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Evaluation Models for Cyclists' Perception Using Probe Bicycle System

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Abstract:
Although bicycles in Japan are widely used for going to school, shopping and so on, satisfaction levels of cyclists for the condition of streets are not high. This is because most bicycle space is shared with pedestrians. The aim of this study is to find evaluation factors from a viewpoint of bicycles' perception by monitoring cycling behavior using a Probe Bicycle System. The Probe Bicycle developed in this study can automatically measure and record speed, braking, steering, lateral distance, and vibration using electric sensors. In addition, apparent traffic density in front of a bicycle can be checked by video recorder. By carrying out experiments on various types of streets in Japan, France and China, the relationship between perception and behavior is analyzed. As a result, the authors developed evaluation models using measurement of braking, vertical vibration, speed, steering and so on.

Keywords: *bicycle street environment, users' perception, Japan, France, China, probe system*

1. INTRODUCTION

Bicycles in Japan are widely used. Bicycle's trip share of the national average in urban areas is 15% for all purpose of trips (MILIT,1999). This is quite a high level compared to other developed countries. Bicycles are commonly used by old people, females, and students as a casual and economical transport mode for shopping, going to school, commuting and so on. On the other hand, satisfaction levels of cyclists for the condition of streets are not high. As a result, average trip distance is less than 1km and average travel speed is less than 10km/h (Owaki, 2009). This is insufficient physical activity to be beneficial for one's health. In addition, most people tend not to have a positive attitude toward bicycle users, because of bad manner of their usage of bicycles, and illegal bicycle parking on sidewalks. Most pedestrians complain of problems with cyclists riding on sidewalks. Although the total number of accidents globally has been decreasing in recent years, the ratio of bicycle accidents has been increasing in Japan (ITARDA,2008). Such situations are caused mainly by lack of bicycle-friendly streets and too much use of shared space for bicycles and pedestrians.

The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and the National Police Agency (NPA) published "Guidelines for creating a safe and comfortable bicycle friendly environment" on November 29th, 2012 (MLIT, NPA (2012)). These guidelines aim to promote local authorities to plan and establish an environment of a network of bicycle friendly streets. A remarkable change in policy appeared in which shared space with pedestrians is not regarded as safe and comfortable bicycle friendly streets, so that bicycle networks should be created mainly by bicycle lane type, and shared space on carriageway. These street types should be selected depending on local traffic conditions, such as vehicle speed and vehicle traffic volume.

In order to promote such an innovative project for Japan, where most people take it for grated that bicycles run on sidewalks, an evaluation system from a viewpoint of bicycles would have a role for effective and rational planning which can evaluate road sections to be treated, and to appraise effects of treatments from the viewpoints of users.

The aim of this study is to build evaluation models from a viewpoint of bicycles' perception by monitoring cycling behavior using the Probe Bicycle System. The Probe Bicycle developed in this study can automatically measure and record speed, braking, steering, lateral distance, and vertical vibration using electric sensors. In addition, apparent traffic density in front of the bicycle can be checked by video recorder images.

The Probe Bicycle is useful because it can obtain a continuous flow of information on various streets. This approach can be employed to evaluate time of day or day-to-day conditions. For example, as it unnecessary to gather detailed information of road and traffic conditions this system uses only bicycle behavior information. In this study, by carrying out experiments on various streets of Japan, France and China, the relationship between perception and behavior indices is analyzed, and evaluation models for cyclists' perceptions were developed using data acquired by the Probe System.

2. LITERATURE REVIEW

To date, many works have been carried out to develop evaluation methods for cycling. Most of them have focused on the relationship of users' perceptions and road/traffic conditions.

The concept of level-of-service is a key term used to describe how well a road is operating for users. According to a review paper by Epperson (1994), Davis (1987) is credited as being the first researcher to attempt to introduce a measuring method of road conditions for cyclists. He proposed two indices for road sections and intersections. It is calibrated using commonly held perceptions of the perceptions from observing people but not real-time user perceptions. Sorton *et al* (1994) developed "bicycle stress level" indices explained with the three "primary variables"; flow, speed of traffic and width of kerb lane. This work did not use actual conditions but rated the conditions of cyclists using video images of road segments. Landis *et al* (1997) developed a bicycle level-of-service (BLOS) considering real-time perceptions. 150 cyclists rode a 27km urban course, divided into 30 segments. The participants evaluated on a six-point scale of how well, safe, or comfortable they felt along each segment. The model proposed by Landis is based on variables of traffic volume of kerbside lane, speed limit, heavy vehicle ratio, crossing way and kerbside parking, pavement surface condition, and effective width of lane.

Guthrie *et al* (2001) also carried out an experiment of cyclists' perception in the UK using Landis' approach. They analyzed cyclists' assessment called "cyclability" along with road and traffic conditions and explained their findings by way of regression models. Although, fitting of the model in terms of measurable conditions was not so accurate. They noted that it was probably due to the consideration of aesthetics and effort in cyclability. The Highway Capacity Manual (1994) described 'level-of-service' for bicycles, which considers factors of speed, travel time, freedom to maneuver, traffic interruptions, comfort, convenience and safety. It is based on Sorton's study but still needs to be improved by using a numerical study and localization for varying street and traffic conditions.

Some researchers focused on the LOS considering junctions. Landis et al. (2003)

developed a model to predict the perceived hazard of cyclists riding through intersections as a function of motor vehicle volume, width of the outside lane, and crossing distance of the intersection. In order to improve on research into the perception of cycling that had hitherto only considered links, Parkin et al. (2007) also used rating method by video clips for combinations of routes and junctions and developed a logistic regression model so that flow passing the cyclist was found to be significant.

Yamanaka *et al* (2007) also developed an evaluation model of level-of-service for bicycles using the Probe Bicycle System, which can obtain 3-axis acceleration, speed, and pedaling power by sensors, and location by GPS. This study proposed the level-of-service index using level of vertical vibration, average speed, variance of speed and average of pedaling power, from experiments only in Japanese streets; shared sidewalks and residential streets without sidewalks.

Measuring method by an instrumented bicycle is also introduced to found factors objective data of bicycle behavior. Parkin and Meyers (2010) used an instrumented bicycle to record motorist passing occurrences on various roads, with or without a bicycle lane, and with different road speed limits, and found the effect of cycle lane. Chuang K.H. et al (2013) used an instrumented bicycle fitted with ultrasonic distance sensors.to analyze bicyclists behavior during passing events, and found weaker lateral stability for buses or longer passing times and smaller lateral distances for motorcycles. They found that a longitudinal solid line results in better effects of lateral distance, wheel angle, and speed control.

3. PROBE BICYCLE

Figure 1. shows the Probe Bicycle developed for this study. The following cycling behaviors are chosen to be collected in order to measure conditions of cycling,

1)Cycling speed 2)Steering 3)Braking 4)Lateral Distance 5)Vibration: vertical acceleration

Figure 1. Probe Bicycle

Speed is obtained from wheel revolutions by using a magnetic sensor attached to the front tire spokes and front right fork. Steering angle can be measured by using string sensor. Braking is checked using a displacement sensor attached to the braking cable. Lateral distance means the distance between bicycle and object existing on the left or right side. This is measured by PSD distance sensor (SHARP GP2Y0A02YK0F). This sensor can measure a distance from 20cm to 150cm using LED. Vibration is measured by motion sensor using a super-thin crystal (MicroStone MA3-04AD), which can acquire ±4G acceleration in three axes. In this study, vertical acceleration is chosen for evaluation as with our previous study (Yamanaka et. al, 2007). The data from these sensors are recorded at 100Hz sampling rate by way of a logger (Race Technology DL1), and are transformed by smoothing method considering the characteristics and precision of sensors in order to calculate indices such as mean, standard deviation, maximum, or minimum of values. Position data is recorded at 10Hz rate because of the ability of GPS embed in the logger.

For the research experiments, the bicycle is also equipped with a video camera recorder to record the actual situation of streets. In this study, apparent traffic density in front of the bicycle is counted from the recorded video clips. A video microphone is used to record cyclists' voice in order to report real-time perception when moving. This is called Protocol Survey in this study.

Because sensing data, video and voice are separately stored in this PROBE system, they are combined by matching their recorded times. GPS position data is used to determine the start and end of segments by referring to speed data as well. This is because accuracy of GPS position data is not sufficient to determine the location in the segments.

4. EXPERIMENTS

4.1 Observed Streets

Street segments with varying conditions were selected for the Probe Bicycle survey, in China (Shanghai, Hangzhou city), France (Toulouse city), and Japan (Takamatsu, Okayama, Osaka and Tokyo) considering the bicycle street type (bicycle track, bicycle lane, shared carriageway, and shared sidewalk), street width, and traffic situation. As a result, 74 segments of 7 cities were studied as shown in Table 1.

The length of street segments ranges from 300m to 700m. 21 road segments are bicycle tracks exclusively for bicycle use, 11 segments are bicycle lane type, 9 segments are shared carriageways, 4 are residential street shared with vehicles and pedestrians, and 29 segments are shared sidewalks. These segments have a bicycle space of 1.5m to 8m wide. Figure 2. shows the examples of observed street segments

4.2 Probe survey

The number of probe bicycle surveys is shown in the Table.1.Young adult cyclists were asked to remember the routes of each district of the city, and to cycle along them as subjects. Except for China, four cyclists ran the routes four times as subjects, in China, six cyclists took part in the experiment including two Chinese students. In Tokyo, subjects ran 6 or 8 times along each route. Six people were involved in total, two people ran all segments, two people ran the segments except Tokyo, and two people ran only France and Tokyo. 74 segments were examined from sixteen to thirty two times; that is a total of 1432 trials were carried out. As there were measuring system errors in some cases, a total of 1164 samples with valid data were used in the analysis.

Table 1. Street segments; bicycle street type and width of bicycle space

Seg No.	City	Tyoe	Width for bicycle(m) Bic. only	carria-geway	side-walk	shared with	One way	Probe run Subjects	Run
Sa1	Shnaghai	B	2.0				○	6	24
Sa2		B	2.5				○	6	24
Sa3		B	3.0				○	6	24
Sa4		B	2.2				○	6	24
Sa5		C		4.5		C	○	6	24
Sa6		B	2.6				○	6	24
Ha1	Hangzhou	B	3.5				○	6	24
Ha2		B	3.5				○	6	24
Ha3		B	4.2				○	6	24
Ha4		B	5.4				○	6	24
Ha5		B	4.5				○	6	24
Ha6		B	3.1				○	6	24
To1	Toulouse	C		3.7		BUS	○	4	16
To2		C		3.2		C	○	4	16
To3		C		5.0		C	○	4	16
To4		L	1.5	3.0			○	4	16
To5		S			3.7	P	○	4	16
To6		L	1.3	3.0			○	4	16
To7		L	1.7	2.9			○	4	16
To8		L	0.9	3.0			○	4	16
To9		C		3.2		C	○	4	16
To10		C		3.5		BUS	○	4	16
To11		L	1.3	3.0			○	4	16
To12		C		3.8		C	○	4	16
To13		B	1.8				○	4	16
To14		S			3.5	P	×	4	16
To15		B	2.0				○	4	16
To16		L	1.2	3.1			○	4	16
To17		C		3.6		C	○	4	16
Ta1	Takamatsu	B	2.0				×	4	16
Ta2		S			4.7	P	×	4	16
Ta3		S			6.3	P	×	4	16
Ta4		S			3.0	P	×	4	16
Ta5		S			3.7	P	×	4	16
Ta6		S			3.1	P	×	4	16
Ta7		C		2.6		C/P	○	4	16
Ta8		S			4.0	P	×	4	16

Seg No.	City	Tyoe	Width for bicycle(m) Bic. only	carria-geway	side-walk	shared with	One way	Probe run Subjects	Run
Ok1	Okayama	B	1.8				×	4	16
Ok2		R		5.1		C/P	○	4	16
Ok3		S	*2.1*		4.7	P	×	4	16
Ok4		S	*2.0*		3.4	P	×	4	16
Ok5		S			2.6	P	×	4	16
Ok6		S			2.6	P	×	4	16
Ok7		S			2.1	P	×	4	16
Ok8		B	2.0				×	4	16
Ok9		B	2.1				×	4	16
Ok10		S			2.2	P	×	4	16
Ok11		S			1.8	P	×	4	16
Os1	Osaka	S			4.9	P	×	4	16
Os2		S			4.5	P	×	4	16
Os3		S			3.7	P	×	4	16
Os4		R		6.3		C/P	○	4	16
Os5		S			4.5	P	×	4	16
Os6		S			6.0	P	×	4	16
Os7		R		5.8		C/P	○	4	16
Os8		C		3.2		C	○	4	16
Os9		C		4.2		C	○	4	16
Os10		S			6.0	P	×	4	16
Os11		B	2.0				×	4	16
Os12		S			3.0	P	×	4	16
Os13		S			3.1	P	×	4	16
Tk1	Tokyo	S			1.9	P	×	4	32
Tk2		S			1.9	P	×	4	32
Tk3		S			1.9	P	×	4	32
Tk4		L	1.4	3.0			○	4	32
Tk5		L	1.4	3.0			○	4	32
Tk6		L	1.4	3.0			○	4	32
Tk7		B	2.0				×	4	24
Tk8		B	2.0				×	4	24
Tk9		R		4.7		C/P	×	4	24
Tk10		S			3.6	P	×	4	24
Tk11		S			2.0	P	×	4	24
Tk12		S			1.7	P	×	4	24
Tk13		B	2.0				×	4	24

Bicycle street type	
B: bicycle track	R: residential street
L: bicycle lane	S: shared sidewalk
C: shared carriageway	

Shared with
C: motor vehicles
P: pedestrians
BUS: bus

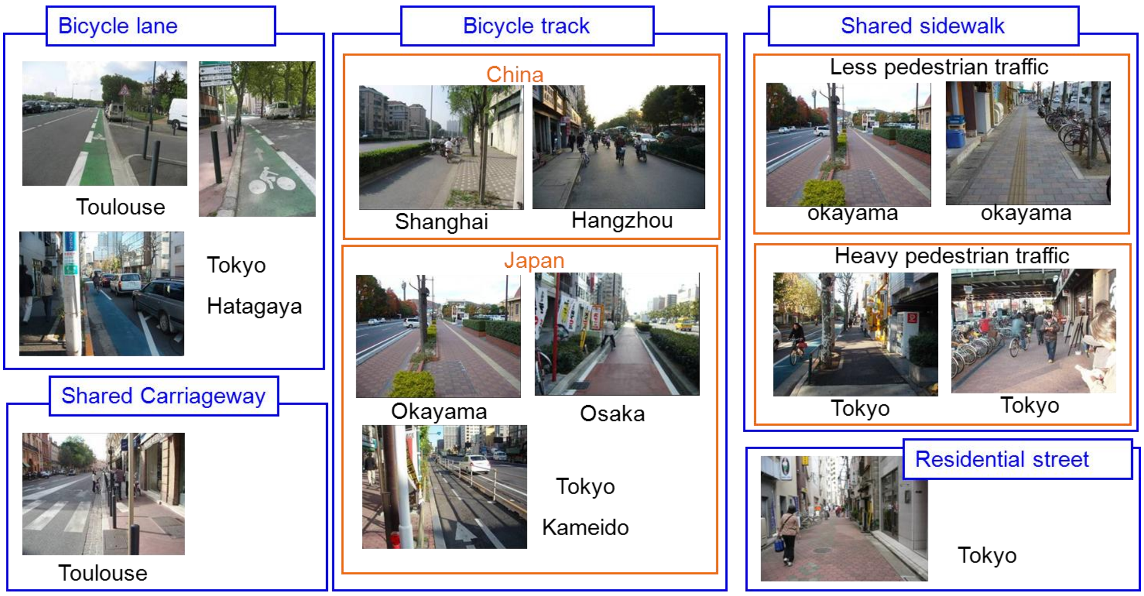

Figure 2. Examples of observed streets

4.3 Traffic situation of observed streets

The traffic situation of observed streets changes not only by segments but also over time. In this study, number of bicycles, pedestrians and motor vehicles present in the space of 10m length within the bicycle running space in front of testers was counted every 4.0 seconds from the records of front-mounted video camera. Motor vehicles beside bicycle lanes were also counted depending on bicycle lane type. The distance from probe bicycle was estimate by using a template of apparent size of people, bicycles, and cars. Apparent traffic density can be estimated from these data, and also traffic flow rate can be estimated by assuming the space mean speed of bicycles, pedestrians and motor vehicles using the well-known equation "Q=KV".

Table 2. shows the average and 85 percentile value of estimated flow rate for country and bicycle space type. The assumed values of speed are shown at the bottom of this figure. Average flow rate of bicycles ranged from 12 to over 1000 per hour. Numbers are especially large in China, and in Japanese bicycle tracks and sidewalks. Average pedestrians' flow ranges 70 to 200, but the 85 percentile value of pedestrians flow rate on Japanese sidewalks reached 600 people per hour. Traffic flow of motor vehicles on the kerbside lane ranges from 1200 to 7000 per hour considering 85 percentile values.

4.4 Protocol survey

In order to obtain real-time perceptions, subjects evaluated their levels related to perceived safety sense and comfort levels of street as shown in Table.3 They spoke into a video microphone every time they passed through each road segment. A five-level scale, as shown Table 3. was used, where a rating score of "1" signifies good condition and a rating score "5" siginifies an unacceptable or dangerous condition.

Table 2. Estimated flow rate of observed streets

		Bicycles		Pedestrians		Motor Vehicles	
Country	Type	Mean	85 percemtile	Mean	85 percemtile	Mean	85 percemtile
China	Bicycle track	934	2452				
	Carriageway	1038	2528			4432	5776
France	Bicycle track	92	537				
	Bicycl lane	106	569			1307	2018
	Carriageway	12	145			3077	4266
	Sidewalk	36	268	76	321		
Japan	Bicycle track	535	1598				
	Bicycl lane	32	250			1255	2045
	Carriageway	238	829			5501	7071
	Sidewalk	439	1375	198	588		
	Residential street	395	1245	81	283	1703	2447
Assumed space mean speed		Bicycle=15km/h Pedestrians=4km/h					Units: per hour
		Motor vehicles=30km/h(residential street) 40km/h(other)					

Table 3. Protocol survey's index and rating scale

	Index	Question	Category for answer, score	
Q1	Safe sense to other traffic	Did you feel danger or near miss to the other traffic ?	1 I felt not at all	4 I felt quite
			2 I did not feel so much	5 I felt much
			3 I felt a little	
Q2	Discomfort on roughness of road surface	Did you feel discomfort on roughness of road surface ?	1 I felt not at all	4 I felt quite
			2 I did not feel so much	5 I felt much
			3 I felt a little	
Q3	Discomfort of narrow bicycle space	Dis you feel discomfort of narrow cycling space ?	1 I felt not at all	4 I felt quite
			2 I did not feel so much	5 I felt much
			3 I felt a little	
Q4	Comfort of cycling speed	Were your cycling speed comfortable?	1 very confortable	4 discomfortable
			2 comfortable	5 very discomfortable
			3 normal	
Q5	Total level of comfort	What was the total level of comfort?	1 very confortable	4 discomfortable
			2 comfortable	5 very discomfortable
			3 normal	

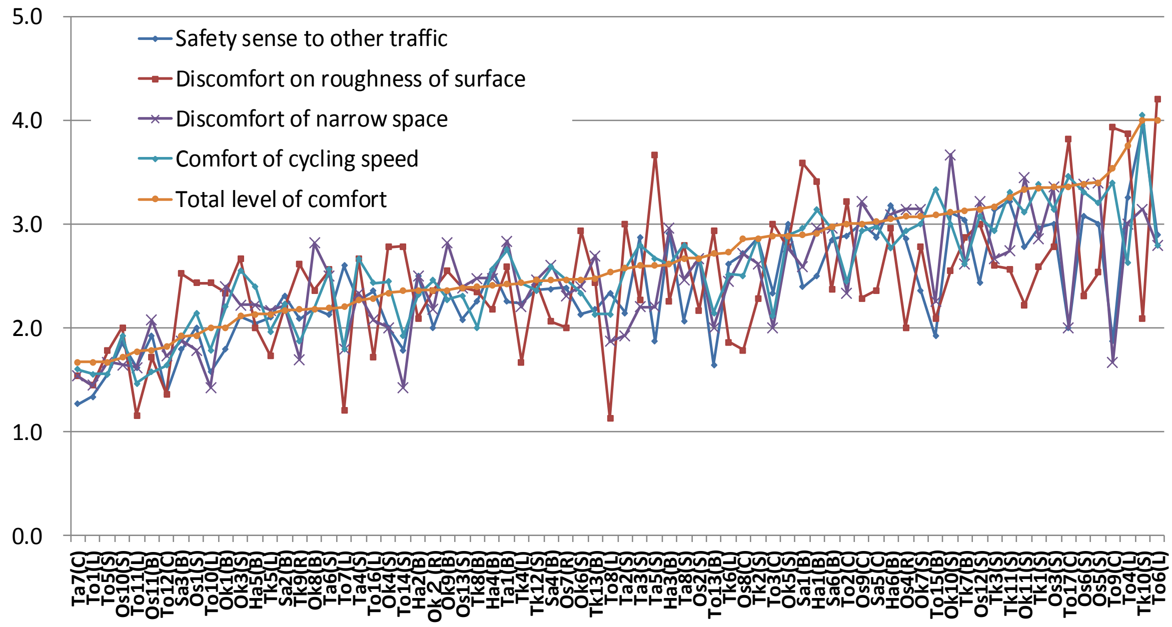

Figure.3 Profile of perceived rating scale for each street segment

Figure 3 shows average perceived scores for each street. From a viewpoint of total level of comfort, street segment To6(L) (bicycle lane in Toulouse) has the best reputation because of having less traffic and a smooth road surface. Ta7(C) (shared carriageway in Takamatsu city of Japan) has the worst score because of having heavy traffic and on-street parking with narrow cycling space. Although there have been no such international comparison of cyclists' evaluation on various type of streets, the tendency that traffic and street space for cyclist effects the comfort level fitted to the results of the previous studies.

5. EVALUATION MODEL OF CYCLISTS' PERCEPTION

5.1 Variables from Probe System observations

The aim of the analysis in this study is to determine key factors which can be obtained from the Probe Bicycle system and can explain cyclists' perception. Data was obtained using the sensors of the Probe Bicycle and apparent traffic density from a front-mounted video camera. They were transformed as variables of each road segment for analysis of the evaluation model of cyclists' perception which was obtained for each road segment.

Variables used for analysis are shown in Table 4. Index of M_TSpd means, for example, the average of travel speed including stopping time at each segment. Because cycling speed at which people desire to run is different from person to person and the street environment also varies, therefore, absolute value of cycling speed would be less significant to explain cyclists' perceptions. The variable of MR_CDSpd, which is a ratio of observed cycling speed to person's desired speed at the street segment, is used to check the possibility to overcome this problem. We assumed that the desired cycling speed is the maximum value for each subject and each city area.

M_ATrd denotes the average of bicycle equivalent space-density. This is estimated from the number of bicycles, vehicles (in case of bicycle lane and shared carriageway) , pedestrians (in case of shared sidewalks) counted from the front-mounted video images. The number of such traffic was transformed into a value of space density using pedestrians' space unit ratio to bicycles (=1/2.5) as shown in Table 4.

Table 4 Variables used for evaluation model of cyclist perception

Variable name		Description ,units
1	M_TSpd	Mean Travel Speed (incl. stop time) km/h
2	M_CSpd	Mean Cycling Speed (excl. stop time) km/h
3	SD_TSpd	Standard deviation of Travel Speed km/h
4	SD_CSpd	Standard deviation of Cycling Speed km/h
5	CV_TSpd	Coefficient of variation by Travel Speed %
6	CV_CSpd	Coefficient of variation by Cycling Speed %
7	MR_CDSpd	Mean ratio of cycling speed to desired speed* %
8	TR_SlowC	Time ratio of slow cycling (<10km/.h) %
9	TR_FastC	Time ratio of fast cycling (>18km/.h) %
10	T_SlowC	Total time of continuous slow cycling sec/100m
11	N_SlowC	Number of continuous slow cycling /100m
12	MT_SlowC	Maxium time of continous slow cycling sec
13	TSTime	Total stop time sec/100m
14	Nstop	Number of Stop /100m
15	MSTime	Maxium stop time sec
16	TR_ACC	Time raio of speed acceleration (>0.02G) %
17	TR_DEC	Time ratio of speed deccelation (<-0.02G) %
18	SD_Sta	Standard deviation of Steering Angle deg
19	TR_ASta	Time ratio of abrupt steering (>1.5deg/0.1sec) %
20	TR_Lsta	Time ratio of large angle steering (10deg/1sec) %
21	TR_05G	Ratio of exprosure time with 0.5G or over vertical vibration %
22	TR_06G	Ratio of exprosure time with 0.6G or over vertical vibration %
23	TR_07G	Ratio of exprosure time with 0.7G or over vertical vibration %
24	TT_05G	Total exprosure time with 0.5G or over vertical vibration sec/100m
25	TT_10G	Total exprosure time with 1.0G or over vertical vibration %
26	TR_BRK	Time ratio of braking %
27	N_BRK	Number of braking /100m
28	TT_BRK	Total time of Braking sec /100m
29	TR_Sobj	Time ratio of short distance to side objects (<1.0m) %
30	M_ATrD	Mean of bicycle equivalent space density** in front /m^2
31	TT_HTrD	Time ratio of M_ATrD > 0.1/m^2 %

*: desired speed : maxmum speed observed for each person adneach city area
**: bicycle equivalent spcae density = (pedestrinans/2.5+bicycles+vehicles)/area
/100m Indices per 100m street distance

5.2 Factor analysis of variables

The analysis approach uses “Factor analysis” and “Correlation analysis“ first to find the relationship between variables. Table 5. shows results of rotated component matrix from the factor analysis. From the component matrix, explanation variables are grouped into six factors. The first factor is related to coefficient of variation and standard deviation of travel speed, slow cycling, and so on. It can be regarded as an indicator of “stability of speed”. The second factor is related to continuous slow cycling, braking, stopping time and so on .It is regarded as an indicator of “stop”. The fifth factor, which is related to space density indices, fast cycling, and so on, can be regarded as an indicator of "density". Table 5. shows the correlation value to the rating score of cyclists perception. Candidate variables for the evaluation models are selected from these results.

5.3 Ordinal Logit Regression Model

The “Ordinal logit regression model” (Norusis, M, J., 2006) is used to develop level-of-service models by selected explanatory variables. This model is defined as follows,

$$prob(score \leq k) = P_{ki} = \frac{1}{1+\exp\left(a_k - \sum_j \beta_j x_{ij}\right)} \quad (1)$$

Table 5. Rotated component matrix of factor analysis
and correlation value to the rating score of cyclists' perception

	Variables	Component of factor						Correlation with pecption score				
		1	2	3	4	5	6	Q1	Q2	Q3	Q4	Q1
5	CV_TSpd	0.94	0.16	−0.05	0.04	−0.11	0.02					
3	SD_TSpd	0.84	−0.04	−0.02	−0.13	−0.02	0.32					
8	TR_SlowC	0.78	0.31	−0.06	0.16	−0.28	0.09	0.20			0.32	0.27
6	CV_CSpd	0.71	0.04	−0.02	0.03	−0.32	0.49	0.21		0.17	0.27	0.23
15	MSTime	0.69	0.00	−0.05	0.05	0.02	−0.24					
4	SD_CSpd	0.66	−0.08	0.03	−0.18	−0.07	0.58					
7	MR_CDSpd	−0.63	−0.18	−0.04	−0.10	0.54	−0.06	−0.18		−0.15	−0.32	−0.26
14	Nstop	0.58	0.16	−0.02	0.04	0.00	−0.16					
11	N_SlowC	0.13	0.95	−0.03	0.04	−0.07	0.02					
27	N_BRK	0.06	0.93	−0.01	0.04	−0.10	0.06					
10	T_SlowC	0.03	0.91	0.01	0.02	−0.14	0.04				0.16	
13	TSTime	0.37	0.83	−0.02	−0.02	0.04	−0.15					
28	TT_BRK	0.02	0.75	0.04	0.13	0.02	0.27					
22	TR_06G	0.00	−0.03	0.96	−0.18	0.10	0.07		0.24			
23	TR_07G	0.01	−0.03	0.96	−0.15	0.09	0.04		0.21			
21	TR_05G	−0.01	−0.03	0.94	−0.22	0.11	0.11		0.27			
25	TT_10G	−0.01	0.00	0.87	0.01	0.03	−0.05					
24	TT_05G	−0.10	0.06	0.48	−0.01	−0.08	0.15					
19	TR_ASta	−0.10	0.04	−0.14	0.88	0.02	0.13					
20	TR_Lsta	−0.11	0.03	−0.14	0.87	0.03	0.10					
18	SD_Sta	0.41	0.20	−0.10	0.66	−0.25	0.22	0.21		0.20	0.28	0.30
29	TR_Sobj	0.08	0.00	−0.07	0.41	0.11	−0.02					
2	M_CSpd	−0.12	−0.14	0.09	−0.49	0.72	0.16	−0.28		−0.21	−0.40	−0.34
31	TT_HTrD	−0.04	0.04	−0.03	−0.31	−0.67	0.15	0.28		0.25	0.31	0.22
1	M_TSpd	−0.43	−0.16	0.11	−0.45	0.64	0.21	−0.24		−0.20	−0.35	−0.30
9	TR_FastC	−0.10	−0.05	0.15	−0.56	0.56	0.33	−0.24		−0.23	−0.36	−0.30
30	M_ATrD	0.13	0.01	−0.05	−0.25	−0.51	0.02	0.15		0.16		
12	MT_SlowC	0.33	0.00	0.03	0.11	−0.39	0.26				0.20	
16	TR_ACC	0.03	0.00	0.15	0.07	0.02	0.81					
17	TR_DEC	0.03	0.08	0.06	−0.02	−0.12	0.72					
26	TR_BRK	−0.02	0.18	0.09	0.16	0.19	0.42					
	contribution (%)	16.36	13.47	12.41	10.71	8.99	8.41	Safe sense to other traffic	Discomfort on roughness	Discomfort of space	Comfort on speed	Total level of comfort
	accumulate (%)	16.36	29.83	42.24	52.95	61.93	70.34					
	Factor description	speed stability	stop	vibration	steering	density	braking					

(Correlation values to the perception score are shown only when the absolute value of them is over 0.10)

where i: individuals k : rating score (1-5)

$P_{k\,i}$: cumulative probability: probability rating score is k or less for individual i

α_k : threshold values for rating score k

β_j : parameters

x_{ij} : explanation variables

Table 6. shows results of model estimation for five indices of cyclists' perception. In developing these models, variables were selected from Factor and Correlation analysis, and results of the Wald value test for variables on the condition that significance is less than 0.05.

5.4 Proposal of Level-of-Service Indices

From these results, level-of-service indices measured by the Probe Bicycle can be defined for the evaluation model of comfort for cycling as follows.

Safe sense to other traffic

$$LOS\_safety = 2.1943(CV\_CSpd) + 0.2761(N\_BRK) + 0.0168(TR\_Sobj) \\ +0.0169(TT\_HTrD) - 0.0101(TR\_FastC) \quad (2)$$

Discomfort on roughness of road surface

$$LOS\_roughness = -0.0139(TR\_SlowC) - 0.0169(MR\_CDSpd) + 0.0618(TR\_05G) \quad (3)$$

Discomfort of narrow bicycle space

$$LOS\_space = 0.1539(SD\_Sta) + 0.0160(TR\_Sobj) \\ +0.0170(TT\_HYrD) - 0.0085(TR\_FastC) \quad (4)$$

Comfort of cycling speed

$$LOS\_speed = -0.0085(MR\_CDSpd) + 0.0025(T\_SlowC) \\ +0.1372(SD\_Sta) + 0.0193(TT\_HTrD) \quad (5)$$

Total level of comfort

$$LOS\_comfort = 0.0222(MR\_CDSpd) + 0.5032(N\_BRK) + 0.0447(TR\_05G) \\ +0.3428(SD\_Sta) - 0.1769(M\_CSpd) + 0.0117(TT\_HTrD) \quad (6)$$

Figure 4 shows the relationship between rating score for cyclists' perception and estimated level-of-service indices using the above functions. Values of indices are transformed into five banded categories by using their means *M* and standard deviations σ. The thresholds between categories are shosen as $M\text{-}\sigma$, M, $M+\sigma$, $M+2\sigma$ considering the distribution of observed perception scores. Appropriate relationships can be validated from these results.

5.5 Comparison of bicycle space type by LOS_comfort

Figure 5. shows a comparison of bicycle space type using the level of comfort index. According to the ratio of level 2 or better, it was found that less than 0.4 of index value, bicycle lane type shows a good evaluation. Shared carriageways in local cities of Japan are also evaluated, but it should be noted that the worst level of LOS also appears at a rate of about 10%.

Shared sidewalks, especially in Tokyo and Osaka, have the lowest evaluation as expected because these cities have many pedestrians. It should be noted that bicycle tracks in Japan do not have such a good evaluation even when compared with bicycle lane type, due to the narrow width of tracks with both directions.

Table 6. Results of Ordinal Logit Models

Model Q1	**Safe sense to other traffic**			
	Varibales	Estimate	Wald	Sig.
Threshold	[Rating = 1.00]	-1.0331	33.2453	0.0000
	[Rating = 2.00]	1.1385	42.5027	0.0000
	[Rating = 3.00]	2.9347	212.0050	0.0000
	[Rating = 4.00]	5.0856	288.6950	0.0000
Location	CV_CSpd	2.1948	8.1083	0.0044
	N_BRK	0.2761	14.9060	0.0001
	TR_Sobj	0.0168	9.6229	0.0019
	TT_HTrD	0.0169	51.8038	0.0000
	TR_FastC	-0.0101	33.7806	0.0000
Over All Model Test		-2 Log Likelihood	Chi-square	Sig.
	Intercept only	2495.6		
	Final	2309.4	186.2	0.0000
Mcfadden R^2			0.0746	
Model Q2	**Discomfort on roughness of road surface**			
	Varibales	Estimate	Wald	Sig.
Threshold	[Rating = 1.00]	-3.4855	104.4536	0.0000
	[Rating = 2.00]	-0.8066	6.2977	0.0121
	[Rating = 3.00]	1.1082	11.5157	0.0007
	[Rating = 4.00]	3.5266	67.5815	0.0000
Location	TR_SlowC	-0.0139	10.7311	0.0011
	MR_CDSpd	-0.0169	20.1592	0.0000
	TR_05G	0.0618	76.8570	0.0000
Over All Model Test		-2 Log Likelihood	Chi-square	Sig.
	Intercept only	2589.4368		
	Final	2504.0212	85.4156	0.0000
Mcfadden R^2			0.0330	
Model Q3	**Discomfort of narrow bicycle space**			
	Varibales	Estimate	Wald	Sig.
Threshold	[Rating = 1.00]	-1.1156	21.4796	0.0000
	[Rating = 2.00]	1.1062	21.9207	0.0000
	[Rating = 3.00]	2.8865	125.6387	0.0000
	[Rating = 4.00]	6.1991	148.1670	0.0000
Location	SD_Sta	0.1539	6.5181	0.0107
	TR_Sobj	0.0160	7.8017	0.0052
	TT_HTrD	0.0170	52.0363	0.0000
	TR_FastC	-0.0085	18.6017	0.0000
Over All Model Test		-2 Log Likelihood	Chi-square	Sig.
	Intercept only	2245.9983		
	Final	2128.9837	117.0146	0.0000
Mcfadden R^2			0.0521	
Model Q4	**Comfort of cycling speed**			
	Varibales	Estimate	Wald	Sig.
Threshold	[Rating = 1.00]	-2.4106	33.1094	0.0000
	[Rating = 2.00]	-0.0359	0.0077	0.9300
	[Rating = 3.00]	1.9029	20.9794	0.0000
	[Rating = 4.00]	4.8460	87.0272	0.0000
Location	MR_CDSpd	-0.0085	4.9673	0.0258
	T_SlowC	0.0025	3.7389	0.0500
	SD_Sta	0.1372	4.8033	0.0284
	TT_HTrD	0.0193	69.6272	0.0000
Over All Model Test		-2 Log Likelihood	Chi-square	Sig.
	Intercept only	2592.1665		
	Final	2379.1216	213.0449	0.0000
Mcfadden R^2			0.0822	
Model Q5	**Total level of comfort**			
	Varibales	Estimate	Wald	Sig.
Threshold	[Rating = 1.00]	-2.4875	20.3143	0.0000
	[Rating = 2.00]	0.5492	1.0562	0.3041
	[Rating = 3.00]	2.3800	19.1786	0.0000
	[Rating = 4.00]	5.2755	71.7955	0.0000
Location	MR_CDSpd	0.0222	17.2319	0.0000
	N_BRK	0.5032	24.4883	0.0000
	TR_05G	0.0447	33.9867	0.0000
	SD_Sta	0.3428	24.3131	0.0000
	M_CSpd	-0.1769	58.0996	0.0000
	TT_HTrD	0.0117	23.0429	0.0000
Over All Model Test		-2 Log Likelihood	Chi-square	Sig.
	Intercept only	2303.1506		
	Final	2080.2542	222.8964	0.0000
Mcfadden R^2			0.0968	

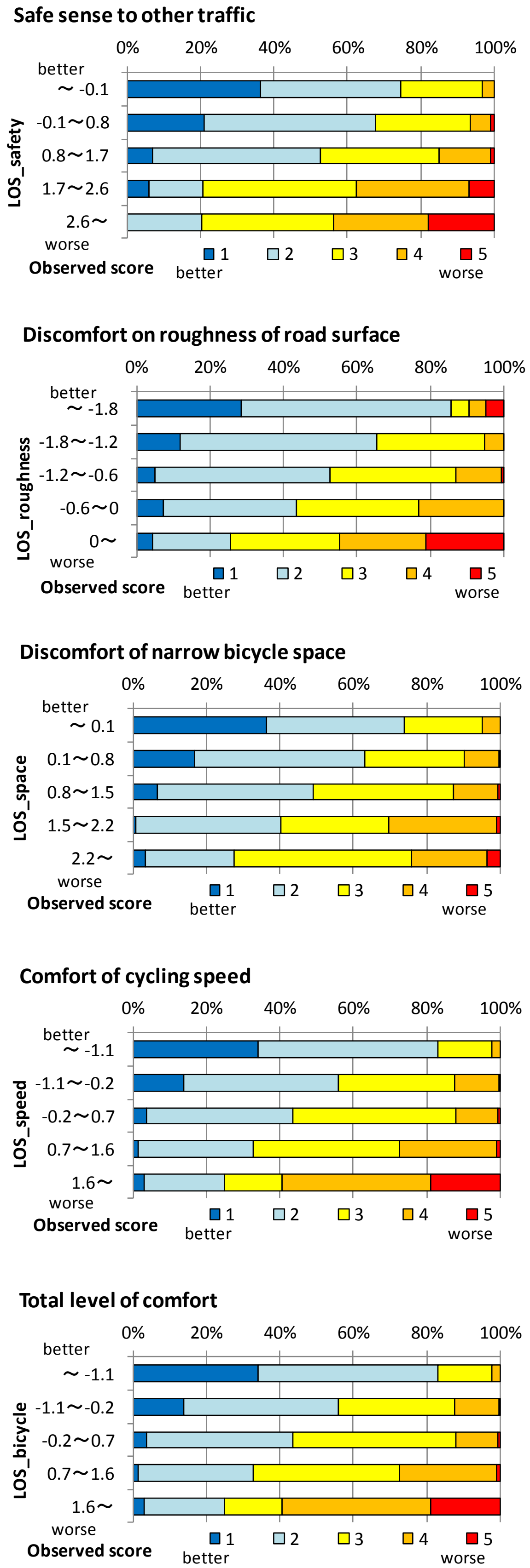

Figure.4 Relationship between LOS index and perceived score

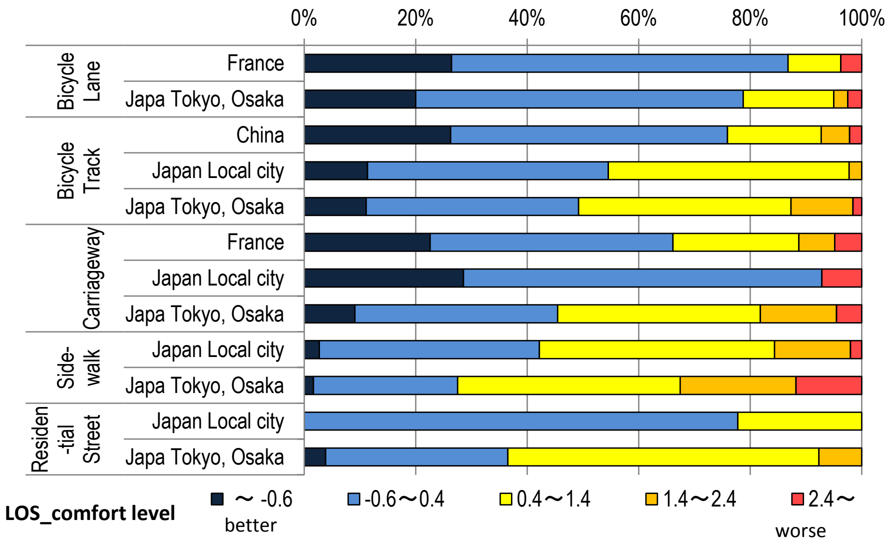

Figure 5. Comfort level by bicycle space type and countries

6. CONCLUSIONS

This study developed the Probe Bicycle System which can provide real-time data of cycling conditions and evaluate cyclists' comfort by using LOS index functions.

LOS indices can be measured from speed of cycling with regard to the desired speed of the cyclist, standard deviation of steering, bicycle vertical vibration level, braking behavior, traffic density in front of cyclist, distance to side objects by using Probe Bicycles.

The evaluation models the author proposed can be used to appraise the present street conditions, and evaluate the schemes such as install of bicycle lane, improvement of road surface, one-way traffic regulations, and so on, using the objective data from Probe Bicycle monitoring.

There remain several things, listed below, to be considered in future research.

1) It is necessary to examine effects directly by cyclists' attributes or abilities, especially elderly people, middle aged females, and young students who are the main bicycle users, since the subjects for cyclists in this study were young adults only (males of 20-24 years old).
2) The relationship between data from Probe Bicycle and that of detailed road/traffic conditions, such as traffic, parking, obstacles on the bicycle space and so on, should be examined,
3) It is necessary for LOS indices to consider variables of other traffic, by improving sensors. For example, the apparent traffic density in front a cyclist is at present measured by a video recorder and is counted manually It may be able to be estimated by scanning laser sensor or such.
4) Conditions of sharing with vehicles for example, at an intersection would be an important factor of bicycling comfort or safety, measuring of cyclists' behavior or conflicts at intersections are future areas for this study.

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