METHOD TO DETERMINE OVERALL LEVEL-OF-SERVICE OF PEDESTRIANS ON SIDEWALKS BASED ON TOTAL UTILITY VALUE *

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1. Introduction

It is necessary to objectively quantify how well roadways accommodate pedestrian travel. Such a measure of walking conditions would greatly aid in roadway cross-sectional design and would help in evaluating and prioritizing the needs for sidewalk retrofit on existing roadways[1]. Estimation of pedestrian level-of-service (LOS) is the most common approach in assessing the quality of pedestrian facilities. Studies on pedestrians have found that there are numerous factors affecting pedestrian LOS[2)−5)]. Although most of the existing methodologies identify the factors affecting pedestrian LOS, many of the factors are not directly included in the computation of LOS. Also these factors are qualitative and can not be measured easily. The Highway Capacity Manual (HCM) 2000 provides LOS analysis for each factor affecting pedestrian facilities[6]. However, the HCM gives relatively little guidance on compiling the LOS of each factor into a measure of overall LOS. Therefore it has been recognized that the pedestrian LOS must be estimated as a function of all factors.

We propose "overall LOS" as an index that combines the factors and indicates an overall value for the pedestrian LOS. Using the value of overall pedestrian LOS, people can understand how well a particular street accommodates pedestrian travel. A conjoint technique is proposed to combine the factors affecting pedestrian LOS[7]. Total utility value from the conjoint analysis represents an "overall value", which specifies how much value a user puts on a product or service. The maximum total utility value indicates the best case, while minimum indicates the worst case. This means that the maximum total utility is the upper limit of overall LOS and the minimum total utility is the lower limit of overall LOS. Therefore an assumption was made that there is a linear relationship between the total utility of a specified sidewalk and overall LOS of that sidewalk. To test this assumption, a validation process was designed and conducted in this research. Validation allows us to compare the results of the proposed method and real-world data. Toward this, pedestrians were surveyed. The scores given by surveyed pedestrians were compared with the total utility values which were calculated from the field measurement data.

2. Methods

(1) Selected Locations

In the city of Sapporo, the area within and surrounding of Hokkaido University is occupied by a considerable number of pedestrians because of sidewalks on both sides of the streets and transit points such as Sapporo railway station, Kita-12 subway station and Kita -18 subway station. Four locations were chosen from the study area which covers Hokkaido University and its peripheries as shown in Figure 1. Each location includes 5 or 6 sidewalk segments. Calculated total utility values of the selected sidewalks are shown in Table1. The first location includes six sidewalk segments. Since this location was near the Kita-12 subway

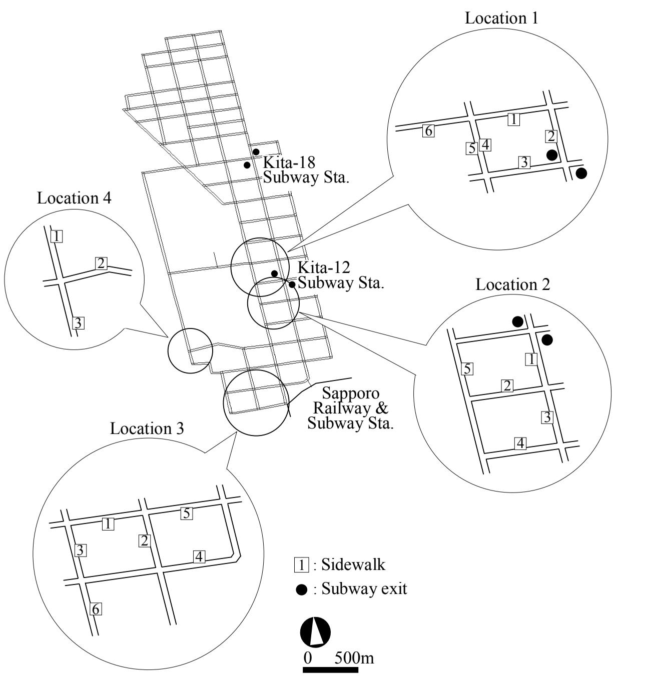

Figure 1 Selected locations for the survey

*Keywords: pedestrians, sidewalks, overall level of service, utility values

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station, a high pedestrian flow rate was observed in the morning rush hour. The second location was adjacent to first location. The field measurements indicated that the overall LOS grades of sidewalk segments had a very wide range at this location. The third location was near to Sapporo railway station. At this location even though the sidewalks are very wide and in excellent condition, field survey showed low LOS grades because of closer interactions among pedestrians. The fourth location was chosen inside the Hokkaido University premises. At this location, the pedestrian environment differs from those at other locations. All the intersections of this location are unsignalized intersections and they are designed to give priority to pedestrians, allowing people to cross at any time without waiting.

Table 1 Total utility values of selected sidewalks

Location	Sidewalk	(1) Width & Separation*				(2) Obstructions**						(3) Flow rate							(4) Bicycle Events		Level				Utility 1	Utility 2	Utility 3	Utility 4	Total Utility
		SW	SH	BZ	OP	P	PB	BP	MV	SD	O	Start time	End time	Ped. ->	Ped. <-	Cyclists ->	Cyclists <-	ped / min / m	Fp	Fm	(1)	(2)	(3)	(4)					
1	1	1.8	0	0.7	2	5	1	2	0	0	0	8:48	8:53	5	0	13	0	10.36	255	0	2	2	1	3	0.15	0.02	1.53	-1.14	4.46
1	2	2.7	0	0.95	1	7	4	2	4	1	0	8:25	8:30	28	7	6	6	9.49	74	123	1	3	1	2	1.36	-0.77	1.53	-0.58	5.44
1	3	3.3	0.4	1	12	4	0	5	2	1	0	8:32	8:37	75	1	25	1	15.65	235	16	1	3	1	3	1.36	-0.77	1.53	-1.14	4.88
1	4	3.5	0	0	0	6	0	5	2	1	0	8:40	8:45	29	5	9	30	10.86	56	309	2	3	1	3	0.15	-0.77	1.53	-1.14	3.67
1	5	3.8	0	0	1	10	1	0	0	1	1	8:50	8:55	1	17	19	6	6.21	108	57	2	3	1	2	0.15	-0.77	1.53	-0.58	4.23
1	6	5.5	1.1	3.4	0	18	0	0	0	0	0	8:16	8:21	0	4	1	11	4.95	10	189	1	3	1	2	1.36	-0.77	1.53	-0.58	5.44
2	1	3.45	0	1.28	1	4	0	0	0	0	0	8:25	8:30	17	5	3	2	3.87	30	33	1	2	1	1	1.36	0.02	1.53	1.72	8.53
2	2	3.2	0.4	1.2	0	8	0	5	2	1	1	8:32	8:37	0	5	1	6	4.71	15	154	1	3	1	2	1.36	-0.77	1.53	-0.58	5.44
2	3	3.5	0	1	2	5	0	0	0	4	1	8:25	8:30	10	10	5	2	5.65	64	42	1	2	1	2	1.36	0.02	1.53	-0.58	6.23
2	4	3.4	0	1	0	4	0	1	1	5	1	8:32	8:37	0	0	9	2	4.89	108	40	1	3	1	2	1.36	-0.77	1.53	-0.58	5.44
2	5	3.3	0	0	0	10	4	1	0	1	1	8:40	8:45	2	5	14	16	11.04	131	250	2	3	1	3	0.15	-0.77	1.53	-1.14	3.67
3	1	1.95	0	1.5	2	5	1	1	1	1	0	8:18	8:23	8	5	12	9	43.11	576	720	1	2	2	3	1.36	0.02	0.04	-1.14	4.18
3	2	3.35	0.4	1.1	1	4	2	0	2	1	0	8:25	8:30	29	8	12	17	24.48	207	490	1	2	2	3	1.36	0.02	0.04	-1.14	4.18
3	3	3.45	0	0	7	8	0	3	1	0	0	8:40	8:45	9	2	6	5	4.15	49	68	1	3	1	2	1.36	-0.77	1.53	-0.58	5.44
3	4	2.2	0.5	0	4	4	84	0	2	7	3	8:37	8:42	190	36	8	2	24.18	79	33	2	3	2	2	0.15	-0.77	0.04	-0.58	2.74
3	5	3.1	1.42	1.4	0	7	1	1	0	1	3	8:20	8:25	16	2	27	10	47.43	833	514	1	3	2	3	1.36	-0.77	0.04	-1.14	3.39
3	6	4.08	0.6	0	0	7	0	0	0	0	1	8:50	8:55	7	4	13	8	4.66	69	71	2	2	1	2	0.15	0.02	1.53	-0.58	5.02
4	1	2.8	1.1	0	0	0	0	0	0	0	0	8:27	8:32	6	3	23	27	14.93	177	347	2	1	1	3	0.15	0.75	1.53	-1.14	5.19
4	2	0.1	0	0	0	0	0	0	0	0	0	8:34	8:39	2	0	2	4	52.00	432	1440	3	1	3	3	-1.52	0.75	-1.57	-1.14	0.42
4	3	2.9	0	0	0	1	0	0	0	0	0	8:27	8:32	6	3	1	1	1.17	7	12	2	2	1	1	0.15	0.02	1.53	1.72	7.32

* SW: Sidewalk (m)
SH: Shoulder (m)
BZ: Buffer zone (m)
On-street parking

** P: Poles
PB: Parked bicycles
BP: Building portions
MV: Mailboxes & vending machines
SD: Store displays
O: Others

(2) Questionnaire Design

Photos of sidewalks were used to make questionnaires and the locations of sidewalks were indicated on maps. Figure 2 shows sample questionnaire sheet used for the survey. Instructions and explanations of LOS were given in the first few pages of questionnaire in order to clarify what was expected from respondents.

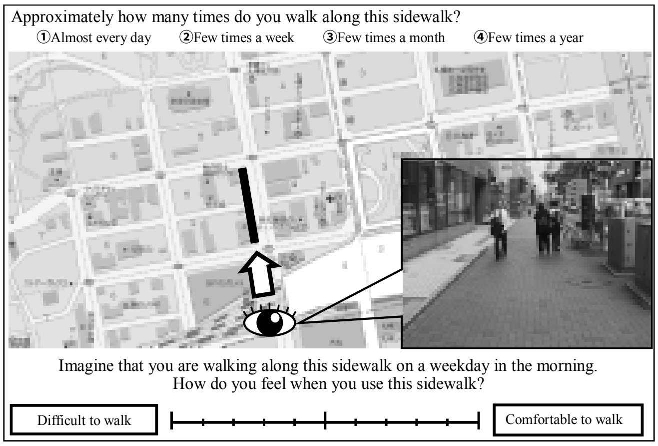

Figure 2 Sample questionnaire sheet used for validation

(3) Survey with Pedestrians

Questionnaires were distributed to the pedestrians walking along the sidewalk. Respondents were requested to record their perceptions on a scale that indicated the ease of walking on that sidewalk. The major advantage of this approach is that perceptions are based on walking and crossing experiences in real situations. Respondents were given enough time to answer the questions. To simplify the matter of providing an assessment, the scale was made ranging from 0 to 10, with 10 indicating great ease of walking and 0 indicating great difficulty of walking. In addition to their perceived LOS of the indicated location, the respondents were also asked to indicate how often they used the path.

3. Results

(1) Age Distribution and Gender of Participants

A total of 252 participants responded to the survey, 157 males and 95 females. Table 2 shows their age distribution, which was broken into six age cohorts. The result indicates that a wide range of respondents participated. The age distribution of the respondents was almost uniform at the first and second locations. At the first location, about 8% were younger than age 20, 29% were age 20 and 29, 17% were age 30 to 39, about 24% were age 40 to 49, and about 21% were age 50 or older. At the second location, 6% were under 20, 30% were age 20 to 29, 12% were age 30 to 39, 23% were age 40 to 49, 17% were age 50 to 59 and 12% were age 60 of older. As can be seen in Table 3, the age distribution of respondents was not uniform at the third location. Of the participants, 2% were younger than age 20, 12% were age 20 to 29, 12% were age 30 to 39, 19% were age 40 to 49, 27% were age 50 to 59 and 28% were 60 or older. There was a greater variety in age distribution at the forth location: 3% were younger than age 20; 20% were age 20 to 29; 18 % were age 30 to 39; 15 % were age 40 to 49; 42 % were age 50 to 59; and 2 % were age 60 or older.

Table 2 Age distributions of surveyed respondents

Location	Number of Participants	Age					
		Under 20	20-29	30-39	40-49	50-60	Over 60
1	74	8	29	17	24	17	5
2	52	6	30	12	23	17	12
3	61	2	12	12	19	27	28
4	65	2	20	18	15	42	3

(2) User Scores

As shown in Table 3, the averages of user scores were computed for each sidewalk from survey responses. Responses from persons who were unfamiliar with the location or who only walked there a few times per month or year were excluded. Only responses from frequent users were analyzed. The averages of user scores were compared with the total utility values that were calculated from the field measurement data. Pair wise data for the two variables, total utility values and averaged user scores plotted on a two-dimensional graph, appear as in Figure 3. This figure shows that there is a general tendency for the user scores to increase with increasing values of total utility. The correlation coefficient (R) between total utility and user scores is 0.82. This confirms that the total utility values can be used to predict the overall LOS of the sidewalk environment.

Table 3 Average user scores

Location	Sidewalk	Total Utility	Number of Participants	Average Users' Score	Std Dev
1	1	4.46	33	3.58	2.26
	2	5.44	47	5.30	2.87
	3	4.88	37	4.32	2.81
	4	3.67	51	4.51	2.68
	5	4.23	49	4.33	2.66
	6	5.44	40	6.20	2.73
2	1	8.53	25	7.08	2.23
	2	5.44	8	6.00	1.6
	3	6.23	13	6.77	1.48
	4	5.44	5	5.00	1
	5	3.67	8	4.00	1.93
3	1	4.18	25	5.08	2.22
	2	4.18	35	5.49	2.78
	3	5.44	25	5.64	2.8
	4	2.74	41	2.20	2.08
	5	3.39	22	4.45	2.54
	6	5.02	21	4.86	2.74
4	1	5.19	29	7.21	2.02
	2	0.42	9	3.11	3.59
	3	7.32	42	7.88	2.33

(3) Hypothesis Test

Often the problems of analyzing the quality of the estimated regression line are handled through an analysis-of-variance (ANOVA) approach[8]. We used ANOVA to test the hypothesis which relates to the significance of regression. A decision to reject null hypothesis (H_o) implies an acceptance of alternative hypothesis (H_1). The analysis of variance is summarized in Table 4. In Table 4, the computed F-statistic, F = 35.687, exceeds the critical value $F_{0.01,\ 1,\ 18}$ = 8.285, therefore the null hypothesis, H_o: $\beta_1 = 0$, is rejected for a significance level of $\alpha = 0.01$. It means that the computed F values are incompatible with the null hypothesis; that is, we will reject H_o and conclude that the alternative hypothesis is true. Rejecting null hypothesis implies that there is linear relationship between total utility value and user's score. Now, it can be concluded that total utility is of value in explaining the variability in users' scores for sidewalks.

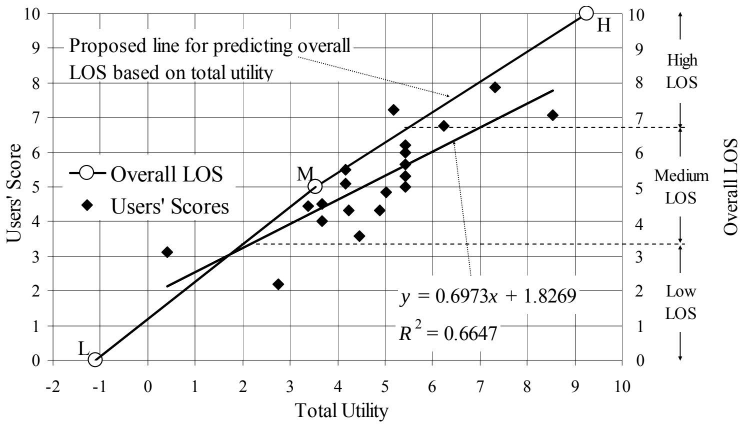

Figure 3 Utility values versus users' scores of sidewalk

Table 4 Analysis of Variance for testing $\beta = 0$

Source of Variation	Sum of Squares (SS)	Degree of Freedom (df)	Mean Square (MS)	Computed F
Regression	26.1181	1	26.1181	35.6886 **
Residual Error	13.1730	18	0.7318	
Total	39.2910	19		

4. Discussions and Conclusions

A term called 'overall LOS' was defined and used to combine the factors affecting pedestrian LOS. Even though HCM 2000 provides LOS analysis for each factor, there are no descriptions of how to combine LOS of each factor for an overall LOS of pedestrians. Using overall LOS makes it much easier to understand how well a particular street accommodates pedestrian travel, rather than LOS of individual factors. In other words, the concept of overall LOS may provide an easy understanding about the overall condition of a sidewalk. In this research, a methodology was developed for estimating the overall LOS of pedestrians for sidewalks based on total utility value. Site characteristics were collected to calculate the total utility values for each sidewalk. The level of each attribute to a specified sidewalk was determined using field measurement data. Utility values from a conjoint analysis were assigned to each attribute according to the attribute's level. Then the total utility was calculated by adding the utilities for the level of each attribute.

According to conjoint analysis theory, a product or service that receives a higher total utility value than any other product or service will be considered the most valuable of the products or services. In contrast, a product or service that receives a low total utility value will be considered to have a low use value. This means that the maximum total utility is an upper limit of overall LOS and the minimum total utility is a lower limit of overall LOS. The summation of utility values corresponding to medium level of each attribute will be the total utility value for the medium LOS. A graph was plotted by using the three total utility values corresponding to high, medium and low LOS. Then a line was drawn connecting 3 points; H (maximum total utility, upper limit of overall LOS), M (the summation of utility values corresponding to medium level of each factor, medium overall LOS), and L (minimum total utility, lower limit of overall LOS) as indicated in Figure 3. It was observed that these three points to form an almost straight line. Therefore it was assumed that there is a linear relationship between the total utility of a sidewalk or crosswalk and the overall LOS of that sidewalk or crosswalk. To clarify this assumption a validation process was conducted. Real pedestrians were surveyed and their evaluations were collected in the form of scores. The total utility values calculated from the field measurement data and the scores given by path users at selected sidewalks were compared. Results shown in Figure 3 indicate that the total utility value has a linear relationship with overall LOS. From this behavior we may conclude the total utility value is an accurate indicator of overall LOS of pedestrians. Furthermore, the method proposed in this study for the assignment of overall LOS to roadways may be useful in producing maps that show pedestrians the overall LOS on each roadway segment. Although this study proposed a method of determining overall LOS, it did not include all factors affecting pedestrian LOS. A fuller and broader consideration of all such factors is necessary.

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