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Development of a Bicycle Level of Service Model from the User's Perspective

Kyungwoo Kang* and Kyeora Lee**

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Abstract

South Korea is seeking a solution to the problems of traffic congestion and environmental issues by increasing bicycle use. However, many people feel that using bicycles is inconvenient. Therefore, a bicycle level of service model from the user's perspective was developed so that the existing bicycle roads can be evaluated and improved. The purpose of this paper is to develop a bicycle Level of Service (LOS) model by considering the user's level of satisfaction and multiple factors that affect the bicycle LOS. Bicycle LOS criteria are estimated by applying an ordered probit model, which is suitable for research relating to choice. The results with the marginal effect show that the bicycle LOS is largely determined by the width of the road on which the bicycle is ridden. Other factors are also statistically significant in the bicycle LOS, including the road type, the total number of lanes on the approach to the intersection, and the number of encounters (travelers and bicyclists moving in the opposite direction).

Keywords: *bicycle, level of service, satisfaction score, ordered probit model, Korea*

1. Introduction

The Korean "National Intermodal Transportation Network Plan (2007-2019)" aims to establish a main transport system that maximizes the features and advantages of each mode of transportation. Adopted in 2009, the "Sustainable Transport and Logistics Development Act" emphasizes the development of sustainable transportation/logistics systems that would allow the present generation, which is facing climate change and energy shortages, to enhance the growth potential of future generation. It aims to shift the transport policy paradigm from the previous supplier-oriented policy, which was focused on facility expansion, to a new environmentally-friendly, people-oriented, sustainable transportation policy that takes transportation vulnerabilities into account. The act provides policy tools to stimulate the use of Non-Motorized Transport (NMT). A comprehensive plan (over a 5-year period) that aims to increase the transport share of NMT is to be devised and shall consist of an analysis of the present state and prospects of NMT, the objectives and general outline of the policy, and a plan for the increase in the transport share of NMT. Starting from the end of 2010, the Ministry of Land, Transport, and Marine Affairs (MLTM) actively implemented public information campaigns and promotional activities to stimulate cycling. TAGO (Transport Advice on Going anywhere) service has been providing integrated traffic information for road, air, rail, bicycle transportation and etc. Currently, the service regarding bicycles has been offering information on bicycle parking locations and the available parking spaces. In the future, path-finding services will be added. As part of promotional activities, the "Bicycle Love" campaign conducted a bicycle-related UCC, photos, and travel stories contest. Also, a Bicycle-related quiz contest was held and a bike will be awarded as a gift through the lottery.

The South Korean government suggested a national vision of "Low Carbon, Green Growth" and has been promoting the use of bicycles as a key solution to mitigate severe traffic congestion. Currently, only about 1.2% of Koreans use bicycles as a means of transportation compared with 14% in Japan and 27% in the Netherlands. The MLTM of Korea released the master plan of the bicycle promotional policy to increase the percentage of bicycle users from 1.2% in 2009 to 5% in 2012. A bicycle promotional policy means that the Korean government is encouraging people to use bicycles by implementing public information campaigns and promotional activities to stimulate cycling; accordingly, the government also decided to expand the public bicycle infrastructure. According to this plan, bicycle roads will expand from 9,170 km to 17,600 km, and the bicycle supply rate will increase from 16.6% to 30% in 2012. However, despite these efforts, many people feel that using a bicycle is inconvenient. Therefore, a bicycle Level of Service (LOS) model was developed from the user's perspective to enable the existing bicycle roads and facilities to be evaluated and improved.

The existing bicycle LOS in South Korea is estimated by only one measurement, such as speed, delay, and frequency of encounters, at a time. In this paper, the bicycle LOS model was developed by considering user satisfaction and multiple factors, such as bicycle road width, bicycle road type, bicycle volume and etc.

*Member, Professor, Dept. of Transportation Engineering, Hanyang University, Ansan 426-791, Korea (Corresponding Author, E-mail: kyungwoo@hanyang.ac.kr)
**Graduate Student, Dept. of Transportation Engineering, Hanyang University, Ansan 426-791, Korea (E-mail: vpg85@hanmail.net)

The objective of this research was to capture the users' perceptions by using a survey in which bicyclists expressed their preferences with ordinal rankings. Surveys were conducted to classify the user's perspective into six categories in accordance with user satisfaction.

The analysis of the data was used in an ordered probit model to determine which factors influenced the bicyclists' decisions and in what way. In addition, bicycle LOS criteria were presented by applying an ordered probit model, which is suitable for research related to choice. In the past, Korea constructed a vehicle-oriented transportation system. With the bicycle promotional policy, Korean bicycle facilities were recently expanded and improved. However, it is difficult to construct facilities exclusively for bicycles in the existing transportation system because of limited land availability.

Therefore, most of the bicycle roads in Korea are shared off-street paths, and existing sidewalks are improved for bicycle users. Bicyclists and pedestrians share the paths, and, thus, safety problems exist. In such situations, users choose bicycles because bicycles have advantages over other means of transportation. In particular, bicycles have advantages such as low cost and environmental and health benefits, but rapid mobility is not guaranteed compared with vehicles. Thus, bicycles are mainly used for commutes involving short-distance trips. In other words, bicyclists choose a bicycle because it has different advantages compared with other transportation options. In addition, although bicycles are slightly uncomfortable and even slower than other modes of transportation, bicyclists choose bicycles because of the advantages listed above, which indicates that bicyclists determine the level of service depending on satisfaction with their trip by considering multiple factors, not by considering speed or delay alone.

The existing level of service is divided into six levels in traffic engineering, and the traditional six levels were tested in Model 1. Although the bicycle facilities are rated highly from an operator's position, bicycles are chosen when the user selects an inconvenience because of their characteristics of discomfort as a short-distance mode. In other words, bicycle availability depends on the choice of users; thus, the bicycle LOS should be defined as a three-level structure (satisfied, fair, dissatisfied) that can be distinguished easily from a user's perspective. In addition, three levels of service (A-C) were developed for the bicycle mode by considering the level of utilization and facility size in South Korea. Using three levels of LOS exclusively for the bicycle roads may be controversial from the conventional traffic-engineering perspective. However, these problems can be solved by normalizing or weighting the LOS gradations across modes in future studies.

Most bicyclists share the sidewalk with pedestrians because bicycle roads are generally shared off-street paths in South Korea. Therefore, variables that relate to the presence of pedestrians were considered to establish the bicycle LOS model and reflect Korean bicycle road conditions.

2. Previous Research

The Highway Capacity Manual (HCM) provides bicycle LOS measures, thresholds, and estimation procedures for off-street paths and designated bicycle lanes on urban streets. For urban streets, the bicycle LOS is measured by using the average bicycle speed and average control delay. For off-street paths, the HCM bases the bicycle LOS on the frequency of encounters between bicyclists and pedestrians on the path. For two-way, two-lane paths, less than 40 encounters per hour is defined as the "A" level of service, whereas more than 195 encounters per hour is the "F" level of service.

Only one service measure determines the bicycle LOS in HCM, but the bicycle LOS in the Florida Q/LOS Handbook is based on multiple factors. The bicycle LOS score is estimated according to the regression model, and the six LOS designations (A through F) are defined.

Previously, Landis *et al.* (1997) developed field validated methods for measuring the bicycle LOS to identify the quality of service that currently exists for bicyclists. Sprinkle Consulting Inc. (SCI) originally developed the bicycle LOS model. The Florida Department of Transportation (FDOT) has adopted these LOS methodologies in its Quality/Level of Service Handbook. An FDOT model has been applied to over 200,000 miles of roadways in the U.S. and Canada. In this bicycle LOS model, the bicycle level of service is based on the following variables:

- Average effective width of the outside through lane
- Motorized vehicle volumes
- Motorized vehicle speeds
- Heavy vehicle (truck) volumes, and
- Pavement conditions.

Jensen (2007) noted that walking against traffic, sounds other than traffic, weather, and pavement quality all affected perceptions of either bicycle or pedestrian LOS. The cumulative logit model forms were selected for both the bicycle and pedestrian LOS models. These models predict the percentage of responses for each of the six levels of service. The methodology used was to have respondents view numerous roadway segments captured on videotape and rate these segment with respect to how satisfied they would be riding a bicycle under the roadway conditions shown on the videos. They did not calibrate their video-based findings to bicyclists riding on the roadways, and they only validated viewpoints from still-standing respondents, i.e., not obtaining realistic perspectives of bicyclists. In this paper, the survey directly obtained the level of service perceptions of actual bicyclists making real trips. Surveyors stopped cyclists mid-trip and immediately conducted oral interviews with them. The bicyclists share the road with pedestrians in general so that the bicycle speed is not high in Korea. Thus, the surveys were able to be conducted in an actual trip-making situation.

Additionally, Harkey *et al.* (1998) developed the Bicycle Compatibility Index (BCI), which was designed to evaluate the ability of urban and suburban roadways to accommodate both motor vehicles and bicyclists. The geometric and operational variables

Table 1. KHCM Bicycle LOS Measures Classified by Bicycle Road Type

Bicycle Road Type	Measure
Exclusive off-street bicycle paths	Frequency of encounters
Shared off-street paths	
On-street bicycle lanes	
Signalized intersections	Average control delay
On-street bicycle lanes on urban street	Average bicycle speed

collected in the field or from the video clips and incorporated into the regression modeling included the number of lanes, directions of travel, bicycle lane width, and traffic volume. The bicycle level of service model in this paper was developed by considering variables that related to pedestrian because the most common bicycle road type in South Korea is generally the shared off-street path.

Petritsch *et al*. (2005) created a method that could be used to rate entire arterial sections for the bicycle mode. In the studies of Petrish *et al*. (2005) and Landis *et al*. (2003), data for the new Bicycle LOS for Arterials model were obtained from the innovative “Ride for Science” field data collection event and video simulations of the FDOT. 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 Korean Highway Capacity Manual (KHCM) provides a bicycle LOS measure according to the bicycle road type (Table 1). Only one measure was estimated at a time in the bicycle LOS with a 6-level LOS structure in South Korea; various factors are not considered simultaneously. In this research, the model was developed by considering multiple factors reflecting the situation in Korea. In addition, the bicycle LOS was determined using a 3-level LOS structure from the user’s perspective.

3. Research Methodology

3.1 The MOE for Bicycle LOS

The existing bicycle LOS in the KHCM (Korean Highway Capacity Manual) is estimated by only one measure at a time, such as average travel speed, average control delay and frequency of encounters. In addition, the MOE for an arterial road is an average travel speed and average length of delay. It is reasonable that the LOS for an arterial road be defined by the speed and delay because rapid mobility should be verified using vehicles. Speed is a major concern for drivers, as related to service quality. In addition, the delay incurred by drivers is used to define the level of service for signalized intersections because it reflects drivers discomfort, frustration, energy consumption, and travel time. However, the primary purpose of a bicycle is not rapid mobility. In Korea, bicycles are not defined as vehicles. It is dangerous to share the road with vehicles. Usually, bicycles share the sidewalk with pedestrians in Korea. In other words, the existing MOE for bicycle roads did not consider the bicyclists’ perspectives and bicycle characteristics. It was defined from the operator’s point of view.

The MOE for a bicycle road is defined as a bicyclist satisfaction score in this paper. The bicycle LOS represents the level of satisfaction that a bicyclist would experience while riding on a bicycle road. Therefore, the identification of parking (bicycle racks) cannot be involved as a factor in LOS. It does not make sense that LOS, a qualitative measure used to describe the characteristics of travel, would have a parking-related parameter.

3.2 The Model

The bicycle LOS model was developed using an ordered probit model. The objective of this research was to capture the users' perceptions using a survey in which bicyclists expressed their preference with an ordinal ranking. The bicyclist satisfaction scores of actual travelers were obtained directly. The interviews for the surveys were conducted on the path with actual bicyclists. The bicyclists evaluated their level of satisfaction using a six-point scoring system.

According to the “Multimodal Level of Service Analysis for Urban Streets, NCHRP 3-70”, which states that “The 6-letter grade A-F level of service structure of the Highway Capacity Manual (HCM) has been preserved. Many of the statistical results suggest that people can actually distinguish only 2 or 3 levels of service. However, public agency planners and engineers need to be able to predict how close a facility is to an unacceptable level of service. So the 6 levels have been retained for agency planning purposes, rather than because people actually can distinguish between them. Also, the 6-letter grade (A-F) level of service structure of the Korean Highway Capacity Manual (KHCM) was preserved. A questionnaire with 6 levels of satisfaction was created to develop model 1 and model 2 at the same time for comparison.

The existing 6-level LOS scope was applied to model 1 and model 2 developed with 3 levels from the user’s perspective.

In this research, the model was developed from the user’s perspective to enable the three-level (A-C) LOS structure to be applicable to bicycles by considering the satisfaction levels that people can distinguish clearly. Although the six levels of service (graded A-F) are typically used for auto, transit, and pedestrian modes, there is a possibility that three levels of service (A-C) can be developed that would be suitable for the bicycle mode, given the level of utilization and facility size in South Korea. Therefore, the model was developed according to bicyclist’s satisfaction scope in Table 2.

In a typical regression, the difference between y=1 and y=2 was defined as the same as the difference between y=2 and y=3.

Table 2. Comparison Model according to Bicyclist’s Satisfaction Scope

Model	Bicyclist Satisfaction Scope	LOS
Model 1	Very satisfied (1) ~ Very dissatisfied (6)	A~F
Model 2	Satisfied (1), Fair (2), Dissatisfied (3)	A~C
Model 3	Satisfied (1), Fair (2), Dissatisfied (3)	A~C (Considering bicycle road type)

However, if the variables are ordered from "satisfied (y=1)" to "dissatisfied (y=3)" with an ordinal variable, then someone who scored "satisfied (y=1)" might have more satisfaction than someone who scored "dissatisfied (y=3)," but precisely how much more cannot be determined. Thus, OLS regression seems less desirable in this paper.

Ordered logit and probit models are used in cases in which the dependent variable in question consists of a set numbers (more than two) of categories that can be ordered in a meaningful way (e.g., opinion surveys with responses ranging from "strongly agree" to "strongly disagree"), while multinomial logit is used when there is no apparent order (e.g., the choice of car, bus, or rail to take to work). The ordered probit model was used with responses ranging from "very satisfied" to "very dissatisfied". When it is not clear if the categories are ordered or sequentially in the response, multinomial logit models should be used (Liao, 1994).

The results and interpretations of the ordered logit and ordered probit model were notably similar. However, these models differed in their error distribution. In an ordered probit model, it is assumed that the error term is normally distributed with a mean of 0 and a variance of 1. In an ordered logit model, the random error is assumed to follow a Gumble distribution. The logit model is preferred to the probit model because it has a closed form of its likelihood; thus, in the past, when computing power was low, having a closed form provided a large advantage for model estimation, which is related to computational effort. The choice between logit and probit specifications is typically an analyst's preference because, with the current computing power, computational efforts are negligible in most cases, and only the threshold estimates would be shifted, which does not influence conclusions drawn from the model's results.

The bicycle LOS model was established using LIMDEP (limited dependent variables). The ordered probit model was based on the following specifications:

$$\begin{aligned} &y_i^* = \beta X_i + \varepsilon_i\,,\ \varepsilon_i \sim N[0,1] \\ &y_i = 0\,,\ y_i^* \le 0 \\ &y_i = 1\,,\ \text{if } 0 < y_i^* \le \mu_1 \\ &y_i = 2\,,\ \text{if } \mu_1 < y_i^* \le \mu_2 \\ &\cdots \\ &y_i = J\,,\ \text{if } y_i^* \le \mu_{J-1} \end{aligned} \tag{1}$$

It was assumed that y_i takes on one of the values 0, 1, 2, ..., J, depending on the value of y_i^*, where X_i is a vector of variables determining the discrete ordering for observation i, β is a vector of estimable parameters, and ε_i is a random error. In this analysis, y is defined as each bicyclist's satisfaction, while the μ values represent thresholds to be estimated along with the model parameters (β). The resulting ordered probit model has the following probabilities corresponding to each ranking:

$$\begin{aligned} &prob(y_i = o) = \Phi(-\beta X_n) \\ &prob(y_i = 1) = \Phi(\mu_1 - \beta X_n) - \Phi(-\beta X_n) \\ &prob(y_i = 2) = \Phi(\mu_2 - \beta X_n) - \Phi(\mu_1 - \beta X_n) \\ &\cdots \\ &prob(y_i = J) = 1 - \Phi(\mu_{J-1} - \beta X_n) \end{aligned} \tag{2}$$

where Φ is the normal cumulative function.

The marginal effects can be derived simply as follows:

$$\begin{aligned} &\frac{\partial[p(y_i = o)]}{\partial(x_i)} = -\Phi(k_1 - x'_i\beta)\beta \\ &\frac{\partial[p(y_i = 1)]}{\partial(x_i)} = -[\Phi(k_2 - x'_i\beta) - \Phi(k_1 - x'_i\beta)]\beta \\ &\cdots \\ &\frac{\partial[p(y_i = j)]}{\partial(x_i)} = \Phi(k_J - x'_i\beta)\beta \end{aligned} \tag{3}$$

A pseudo R-square value (called rho-squared, ρ^2) is calculated. The R-square is used as an indicator of the "goodness of fit." Generally speaking, an R-square (percentage of total variance) that is close to 1 is an indication that the data fits the model well. Higher R-square values indicate a better-fitted model. Multivariate analysis involving social science data typically results in R-square values ranging from 0.1 to 0.5 (Lattin *et al*., 2003). In this study, McFadden's R^2 was used as the likelihood-ratio index. It compares the likelihood for the intercept only model to the likelihood for the model with the predictors. McFadden's R^2 can be as low as zero but can never equal one.

$$R^2_{McF} = 1 - \frac{\ln L(M_{full})}{\ln L(M_{int})} \tag{4}$$

M_{full}: Model with predictors
M_{int}: Model without predictors
L: Likelihood value of an estimated model.

4. Data Source

A field survey was conducted at four locations: Ya-Top and Su-Won, which are classified as shared off-street paths, and Tan-Stream and Jung-Ang, which are exclusive off-street bicycle paths. These are near or at train stations, except for Tan-stream.

The MLTM (Ministry of Land Transport and Maritime Affairs) of Korea classifies the type of bicycle road by function, cross section, trip purpose, and form of use. The survey was conducted on an arterial bicycle road, and the type of bicycle road was classified by trip purpose through reference to the "Bicycle road facility standards and managements manual, 2009, MLTM". Therefore, the Tan-Stream bicycle paths were classified as leisure bicycle roads, and the others were classified as non-leisure (e.g.,

Table 3. Outline of Survey

Site	Bicycle road type	No. of response	Date
Ya-Top	Non-leisure	50	2008.5.8(Thur.)
Tan-Stream	Leisure	90	2008.5.8(Thur.)
Su-Won	Non-leisure	30	2008.5.7(Wed.)
Jung-Ang	Non-leisure	28	2008.4.3(Thur.)

commute, business, or shopping).

An outline of the survey is presented in Table 3. It was conducted on clear weekdays because there were many bicyclists. A total of 198 people were surveyed.

Figure 1 depicts the number of respondents for each satisfaction score ranging from 1 to 6. “1” means very satisfied, and “6” is very dissatisfied. However, the data were accepted from 0 using LIMDEP (limited dependent variables). Thus, the model was developed with score ranges from 0 to 5 in the analysis process. Survey results indicate that the majority bicyclists gave a score of 1~3, indicating that they were moderately satisfied with their trip.

The descriptions of the variables are shown in Table 4. To reflect multiple factors, the characteristics of facilities, operations, intersections, and safety were considered. The data for the physical facilities were investigated in the field. In addition, the volume of bicycle and pedestrian traffic and the number of encounters were counted every 15 min in the field.

The number of encounters indicates that a bicyclist encountered a bicyclist or a pedestrian traveling in the opposite direction. The number of overtaking means that a bicyclist passed by a bicyclist or pedestrian traveling in the same direction.

To reflect the characteristics of intersections, the intersection crossing distance and total number of lanes on the approach to the intersection were considered. If there were many vehicle lanes, then bicyclists tend to feel a fear of vehicles. In addition, long intersection crossing distances lead to a long time period for the bicyclists to cross the street.

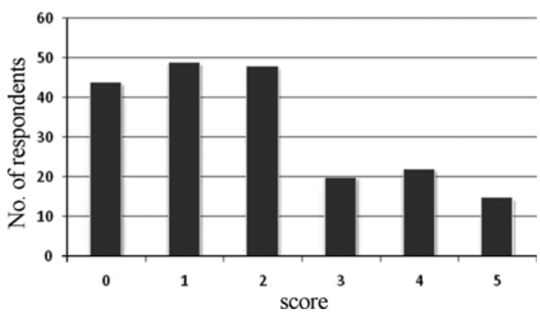

Fig. 1. Bicyclist Survey Results

The number of access and egress points on the bicycle road corridor within 1 km is a variable that represents the bicycle road safety because the increased number of access and egress points can explain the increased conflict and thus the decreased level of service. Therefore, the model was developed to determine the effect of these variables. The model was estimated using the 198 observations with relatively homogenous personal characteristics. Descriptive statistics are listed in Table 4.

5. Research Results and Discussion

5.1 Model 1(LOS: A~F)

The bicycle LOS model was developed by taking multiple factors into consideration. The results of the analysis using the ordered probit model are presented in Table 5. The results show that the bicycle road width, the total number of vehicle lanes on the approach to the intersection, the number of access and egress points on the bicycle road corridor, the pedestrian volume and the number of encounters are statistically significant factors for the bicycle LOS. The bicycle LOS scores approach “LOS A” with the increasing width of the bicycle road. However, the scores approach “LOS F” with increases in other variables.

Bicycle volume was excluded from the estimated model because there were not many bicycles compared with the other modes of transportation in South Korea. In other words, bicyclists evaluated level of service not using the bicycle volume but rather the design of the facilities, such as the width of the bicycle road.

Most bicyclists in the US share the roadway with vehicle traffic. Thus, the variables that relate to vehicles are taken into account in the estimation of the bicycle LOS. However, in Korea, most bicyclists share the sidewalk with pedestrians because the bicycle road type is generally a shared off-street path. Therefore, variables that relate to pedestrians were considered to reflect Korean bicycle road conditions in establishing the bicycle LOS model. The first model had a rho-square value of 0.0722. Using

Table 4. Descriptions of Variables and Basic Statistics

Variable			Unit	Min	Max	Ave.	SD
Dependent variable	Bicyclist’s satisfaction		0~5 score	0	5	1.9	1.5
Independent variable	Facility Characteristic	Bicycle road width	Meters	1.3	3.5	2.7	0.7
		Sidewalk width on shared off-street paths	Meters	0	8.5	2.7	3.6
		Bicycle road type (by trip purpose)	Leisure : 1 Non-Leisure : 0	0	1	0.6	0.5
	Operation Characteristic	Bicycle volume	Bicycles/15 min	1	72	23.1	21.5
		Pedestrian volume on shared off-street paths	Pedestrians/15 min	0	148	33.3	46.2
		The number of encounters	Encounters/15 min	0	100	35.7	30.7
		The number of overtaking	Overtaking/15 min	0	34	6.9	7.1
	Intersection Characteristic	Intersection crossing distance	Meters	8	35	15.4	10.4
		Total number of lanes on the approach to the intersection	Lanes	1	5	2.6	1.4
	Safety Characteristic	The number of access and egress point on the bicycle road corridor	Point/1 km	2	8	6.1	2.1

Table 5. Bicycle LOS Model Estimation Result (Model 1)

Model terms	Parameter	t-statistic	S.E.	p-value
Constant	2.4040	5.162	0.4657	0.0000
Bicycle road width	-0.7507	-6.019	0.1247	0.0000
Total number of lanes on the approach to the intersection	0.1162	1.530	0.0759	0.1259
Pedestrian volume	0.0063	3.457	0.0018	0.0005
The number of encounters	0.0012	0.333	0.0035	0.7388
Threshold value				
μ_1	0.7504	9.290	0.0808	0.0000
μ_2	1.4914	15.419	0.0967	0.0000
μ_3	1.8976	17.275	0.1098	0.0000
μ_4	2.5674	16.926	0.1517	0.0000
Number of observations	198			
LL(0)	-335.5174			
LL(β)	-311.2972			
ρ^2	0.0722			

Table 6. Bicycle LOS Score Criteria (Model 1)

Level of Service	Score*
A	≤ 0
B	>0 and ≤ 0.75
C	>0.75 and ≤ 1.49
D	>1.49 and ≤ 1.90
E	>1.90 and ≤ 2.57
F	> 2.57

*The score is a model predicted value not user’s response.

the calculated threshold values in Table 5, the bicycle LOS score criteria are given in Table 6.

5.2 Model 2 (LOS: A~C)

A second model was developed by mapping user satisfaction onto the three levels that people can distinguish clearly (satisfied, fair, and dissatisfied). This model led to a rho-square higher than that of the six-level LOS structure. However, a high rho-square value does not always indicate a good model. Thus, the three-level LOS structure is a possibility. In addition, this study was not attempted from an engineering perspective (existing structure: A-F) but from the user’s perspective (new structure: A-C).

Table 7 shows the results of the second model. On the one hand, the bicycle LOS score approaches “LOS A” as the bicycle road width increases. On the other hand, it approaches “LOS F” as the total number of vehicle lanes on the approach to the intersection, the number of access and egress points on the bicycle road corridor, the pedestrian volume, and the number of encounters increase. The rho-square value is 0.1085.

The results show that bicycle road width is the statistically significant factor for bicyclist satisfaction and that the total number of vehicle lanes on the approach to the intersection, the number of access and egress points on the bicycle road corridor, the pedestrian volume and the number of encounters (opposite direction) are also statistically significant factors in determining the bicycle LOS.

The bicycle LOS score criteria using the calculated threshold

Table 7. Bicycle LOS Model Estimation Results (Model 2)

Model terms	Parameter	t-statistic	Standard error	p-value
Constant	1.8903	2.982	0.6338	0.0029
Bicycle road width	-0.8424	-2.614	0.3222	0.0089
Total number of lanes on the approach to the intersection	0.0988	0.975	0.1013	0.3295
The number of access and egress point on the bicycle road corridor	0.0079	0.054	0.1460	0.9567
Pedestrian volume	0.0055	1.017	0.0054	0.3091
The number of encounters	0.0019	0.467	0.0040	0.6402
Threshold value				
μ_1	1.1356	9.436	0.1203	0.0000
Number of observations	198			
LL(0)	-205.0146			
LL(β)	-182.7684			
ρ^2	0.1085			

Table 8. Bicycle LOS Score Criteria (Model 2)

Level of Service	Score*
A	≤0
B	>0 and ≤1.14
C	>1.14

*The score is a model predicted value not user’s response.

values are in Table 8. In the second model, bicyclist satisfaction was classified into a three-level scoring system: satisfied (1), fair (2), and dissatisfied (3). Consequently, the criteria of the bicycle LOS were marked by three designations (LOS A through LOS C).

5.3 Model 3 (LOS: A~C, Considering bicycle road type)

Model 3 was developed by considering the bicycle road type. Model 3 was also defined with three levels of service. The type of bicycle road was classified as a leisure bicycle road or as non-leisure (e.g., commute, business, or shopping).

Survey results are presented by trip purpose in Fig. 2. In the case of a leisure bicycle road, 13% of the respondents chose “dissatisfied”, 41% chose “fair”, and 46% chose “satisfied”. In the case of non-leisure bicycle roads, 27% of the respondents chose “dissatisfied”, 36% chose “fair”, and 37% chose “satisfied”. The users of leisure bicycle roads revealed higher satisfaction compared with those using non-leisure roads. The users of non-leisure bicycle roads responded with a higher rate of “dissatisfied” compared

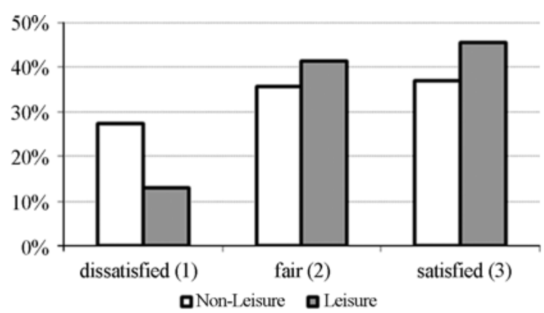

Fig. 2. Bicyclist Satisfaction Score Rate Classified by Trip Purpose

with users of leisure roads.

The bicyclist satisfaction was influenced by the type of bicycle road. In reality, it is true that a leisure bicycle road features relatively better operation and facilities than a non-leisure bicycle road in Korea. Therefore, the third model was developed by considering the bicycle road type. The Tan-Stream bicycle paths were classified as leisure bicycle roads, and the others were classified as non-leisure (e.g., commute, business, or shopping).

The correlation was estimated by the value of the coefficient r (below 0.4 indicates weak, from 0.4 to 0.7 indicates average, and above 0.7 indicates a strong correlation). There is a strong correlation between the bicycle road type and the pedestrian volume with a correlation coefficient equal to -0.8776, as well as between the bicycle road type and the number of access and egress points on the corridor, exhibiting a correlation coefficient that equals 0.8451. To consider the type of bicycle road in Model 3, the two variables indicating a strong correlation were excluded.

Table 9 shows the estimated results of the third model. The bicycle LOS score approaches "LOS A" as the bicycle road width increases and in the case of the leisure bicycle road. However, it approaches "LOS F" as the total number of lanes on the approach to the intersection and the number of encounters increases.

The rho-square value is 0.1060. The results show that the bicycle road width is the statistically significant factor for bicyclist satisfaction and that the bicycle road type, the total number of lanes on the approach to the intersection, and the number of encounters (in the opposite direction) are also statistically significant factors in determining the bicycle LOS.

As an analysis result, the bicycle LOS was affected by the bicycle road width. Korea built a vehicle-oriented transportation system because of limited land space. In most cases, the bicycle roads exist as part of the sidewalk, causing the bicyclists to feel uncomfortable, due to the narrow width.

The parameter of the bicycle road width was estimated in the range of 1.3 to 3.5 m. In this research, the data was collected in specific locations, so the model was limited to the surveyed case. If the width is wider than a certain value, then it does not positively contribute to the LOS; therefore, research will need to be conducted to find a certain value to develop the general model.

The bicycle road type influences the bicycle LOS. The bicycle LOS score approaches "LOS A" in the case of leisure bicycle roads because a leisure bicycle road is relatively better than non-leisure bicycle roads in terms of operation and facilities in Korea.

The number of lanes on the approach to the intersection is a variable reflecting characteristic of the intersection. If there are many vehicle lanes, then bicyclists experience a fear of vehicles. Thus, the level of service will decrease.

The number of encounters means the number of times that a bicyclist encounters a bicyclist or pedestrian from the opposite direction. The number of encounters has the smallest effect on the bicycle LOS.

An interpretation of the results was attempted with a marginal effect. The impact of a continuous explanatory variable on the probabilities of obtaining different satisfaction levels can be evaluated by taking the partial derivative of equations. Table 10 reports the marginal effects that an increase of one unit of the explanatory variable has on the letter grades of LOS.

Table 10 indicates that if the "Bicycle road width" increases by one unit, the probability of obtaining the best grade (A) increases by 27.71%, while the chances of receiving the grades "B" and "C" decrease by 10.77% and 16.94%, respectively, which shows the strength of the relationship between "Bicycle road width" and the letter grade of LOS compared with the other explanatory variables.

The bicycle LOS score criteria using the calculated threshold values are given in Table 11.

Table 9. Bicycle LOS Model Estimation Results (Model 3)

Model terms	Parameter	t-statistic	Standard error	p-value
Constant	1.9678	3.763	0.5229	0.0002
Bicycle road width	-0.7007	-5.238	0.1338	0.0000
Bicycle road type (Leisure: 1, Non-leisure: 0)	-0.4423	-2.397	0.1845	0.0165
Total number of lanes on the approach to the intersection	0.1044	1.260	0.0829	0.2077
The number of encounters	0.0025	0.643	0.0039	0.5200
Threshold value				
μ_1	1.1317	9.435	0.1199	0.0000
Number of observations	198			
LL(0)	-205.0146			
LL(β)	-183.2881			
ρ^2	0.1060			

Table 10. Impact of Explanatory Variable on Letter Grade of LOS

Letter grade of LOS	Marginal effects			
	Bicycle road width	Bicycle road type	Total number of lanes on the approach to the intersection	The number of encounters
A	0.2771	0.1725	-0.0413	-0.0010
B	-0.1077	-0.0611	0.0161	0.0004
C	-0.1694	-0.1114	0.0252	0.0006

Table 11. Bicycle LOS Score Criteria (Model 3)

Level of Service	Score*
A	≤0
B	>0 and ≤1.13
C	>1.13

*The score is a model predicted value not user's response.

6. Conclusions

The objective of this research was to reflect multiple factors and to capture the users' perceptions using a survey in which bicyclists expressed their preference with an ordinal ranking. The bicycle LOS represents the level of satisfaction that a bicyclist would experience while riding on a bicycle road. Therefore, the MOE for bicycle roads was defined as a bicyclist satisfaction score. The bicyclist satisfaction score reflects the comprehensive evaluation of various elements from the user's perspective.

A three-level (A-C) LOS structure for bicycles could be developed from the user position. It has a rho-square value higher than that of a six-level LOS structure. This study was not attempted from an engineering perspective (existing structure: A-F) but from the user's perspective (new structure: A-C).

Bicycles have the advantages of low cost and environmental and health benefits, but rapid mobility is not guaranteed compared to other vehicles. In other words, bicyclists choose bicycling because it has certain advantages compared with the other modes of transportation. Due to these advantages, bicycles can be used to satisfy the needs of a trip, although bicycles are slightly uncomfortable and even slower than other modes of transportation. Thus, bicyclists determine the level of service depending on their satisfaction with their trip and not by only speed or delay. Using three levels of LOS only for the bicycle roads dose not exactly match with conventional 6-level LOS. However, these problems can be solved by normalizing or weighting the LOS gradations across modes in future studies.

The results from model 3 show that the bicycle LOS is determined by the bicycle road width and that other factors are involved as well, including bicycle road type, total number of lanes on the approach to the intersection, and number of encounters. In particular, the width of the road has a strong relationship on the bicycle LOS by the marginal effect.

The data were collected from shared off-street paths and exclusive off-street paths because they are the most common bicycle road types in South Korea. Although the data were collected from limited locations, the results reflect a general tendency in the bicycle LOS. An attempt was made to interpret the results related to the most important or most influencing factors with a marginal effect. It was found that the bicycle road width is the most influential factor.

The proposed model in this research presents a bicycle LOS evaluation and represents an alternative solution for encouraging bicycling. It is believed that the model will be useful in bicycle network planning, bicycle road and facility alternatives testing, and project funding prioritization. However, it will be possible to use a model for assessing facilities in practice on the assumption that the model is expanded and improved. In addition, alternatives testing is possible for some of the variables, such as road width and road type, but some of the variables cannot be easily collected, such as pedestrian volume and the number of possible alternatives.

Future studies should extend the scope of this study to consider additional factors that influence the bicycle LOS and to identify some of the effects of the factors more clearly. Ordered response does not guarantee the use of ordered response models, and the data must satisfy the proportional odds assumption in future studies.

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