURSE

The *Ride for Science 2005* course included a broad spectrum of arterial- and collector-type roadways typically found in U.S. metropolitan areas. Held in the areas around the University of South Florida and Busch Gardens, the course wound through a large variety of land uses typical of North American metropolitan areas. The course included roadways ranging from two to six lanes; with and without bike lanes or shoulders; and with varying traffic speeds, vehicle types, driveway densities, and pavement conditions. The course was designed to allow participants to experience a variety of roadway facility configurations and traffic conditions. Approximately 20 miles (mi) (32 kilometers (km)) in length, the course included 12 roadway sections (Figure 1). The beginning and end points of each section were identified by fluorescent yellow signs. The sections ranged from 0.3 mi (0.5 km) to 1.5 mi (2.4 km). The number of signalized intersections along each section ranged from 0 to 3, and the number of unsignalized intersections, from 0 to 10. Two sections had the fewest driveways (two each), and one section had the most (37). Several intersections along the course had crossing distances exceeding 100 ft (31 m).

On the day of the event, vehicle traffic volume and speed were recorded in 15-minute intervals for the roadway sections along the bicycling course. Traffic volumes ranged from 5 to 320 vehicles for the 15-minute periods. The number of lanes on the cross streets ranged from two to six, divided and undivided. Posted speeds ranged from 30 to 50 mi/h (49 to 81 km/h) .The course included sections with curb and gutter and other sections with open shoulders. The width of the outside motor vehicle lanes ranged from 10.5 to 15 feet (3.2 to 4.6 m). Striped bike lanes and paved shoulders ranged from non-existent to 9 feet (2.7 m) wide.

Data Collection

Participants were provided scorecards to use during their ride. On the top of each scorecard, each arterial section number was listed followed by the letters, A through F. A map with the numbered roadway sections was shown at the bottom of the scorecard. An example scorecard is depicted in Figure 2. At a pre-ride briefing, participants were directed to grade each section immediately after riding that section. Specifically, they were told to "circle the letter grade that best describes how well you feel each section serves your needs as a bicyclist." The briefing script is presented in Figure 3.

Participants were told to obey the traffic signals when crossing the intersections. Obedience to traffic control devices was considered critical to the relevance of this research. As the intent of the project was to determine how geometric and operational characteristics of signalized arterials/roadways (including intersections) impacted the bicyclists' perceptions, it was important that the participants experienced each intersection as it was designed to operate.

Tube counters on the roadway sections recorded volume, speed, and class of motor vehicles on fifteen-minute intervals throughout the course. Five time keepers along the course recorded the time each participant passed the time keepers' stations. These counts and time checks allowed the researchers to determine what the specific traffic conditions were on the roadways as each cyclist rode the sections.

Event Day

The day of the event was mostly sunny. Early morning temperatures around 60 degrees Fahrenheit (16 degrees Celsius) quickly warmed to around 80 degrees Fahrenheit (27 degrees Celsius) by early afternoon. Most participants first went through the video simulation data collection stage (described in another paper) and then went to the course briefing before riding the course. One out of four participants rode the course prior to watching the video. The first participant started riding the course shortly after 7:00 AM; the last participant finished riding the course shortly after 2:00 PM.

The event personnel included staff from Sprinkle Consulting, Inc., FDOT, the University of South Florida (USF), the USF Student Chapter of ITE, and a temporary employment agency. The event personnel ensured temporally spaced starts, controlled individual bicycling and scoring among participants, and made sure that participants kept current completed response cards.

Because there could be no attempt to "control" traffic or influence bicyclist or motorist behavior through placement of law enforcement officials, and because the bicyclists rode on regular roadways with motor vehicles, there was a degree of risk involved. This was explained to the participants in advance through the registration forms and during a pre-ride briefing session. Participants were also assured that they could stop at any time along the route, contact any one of the proctors along the course, and be picked up by a support vehicle if they were uncomfortable and did not wish to continue their ride. In addition, participants were reminded through the registration form and the pre-ride briefing that they were required to wear helmets at all times while on the course.

A participant's grades were valid only if they were the participant's own grades, reflecting his/her own perceptions of the roadway. Therefore, it was necessary that each participant ride and grade individually, without discussing his/her perceptions with other participants. A starter ensured that participants started at ninety-second intervals. Because of differences in riding speeds, some participants were likely to catch up to others. Therefore, the time keepers and proctors (see above) briefly detained participants at various points as necessary to maintain ninety-second headways.

ANALYSIS OF DATA

Participant Demographics

The sixty-three (63) participants who rode the course represented a good cross section of age, gender, and geographic origin. The riders ranged in age from 20 to 71; minors were prohibited from riding the course. The gender split was 41 percent females and 59 percent males. There was a wide variation in bicycle riding experience among the participants (Figure 4). The participants who rode less than 10 km per week were likely individuals who rarely rode a bicycle but were interested in being part of the research effot. Those who rode more than 200 km per week were likely either bicycle commuters or otherwise "hard core" riders who participated to have an influence on the planning and design of roadways for bicyclists.

Course Grades

As a result of the data event, approximately 700 data points were available for analysis. Because a few participants did not grade all 12 sections of the course, the number of data points available for analysis is somewhat less than 63 multiplied by 12 (756). Figure 5 shows the number of sections that received each grade. For initial analysis purposes, the letter grades were converted to numerical scores: A = 1, B = 2, C = 3, D = 4, E = 5, and F = 6. Figure 6 shows the average grade for each arterial section. Sections 1 and 2 received the best grades (1.62 and 1.58 respectively, both of which correspond to a LOS of “B”). Both of these sections are located on the University of South Florida campus, contain bicycle lanes, and had relatively light traffic volumes during the event (a Saturday, so few classes were in session). Arterial Section 10 received the worst grade (5.26, which corresponds to a LOS of “E”). This section is located on Busch Boulevard, which has no bicycle lanes or paved shoulders, and had some of the higher traffic volumes during the event.

Table 1 shows participants’ responses by demographic characteristics.. At the 0.05 significance level, participants who were 40 years or older graded worse overall than younger participants (3.48 vs. 3.04, $p=0.002$). Females graded worse than males (3.51 vs. 3.24, $p=0.043$). Based on riding experience (0-20 miles/week vs. 21 miles/week or more), there were no differences in how participants graded overall (3.32 vs. 3.43, $p>0.05$).

To test for possible scoring fatigue, some participants were directed to start with Section 7 (“half-on” participants) instead of Section 1. The “half-on” participants rode and graded Sections 7-12 and then proceeded to ride and grade Sections 1-6. Overall, the “half-on” participants graded better than those who started with Section 1 (2.85 vs. 3.43, $p<0.001$). In fact, on 11 of the 12 sections, the “half-on” participants graded better, though not all of the differences were significant at the 0.05 level. Because the differences in scoring were not associated with “miles ridden,” fatigue was not determined to be a factor in the scoring of the arterials. It is hypothesized that perhaps the order the facilities were ridden impacted the participants’ scoring. Perhaps riding less stressful roadways first led to grading the subsequent facilities more harshly.

There were 59 “course and video” participants, i.e., they watched the video simulation showing 11 additional sections and rode the course. Of these, most (42) watched the video before riding the course. Seventeen “reverse” participants watched the video after riding the course. These “reverse” participants did not grade differently compared to those who watched the video first (3.41 vs. 3.24, $p>0.05$).

Course Debriefing

The participants who watched the video simulation first were debriefed after they finished riding the course. The course debriefer reviewed each participant’s scorecard and asked randomly why he/she graded various sections “A” or “B” and why he/she graded various sections “E” or “F.” Each participant could give up to three answers. Although the participants gave a wide variety of answers, they can be categorized as shown in Figure 7. The most common answers pertained to bike lanes (80 responses), traffic volume (58 responses), roadway/pavement condition (42 responses), and accommodation/space (19 responses).

MODEL DEVELOPMENT

This study sought to mathematically express the geometric, operational and traffic characteristics that affect bicyclists' perceptions of quality of service, or level of accommodation, along arterial roadways. The first step taken in the modeling effort was to determine whether the long-established and widely-used Bicycle LOS model for *individual* roadway segments accurately represents the level of service for arterial sections, composed of multiple segments and intersections. The segment model, which has been refined and applied to over 200,000 miles (322,000 km) of roadways throughout North America, has the following format:

Bicycle Segment LOS = $a_1\ln(Vol_{15}/L) + a_2SP_t(1+10.38HV)^2 + a_3(1/PC_5)^2 + a_4(W_e)^2 + C$

where
Vol_{15} = volume of directional traffic in 15-minute time period
L = total number of through lanes
SP_t = effective speed limit (see below)
  SP_t = $1.12\ln(SP_P - 20) + 0.81$
  SP_P = Posted speed limit (mi/h)
HV = percentage of heavy vehicles
PC_5 = FHWA's five point surface condition rating
W_e = average effective width of outside through lane
C = a constant

Coefficients:
a_1: 0.507 a_2: 0.199 a_3: 7.066 a_4: - 0.005 C: 0.760

Distance-weighted average segment levels of service for the study arterial sections were tested with the field-collected data. The results show that the existing model for segments has strong explanatory power for predicting bicycle level of service for segments ($R^2 = 0.53$).

The researchers sought to improve upon this correlation using the FDOT intersection LOS model for the bicycle movement. Consequently, several transformations of the combined or averaged intersection LOS scores for bicyclists were tested in combination with the weighted average segment LOS score for bicyclists. This testing yielded no significant improvement simply using the segment LOS model.

Several other variables were also tested in combination with the average segment LOS. These variables were largely related to potential conflict points. When the Bicycle LOS for Segments model was developed, the number of driveways per mile was significant at the 90% level, but popular application of the Bicycle LOS for Segments model is without this factor. Because some observers have been surprised by the absence of conflict points in the popular model, such variables were re-examined for potential inclusion in the development of the Bicycle LOS for Arterials model. Driveways per mile, signalized intersections per mile, and unsignalized intersections per mile were all candidate variables and were examined using Pearson correlations and stepwise regression. Ultimately the number of unsignalized intersections was selected as the most appropriate variable because it had the strongest correlation with the data (it also has the benefit of being relatively simple data to collect – a valuable property in actual application of the model over a roadway network). Consequently, it was added into the final model form. This variable, the number of unsignalized intersections per mile, is believed to be a surrogate for the number of driveways per mile, but has more explanatory power. Figure 8 shows the response of Bicycle LOS for Arterials model to the number of unsignalized intersections per mile for a hypothetical roadway. The unsignalized intersection term includes only roadway intersections, not driveways. The final model form follows:

Bicycle Facility LOS = a_1(AvSegLOS) + a_2 (NumUnsigpm) + C

where
AvSegLOS = distance-weighted average segment bicycle LOS along the facility
NumUnsigpm = the number of unsignalized intersections per mile along the facility
C = a constant

Table 2 shows the terms, coefficients, and *t*-statistics for the model. The correlation coefficient (R^2) of the best-fit model is 0.72, based on the averaged observations for the course and video simulation data from the twelve facilities. See Figure 9 for a plot of predicted Bicycle LOS values versus mean observed values. The coefficients are statistically significant at the 95 percent level. Table 3 shows the LOS grade as it relates to the numerical score.

APPLICATIONS

The participants in this study represented a broad cross-section of the United States population of bicyclists, and the course arterials were typical of those prevalent in urban and suburban areas of the U.S. The initial result of this research is the development of a highly reliable, statistically calibrated bicycle LOS model for arterials suitable for application in the vast majority of U.S. metropolitan areas. Because the model was developed in urban and suburban environments, the model may not be transferable to rural arterials with few signals (the bicycle LOS model for roadway segments would be more appropriate in that setting (*2*)). Additionally, the model may not be appropriate along arterials where the number of side streets is kept low with frontage roads or facilities with very effective access management.

ACKNOWLEDGMENTS

The authors wish to thank the many volunteer participants and volunteer event personnel who made the *Ride for Science 2005* possible, including those from the FDOT District 7 Office, the FDOT Central Office, the University of Florida, the University of South Florida, URS, and the Tampa Museum of Science and Industry. In particular, we would like to thank Linda Crider, the USF Student Chapter of ITE, Harry Reed, and Michael Munroe. We would also like to thank our corporate sponsors, too many to name here.

REFERENCES

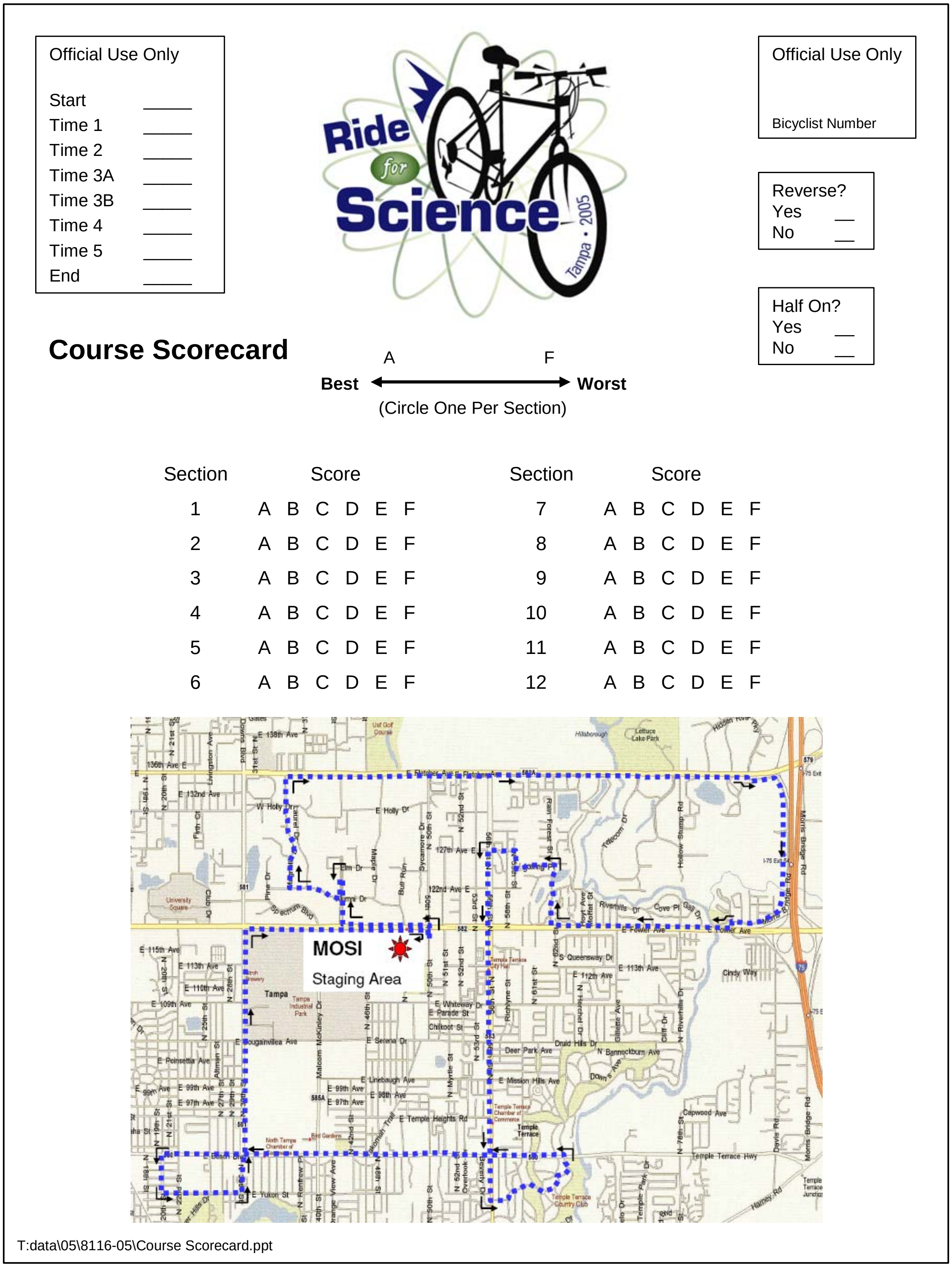
1. Landis, B.W., V. Vattikuti, R. Ottenberg, D. McLeod, M. Guttenplan, Modeling the Roadside Walking Environment: A Pedestrian Level of Service. In *Transportation*

Research Record: Journal of the Transportation Research Board, No. 1773, TRB, National Research Council, Washington, DC, 2001, pp. 82-88.

2. Landis, B.W., Vattikuti, V., and Brannick, M. Real-Time Human Perceptions: Toward a Bicyclist Level of Service. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1578*, TRB, National Research Council, Washington, D.C., 1997, pp. 119-126.
3. Petritsch, T.A., B.W. Landis, H. Huang, P. McLeod, S. Challa, M. Guttenplan., Level-of-Service Model for Pedestrians at Signalized Intersections. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1939*, Transportation Research Board, Washington, D.C., 2005, pp. 55-62.
4. Landis, B.W., V. Vattikuti, R. Ottenberg, T. Petritsch, M. Guttenplan, L. Crider, Intersection LOS for the Bicycle Through Movement. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1828*. Transportation Research Board, Washington, DC. 2003, pp. 101-106.
5. FDOT. *Quality/Level of Service Handbook*. Florida Department of Transportation, Tallahassee, FL, 2002.

LIST OF FIGURES

Figure 1 Bicycling course map



Official Use Only

Start _____
Time 1 _____
Time 2 _____
Time 3A _____
Time 3B _____
Time 4 _____
Time 5 _____
End _____

Official Use Only

Bicyclist Number

Reverse?
Yes __
No __

Half On?
Yes __
No __

Course Scorecard

A　F
Best ⟷ **Worst**
(Circle One Per Section)

Section	Score	Section	Score
1	A B C D E F	7	A B C D E F
2	A B C D E F	8	A B C D E F
3	A B C D E F	9	A B C D E F
4	A B C D E F	10	A B C D E F
5	A B C D E F	11	A B C D E F
6	A B C D E F	12	A B C D E F

T:data\05\8116-05\Course Scorecard.ppt

Figure 2　Course scorecard

COURSE

1. *The course begins and ends at the Museum of Science and Industry (MOSI).*
2. *You will be riding on a 20-mile course, scoring 12 sections along the way.*
3. *All sections on the course that are to be scored are marked with yellow signs where they begin and end. Only score those sections signed along the course. The section number on the yellow signs corresponds to the numbers on your scorecard.*
4. *Much of the course has bike lanes, but some of it doesn't.*

GRADING

1. *Circle the letter grade that best describes how well you feel each section serves your needs as a bicyclist. Each section can be graded from "A" to "F" with "A" being the best grade and "F" being the worst grade. Grade each section as you complete it. You can change your grades at any time; cross through the old grade and circle the new grade.*
2. *Grade only the roadway. Do not consider aesthetics or conditions beyond the roadway. Ignore the surrounding land and buildings, and also ignore any debris in the street.*
3. *There are checkpoints along the course. You must stop and check-in at the checkpoints. The Time Checkers at the checkpoints are monitoring your progress. They are also checking your scorecard for completeness. After your scorecard has been checked, it will be returned to you.*
4. *Ride as you normally would. The whole purpose of the Ride for Science 2005 is to get your* ***individual*** *scores. Please don't compare or discuss your grades with any other rider.*
   Please do not:
   a. *Ride together*
   b. *Share your scores*
   c. *Consider the conditions before the section "start" and after the "end" signs, or beyond the pavement when grading.*

SAFETY

1. ***You must wear a helmet at all times while on the course!***
2. *Ride safely; proceed through the intersections with caution.*
3. *Remember, you have the same rights and responsibilities as motorists. You must obey all traffic lights and STOP signs.*
4. *If you choose to cross at a crosswalk, use pedestrian rules and signals.*
5. *Notify Event Staff if you need assistance or for an emergency. A vehicle will be available to transport riders who need/want to leave the course.*
6. *You may discontinue the Ride at any time; you are under no obligation to finish.*
7. ***This is not a race; travel at your own pace****. You may pass other riders on the course. If another rider passes you, don't be concerned or feel pressured to keep up.*
8. *If you need to, you can stop at any of the businesses along the Ride to purchase something to drink (other refreshments are available at MOSI).*

Figure 3 Course briefing script

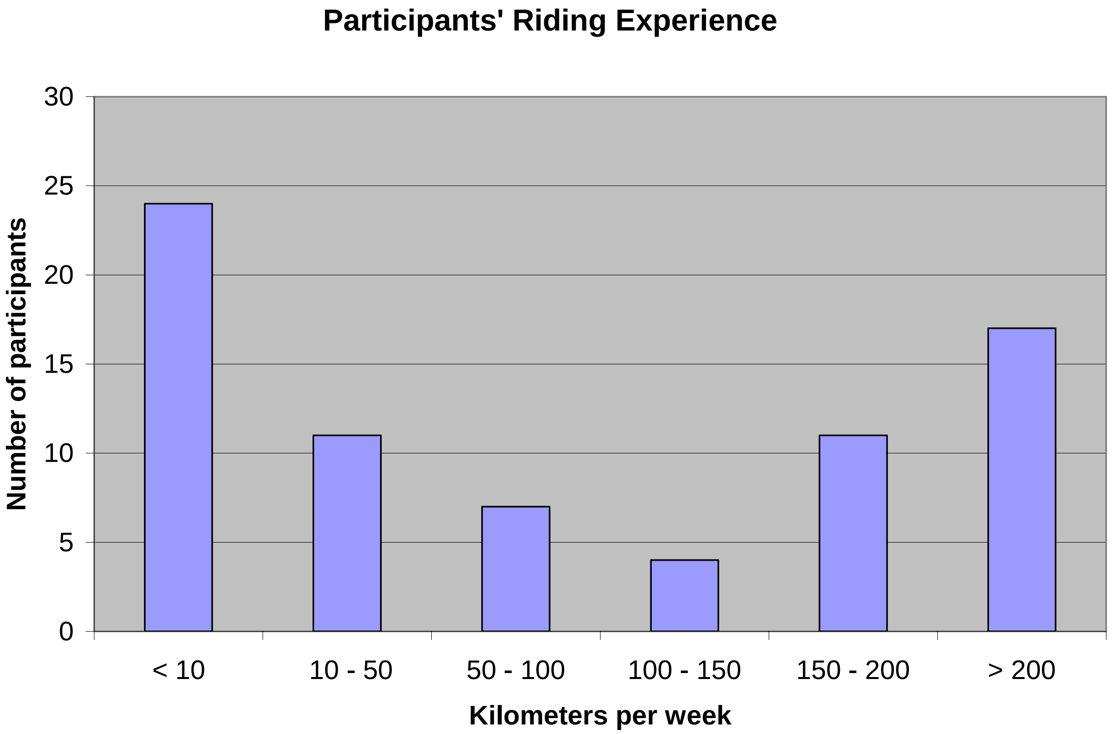


Figure 4 Distribution of participants' riding experience

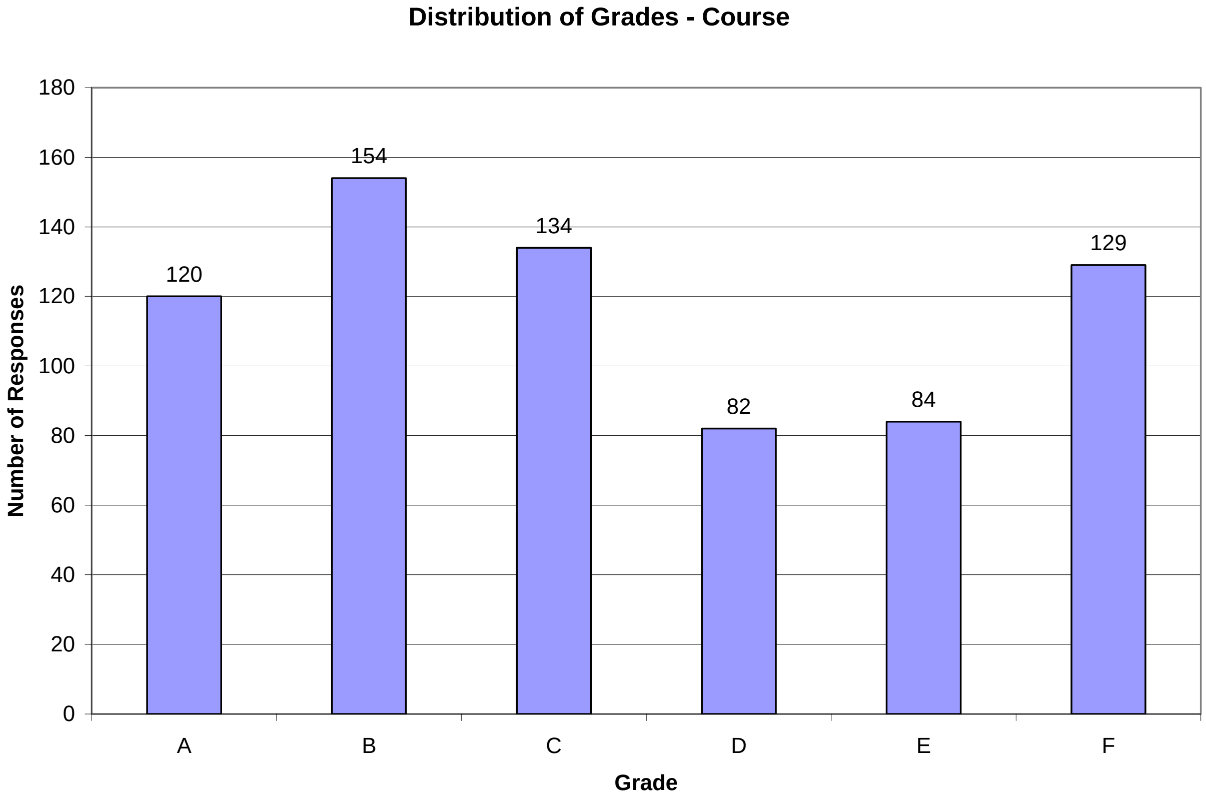


Figure 5 Distribution of course grades

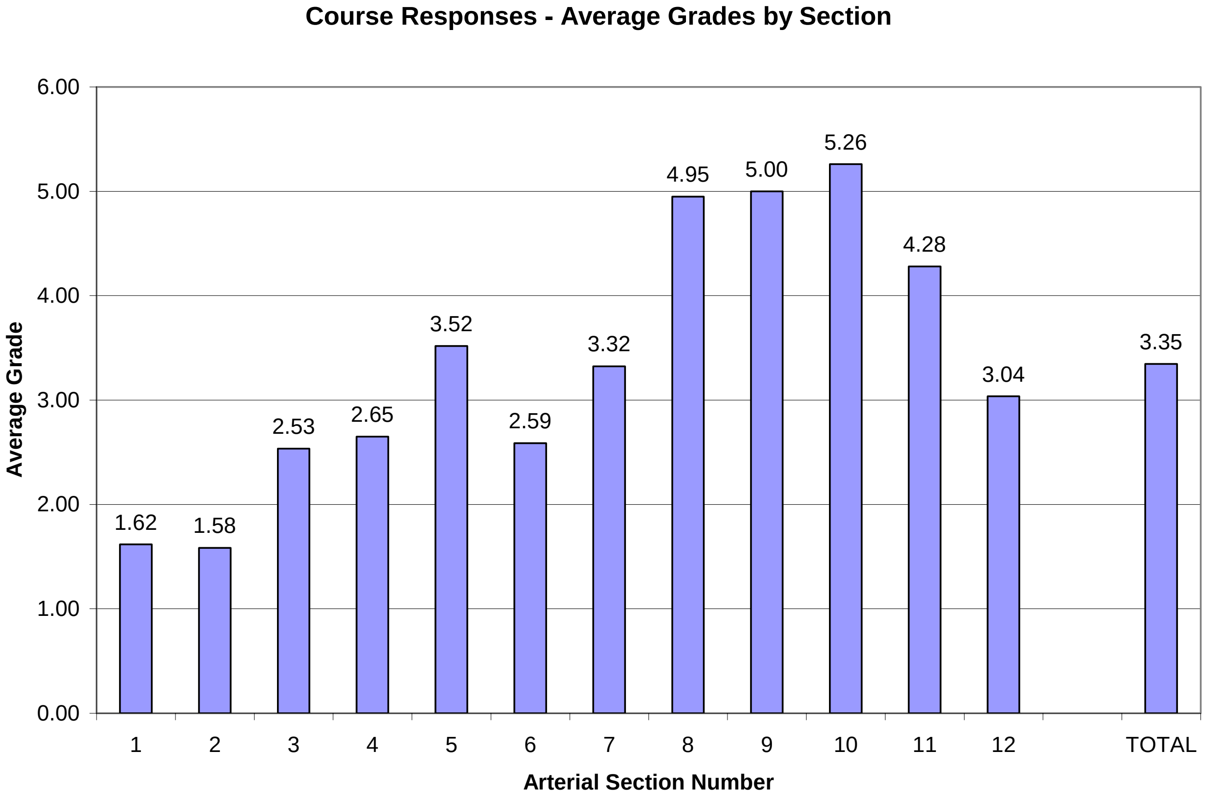


Figure 6 Average course grades by section

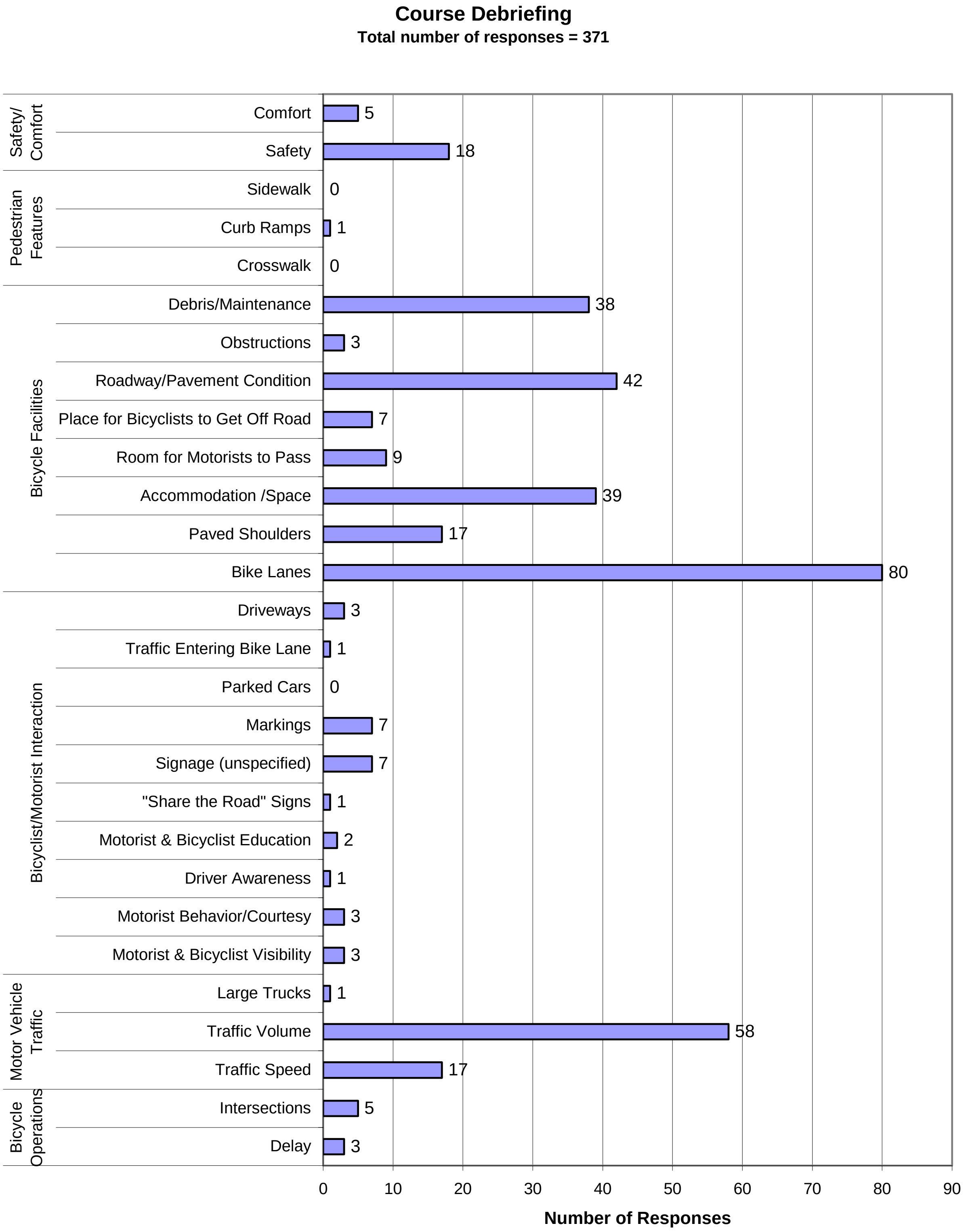


Figure 7 Course debriefing responses

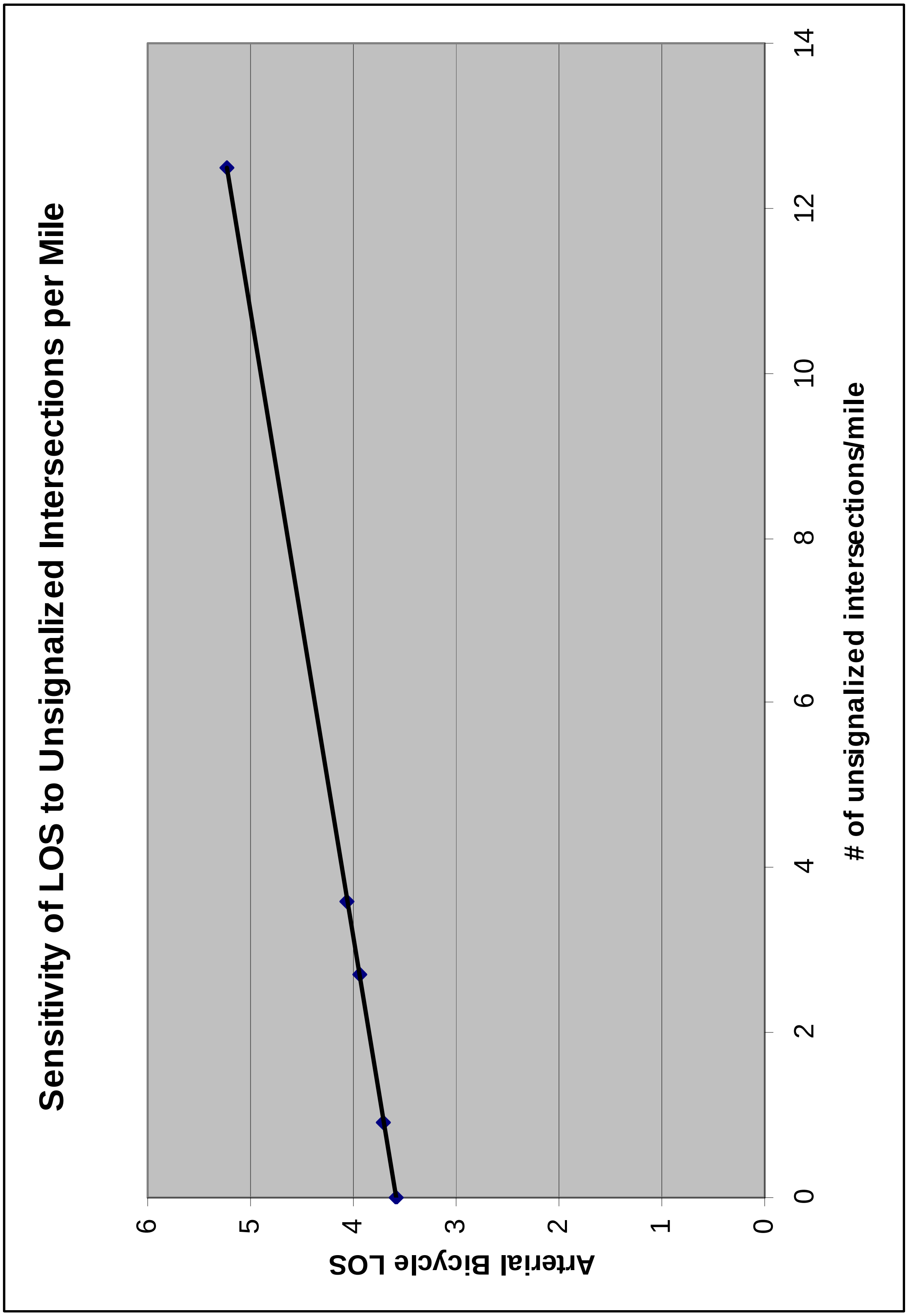


Figure 8 Sensitivity of LOS to unsignalized intersections per mile

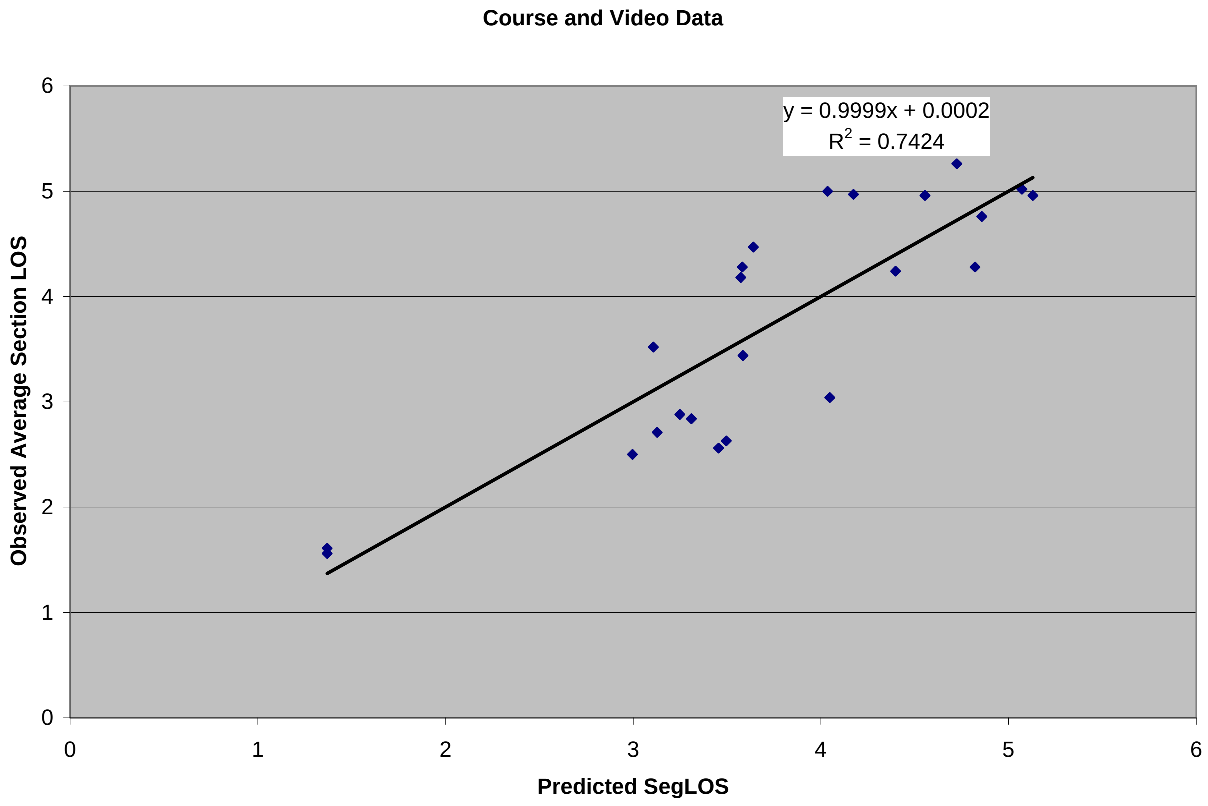


Figure 9 Predicted and observed section LOS values

TABLE 1 Participants' Responses by Demographic Characteristics

CHARACTERISTIC	GROUP 1[1]	GROUP 2[1]	T TEST RESULTS
Gender	Male (N=36) Avg. grade = 3.24	Female (N=25) Avg. grade = 3.51	Significant (p=0.043)
Age	20 to 39 (N=19) Avg. grade = 3.04	40 and over (N=43) Avg. grade = 3.48	Significant (p=0.002)
Residency in Tampa Metro Area	0 to 4 years (N=11) Avg. grade = 3.05	5 years and longer (N=50) Avg. score = 3.40	Not significant
Riding Experience	0 to 20 mi/week[2] (N=11) Avg. grade = 3.32	21 mi/week and more (N=40) Avg. score = 3.43	Not significant
"Half on" Participant	Yes (N=14) Avg. grade = 2.85	No (N=48) Avg. grade = 3.43	Significant (p<0.001)
"Reverse" Participant	Yes (N=17) Avg. grade = 3.41	No (N=42) Avg. grade = 3.24	Not significant

[1] The group sample sizes do not sum to 63 because data were not available for some participants.

[2] 1 mi = 1.61 mi.

TABLE 2 Model Coefficients and Statistics

Model Terms	Coefficients	T-statistics
AvSegLOS	0.797	6.648
NumUnsigpm	0.131	4.061
Constant	1.370	4.074
Model Correlation (R^2)	0.717	

Table 3 Bicycle LOS for Arterial Roadways Categories

Ped LOS for Signalized Intersections	Model Score
A	≤ 1.5
B	> 1.5 and ≤2.5
C	> 2.5 and ≤3.5
D	> 3.5 and ≤4.5
E	> 4.5 and ≤5.5
F	> 5