Scientific
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# Bicycle Level of Service Evaluation Method for Urban Road Segment

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## Abstract

As a sustainable mode of transportation, bicycles significantly improve daily mobility. In order to provide theoretics support for improvement of the bicycling environment, this paper proposed bicycle level of service (BLOS) evaluation method for urban road segment according to cyclists' perception. First, influence factors of BLOS were identified from aspects of road facility, traffic characteristics, and environmental condition. Second, bicycling videos were recorded and a satisfaction survey was conducted. Four BLOS evaluation models for different separation facilities were established. Last, bicycling behavioral stages of travelers were divided based on the transtheoretical model. A new BLOS classification criterion was proposed according to travelers' demand of different stages.

## Keywords

Bicycle, Level of Service, Classification Criteria, Behavioral Stage,
The Transtheoretical Model

## 1. Introduction

The bicycle is not only a Green non-polluting transportation mode but also a healthy life mode. With the problems of the traffic jam, environmental pollution and energy shortage are more and more terrible; bicycle transportation has received people's attention all over the world. In order to promote BLOS, many cities in different countries improved bicycling environment these years [1] [2]. Therefore, it is urgent to propose a scientific BLOS evaluation method for urban road segment. It provides theoretics support for improvement of the bicycling environment.

Previous methods of BLOS data collection include three main types: the

intercept survey, field experiment and video survey. Intercept survey means investigator intercepts cyclists and asks their feelings [3]. Field experiment means investigator recruit volunteers to bicycle in specified road segment, and volunteers describe their feelings [4] [5]. Video survey means investigator shoots bicycle videos and recruits volunteers to describe their feelings after seeing the videos [6] [7].

There are some researches about BLOS, such as bicycle safety index rating [8], bicycle street level [9], roadway condition index [10] and bicycle compatibility index [11] [12]. Highway Capacity Manual [13] studied BLOS according to the width of the bicycle lane, car speed, large vehicle flow and so on. Maaza *et al.* [14] considered travelers' tolerance for the bicycling environment and detouring distance and established a level of traffic stress to describe the quality of the bicycle lane. Davis [8] proposed bicycle safety index rating which established the relationship model between road factors and bicycle travel. This method divided bicycle safety index for four levels. Harkey *et al.* [11] consider the bicycle lane, traffic flow, speed and so on, and used bicycle compatibility index model to describe the safety and comfort of the bicycling environment. Dai *et al.* [15] added the factor of illegal car parking to optimize bicycle compatibility index model.

Previous studies about BOLS mainly considered speed, density and some other factors about transportation efficiency. These studies neglected the demand difference for different travelers, especially for travelers of different bicycling behavioral stages. Therefore, it is necessary to propose a scientific BLOS evaluation method for urban road segment which considered the different demand of travelers of different bicycling behavioral stages.

First, this paper analyzed the influence factors in three aspects, including road facility, traffic characteristics, and environmental condition. Second, bicycling videos were recorded and a satisfaction survey was conducted. These surveys provided data which used to establish models. Third, four BLOS evaluation models for different separation facilities were established. Last, travelers were divided into five clusters according to their bicycling behavioral stages. A new BLOS classification criterion was proposed based on travelers' demand of different bicycling behavioral stages.

## 2. Data and Methods

### 2.1. Analysis of Influence Factors

The bicycle is a transportation mode which the traveler direct exposes to the external environment. BLOS is mainly influenced by travel environment. Based on the bicycle transportation investigation in Beijing, China, the influence factors were divided into three types according to travelers' demand for safety, convenience, and comfort, including road facility, traffic characteristics, and environmental condition.

Influence factors of BLOS were listed in Table 1. There are eleven indexes affected BLOS. The type and assignment of every index can be seen in Table 1.

Table 1. Influence factors of BLOS.

| Type | Influence Factors | Assignment | Demand | | |
|---|---|---|---|---|---|
| | | | Safety | Convenience | Comfort |
| Road Facility | $C_1$: Type of Separation Facilities | 1: mixed traffic road<br>2: traffic marking<br>3: guard bar<br>4: green belt/cement pier | √ | √ | |
| | $C_2$: Surface Evenness | 0: uneven<br>1: even | √ | | √ |
| | $C_3$: Effective Width of Bicycle Lane (m) | 1: [0, 1)<br>2: [1, 2)<br>3: [2, 3)<br>4: [3, 4)<br>5: [4, 5) | √ | √ | |
| Traffic Characteristics | $C_4$: Help-move-vehicle Flow (mop/h) | 1: [0, 240)<br>2: [240, 480)<br>3: [480, 720)<br>4: [720, 960] | √ | √ | |
| | $C_5$: Help-move-vehicle Mixed Rate | 1: [0%, 25%)<br>2: [25%, 50%)<br>3: [50%, 75%)<br>4: [75%, 100%] | √ | √ | |
| | $C_6$: Motor Vehicles Flow (veh/h) (near the bicycle lane) | 1: [0, 230)<br>2: [230, 460)<br>3: [460, 690)<br>4: [690, 920] | √ | | √ |
| | $C_7$: Large Vehicle Flow (veh/h) | 1: [0, 105)<br>2: [105, 210)<br>3: [210, 315)<br>4: [315, 420] | | | √ |
| | $C_8$: Proportion of Curb Parking | 1: 0%<br>2: <50%<br>3: ≥50% | √ | √ | |
| Environmental condition | $C_9$: Shade Rate | 1: 0%<br>2: <50%<br>3: ≥50% | | | √ |
| | $C_{10}$: Road Landscape | 1: messy<br>2: tidy<br>3: graceful | | | √ |
| | $C_{11}$: Gradient | 0: flat<br>1: uphill | | √ | √ |

This study collected the influence factors' data of 42 bicycle lanes in Beijing. The data was used as the basis for model establishing.

## 2.2. BLOS Survey

A BLOS survey was conducted using video survey, including bicycle video recording and score of the satisfaction survey.

### 2.2.1. Bicycle Video Recording

Bicycle videos were recorded in 42 different bicycle lanes in Beijing. Selected bicycle lanes covered all kinds of road facility and environmental condition. In terms of road facility, the effective width of the bicycle lane range between 0.8 m and 5.0 m. There are 10 bicycle lanes which segregate cyclists from cars by green belt/cement pier. There are 10 bicycle lanes which segregate by guard bar. There are 11 bicycle lanes which segregate by traffic marking. Other 11 bicycle lanes are mixed traffic road. In terms of environmental condition, there are 19 bicycle lanes whose shade rates are more than 50%, and there are 7 bicycle lanes have no shade. 12 roads are graceful and 20 roads are tidy.

232 bicycle videos were recorded in 42 selected bicycle lanes from 12 May to 19 May 2017. The length of time of these videos is 30 s. In order to cover all kinds of traffic characteristics, 63 bicycle videos were chosen as satisfaction rating video. In terms of traffic characteristics, there are 17 bicycle lanes whose proportions of curb parking are more than 50%, and there are 11 bicycle lanes have no curb parking. Help-move-vehicle mixed rates are between 11% and 92%, motor vehicles flows are between 98 veh/h and 917 veh/h, and large vehicle flows are between 0 veh/h and 416 veh/h.

### 2.2.2. Score of Satisfaction Survey

This study invited 50 volunteers to watch bicycle videos and grade the bicycling environments which were shown by bicycle videos. They were also requested to fill out a questionnaire which included individual characteristics, past and present bicycling condition, future bicycling willingness and acceptance level for the different bicycling environment. Volunteers cover travelers of all ages, include male and female. So volunteers have a certain representation.

The study requested every volunteer watched 42 bicycle videos and rated volunteers on their satisfaction of bicycling environment on a scale of 0 to 100. The total number of valid samples was 2061. Score of satisfaction was divided into 5 levels. Score of satisfaction distribution proportion was shown in Figure 1. It shows a reasonable distribution. Sample size whose score between 40 and 60 is large, and sample size whose score between 0 and 20 is small.
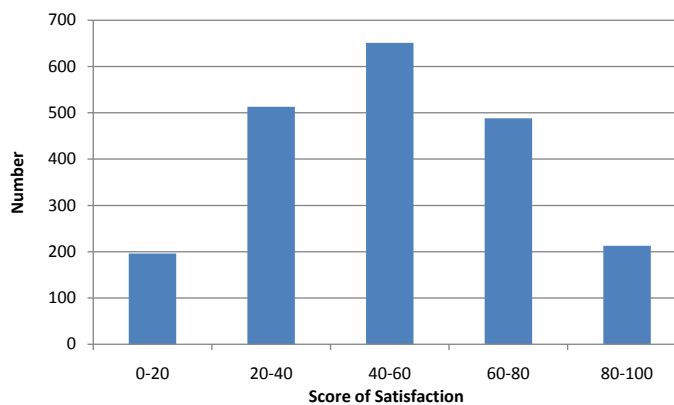


**Figure 1.** Score of satisfaction distribution proportion.

## 2.3. Bicycling Behavioral Stages Classification

The Transtheoretical Model (TTM) describes a process of individual behavior change [16]. TTM proposes that individual behavior change is not a one-time event but a development process. According to TTM, individuals move through the following a series of five stages when changing their behavior:

Pre-contemplation: individuals do not intend to change their behavior in the future.

Contemplation: individuals are thinking about overcoming their behavior, but have made no commitment to take action.

Preparation: individuals intend to take action in the immediate future.

Action: individuals have taken action to modify their behavior.

Maintenance: individuals have sustained an action.

TTM seeks to explain how positive behavior change could be fostered in individuals. Since its inception, the model has been applied to areas of exercise behavior, smoking cessation, alcohol consumption, and contraceptive use [17].

Based on TTM, bicycling behavioral stages of travelers should be divided into 5 stages. Travelers for different stages have different travel demand, so their acceptance levels of the bicycling environment are also different.

## 3. Results and Discussion

### 3.1. BLOS Evaluation Model

BLOS evaluation models used the score of satisfaction as the dependent variables and used influence factors as the independent variable. We removed the low correlation and stronger multicollinearity influence factors and chose key influence factors as the last independent variable by using a parametric test and stepwise regression. The results show that key influence factors for different types of separation facilities have a wide difference. So we established four BLOS evaluation models for different types of separation facilities.

1) BLOS Evaluation Model for green belt and cement pier

$$B_p = 59.224 + 2.653C_3 - 0.112C_5 - 0.510C_7 - 3.136C_8 + 2.742C_9 + 1.903C_{10} \quad (1)$$

where $B_p$ is the score satisfaction for green belt and cement pier, $C_3$ is the effective width of the bicycle lane, $C_5$ is help-move-vehicle mixed rate, $C_7$ is large vehicle flow, $C_8$ is the proportion of curb parking, $C_9$ is shade rate, $C_{10}$ is road landscape.

2) BLOS Evaluation Model for guard bar

$$B_g = 58.044 + 2.303C_3 - 0.084C_5 - 0.569C_6 - 0.666C_7 \\ - 2.992C_8 + 2.341C_9 + 1.603C_{10} \quad (2)$$

where $B_g$ is the score satisfaction for guard bar, $C_6$ is motor vehicles flow (near the bicycle lane).

3) BLOS Evaluation Model for traffic marking

$$B_t = 53.727 + 2.015C_3 - 0.042C_5 - 0.955C_6 - 0.744C_7 \\ - 2.128C_8 + 2.454C_9 + 1.634C_{10} \quad (3)$$

where $B_t$ is the score satisfaction for traffic marking.

4) BLOS Evaluation Model for mixed traffic road

$$B_m = 64.539 - 1.236C_5 - 3.917C_6 - 2.214C_7 - 2.604C_8 + 3.731C_9 + 3.080C_{10} \quad (4)$$

where $B_m$ is the score satisfaction for mixed traffic road.

$R^2$ of these four models is 0.85, 0.86, 0.89 and 0.83 respectively. P of key influence factors are all less than 0.05. The results reach statistical significance.

## 3.2. BLOS Classification Criteria

### 3.2.1. Traveler Classification

Travelers for different bicycling behavioral stages have different travel demand, and their acceptance levels of the bicycling environment are also different. Previous studies on BLOS didn't associate evaluation level with the different demand of different travelers. This study considered the difference of acceptance levels of bicycling environment for travelers in different stages. On this basis, we proposed BLOS classification.

Based on TTM, volunteers were divided into five bicycling behavioral stages of change: Pre-contemplation, Contemplation, Preparation, Action, and Maintenance. The classification is based on individuals' self-reported travel behavior [18], as showed in Table 2.

This study distinguished bicycling behavioral stages of 50 volunteers. The results show that seven volunteers are at the stage of pre-contemplation, six volunteers are at the stage of contemplation, eight volunteers are at the stage of preparation, thirteen volunteers are at the stage of action and sixteen volunteers are at the stage of maintenance. From the results of the questionnaire, travelers in action and maintenance could accept worse bicycling environment, while travelers in pre-contemplation and contemplation could only accept good bicycling environment.

**Table 2.** Survey questions for stages of change classification.

| Survey question | Stages | | | | |
|---|---|---|---|---|---|
| | Pre-contemplation | Contemplation | Preparation | Action | Maintenance |
| Please select which means of transportation you used each day. | Did not bicycle in past week | Did not bicycle in past week | Did not bicycle in past week | Bicycled at least once in past week | Bicycled at least once in past week |
| What mode of transportation do you usually use? | Other | Other | Other | Other | Bicycle |
| Have you thought about bicycling? | No | Yes | Yes | Not asked | Not asked |
| How likely are you to bicycle at least once in the next six months? | Not likely | Somewhat likely | Very likely | Not asked | Not asked |

### 3.2.2. BLOS Classification

BLOS was divided into five levels according to different staged travelers' acceptance for different bicycling environments. The bicycling environment which could be accepted by travelers of all stages is defined as level one, and its BLOS is the highest. The bicycling environment which could be accepted by travelers of preparation, action and maintenance stages is defined as level two, and its BLOS is comparatively high. The bicycling environment which could only be accepted by travelers of action and maintenance stages is defined as level there, and its BLOS is medium. The bicycling environment which could only be accepted by travelers of maintenance stages is defined as level four, and its BLOS is comparatively low. The bicycling environment which couldn't be accepted by travelers of all stages is defined as level five, and its BLOS is low.

We obtained bicycling videos of every BLOS level according to the volunteers' acceptance of bicycling videos. For bicycling videos of each BLOS level, parameters of road facility, traffic characteristics, and environmental condition were put into BLOS evaluation models. Then, the highest score of satisfaction, the lowest score and the average score of every BLOS level were obtained. They were shown in Table 3.

This study classified BLOS level according to the score of every level, it can be seen in Table 4. The bicycle lane whose score of satisfaction was more than 75 was defined as BLOS level one. The bicycle lane whose score of satisfaction was between 70 and 75 was defined as BLOS level two. The bicycle lane whose score of satisfaction was between 60 and 70 was defined as BLOS level three. The bicycle lane whose score of satisfaction was between 50 and 60 was defined as BLOS level four. The bicycle lane whose score of satisfaction was less than 50 was defined as BLOS level five.

**Table 3.** Score of every BLOS level.

| BLOS Level | Highest Score | Lowest Score | Average Score |
| --- | --- | --- | --- |
| Level One | / | / | 76 |
| Level Two | 69 | 74 | 71 |
| Level Three | 59 | 68 | 62 |
| Level Four | 52 | 59 | 56 |
| Level Five | / | / | 48 |

**Table 4.** BLOS classification criteria.

| BLOS Level | Scores Range |
| --- | --- |
| Level One | ≥75 |
| Level Two | 70 - 75 |
| Level Three | 60 - 70 |
| Level Four | 50 - 60 |
| Level Five | ≤50 |

## 4. Conclusions

This paper proposed BLOS evaluation method for urban road segment according to cyclists' perception. It provides theoretics support for improvement of the bicycling environment.

First, influence factors of BLOS were identified from aspects of road facility, traffic characteristics, and environmental condition. These factors can reflect travelers' perception of the bicycling environment. Second, based on bicycling videos recording and a satisfaction survey, four BLOS evaluation models for different separation facilities were established. Last, bicycling behavioral stages of travelers were divided based on the transtheoretical model. A new BLOS classification criterion was proposed according to travelers' demand of different stages.

## Acknowledgements

## References

[1] Greater London Authority (2013) The Mayor's Vision for Cycling in London. Greater London Authority, London.

[2] Stefan, G. (2013) Urban Transport Transitions: Copenhagen, City of Cyclists. *Journal of Transport Geography*, **33**, 196-206.

[3] Transportation Research Board of the National Academies (2010) The Highway Capacity and Quality of Service Manual. National Research Council, Washington DC, 372-392.

[4] Emery, J., Crump, C. and Bors, P. (2003) Reliability and Validity of Two Instruments Designed to Assess the Walking and Bicycling Suitability of Sidewalks and Roads. *American Journal of Heath Promotion*, **18**, 38.
https://doi.org/10.4278/0890-1171-18.1.38

[5] Landis, B.W. (1996) Bicycle System Performance Measures. *Institute of Transportation Engineers*, **66**, 18.

[6] Petristsch, T.A., Landis, B.W., Huang, H.F., *et al.* (2007) Bicycle Level of Service for Arterials. *Journal of the Transportation Research Board*, **2031**, 34.
https://doi.org/10.3141/2031-05

[7] Hunter, W.W., Harkey, D.L., Stewart, J.R., *et al.* (2000) Evaluation of Blue Bike-Lane Treatment in Portland, Oregon. *Journal of the Transportation Research Board*, **1705**, 107. https://doi.org/10.3141/1705-16

[8] Davis, J. (1987) Bicycle Safety Evaluation. Auburn University, City of Chattanooga, and Chattanooga-Hamilton County Regional Planning Commission, Chattanooga.

[9] Sorton, A. and Walsh, T. (1994) Bicycle Stress Level as a Tool to Evaluate Urban and Suburban Bicycle Compatibility. *Transportation Research Record: Journal of the Transportation Research Board*, **1438**, 17-24.

[10] Epperson, B. (1994) Evaluating Suitability of Roadways for Bicycle Use: Toward a Cycling Level-of-Service Standard. *Transportation Research Board: Journal of the Transportation Research Board*, **1438**, 9-16.

[11] Harkey, D.L., Reinfurt, D.W. and Knuiman, M. (1998) Development of the Bicycle Compatibility Index. *Transportation Research Record Journal of Transportation Research Board*, **1636**, 13-20. https://doi.org/10.3141/1636-03

[12] Harkey, D.L., Reinfurt, D.W., Knuiman, M. and Stewart, J.R. (1998) The Bicycle Compatibility Index: A Level of Service Concept. FHWA, Department of Transportation, Washington DC.

[13] Transportation Research Board (2010) TRB 2010 Highway Capacity Manual. Transportation Research Board of National Academies, Washington DC.

[14] Maaza, C., Peter, G. and Hilary, N. (2012) Low-Stress Bicycling and Network Connectivity. Mineta Transportation Institute, San Jose.

[15] Dai, J.F., Zhao, X.L., Lin, J.X. and Li, X. (2015) Level of Service on Urban Bicycle Road. *Journal of Chang'an University: Natural Science Edition*, No. S1, 26-31.

[16] Prochaska, J.O., DiClemente, C.C. and Norcross, J.C. (1992) In Search of How People Change. Applications to Addictive Behaviors. *American Psychologist*, **47**, 1102-1114. https://doi.org/10.1037/0003-066X.47.9.1102

[17] Zimmerman, G., Olsen, C. and Bosworth, M. (2000) A "Stages of Change" Approach to Helping Patients Change Behavior. *American Family Physician*, **61**, 1409-1416.

[18] Thigpen, C.G., Driller, B.K. and Handy, S.L. (2015) Using a Stages of Change Approach to Explore Opportunities for Increasing Bicycle Commuting. *Transportation Research Part D*, **39**, 44-55. https://doi.org/10.1016/j.trd.2015.05.005