

METHOD TO DETERMINE PEDESTRIAN LEVEL-OF-SERVICE FOR CROSSWALKS AT URBAN INTERSECTIONS

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Abstract: The objective of this study is to identify the factors affecting pedestrian level-of-service (LOS) at intersections and propose a method for the estimation of pedestrian LOS at intersections. In order to fulfill this objective, a stepwise multi-variable regression analysis was performed using the observed data of various types of intersections in the city of Sapporo, Japan. A significant number of pedestrians were requested to give ratings for each intersection based on their experiences at the actual sites. The scores given by the pedestrians were considered as the dependent variables for the analysis. A field survey was conducted to collect geometric, operational and traffic characteristics of crosswalks. A number of primary independent variables influencing pedestrian LOS was identified and tested in the stepwise regression analysis. The factors such as space at corner, crossing facilities, turning vehicles, delay at signals, and pedestrian-bicycle interaction were identified as the primary factors affecting pedestrian LOS at intersections. Each of the factors is weighted by coefficients derived by stepwise regression modeling importance. A statistically reliable t-statistics were obtained for each factor. The pedestrian LOS model was developed as a function of identified variables.

Key Words: Pedestrians, Level-of-service, Crosswalks at urban intersections

1. INTRODUCTION

Modeling of pedestrian LOS at intersections can provide an insight to intersection designs that better and more safely accommodate pedestrian mobility. Such a measure would enable pedestrian facility programming to be merged into the mainstream of transportation planning, design and construction. Intersections, by their very nature, are locations where there is considerable potential for conflict between different traffic streams and different users. At busy intersections motorists, cyclists, and pedestrians often have to deal with complex situations and be aware of the position, movement and intent of other users. Mixed traffic of motor vehicles and pedestrians are common in urban intersections. Efficiency of intersections greatly affects the entire network performance. The demand for the improvement of pedestrian facilities is raised due to the reasons such as difficulties in crossing heavily trafficked intersections, turning vehicles across their paths during the green signal, conflicts

among pedestrians and cyclists, physical barriers, low visibility, improper design of handicapped accessible ramps and so on. Road designers have to investigate what kind of mechanism is necessary in order to promote walking. They need to analyze what kind of route adjustment is necessary and how to make walkways safe and comfortable so that pedestrians can travel with pleasant feeling. To represent an integrated picture of facilities for pedestrians, it is important to review, compile, and organize the current state of researches that assess level-of service (LOS). The first attempt on LOS study was made by Lautso and Murole to find out the influence of environmental factors on pedestrian facilities. This research was a milestone in pedestrian LOS research, and it was further expanded by later researchers to accommodate many important factors into the computation of pedestrian LOS (Lautso and Murole, 1974). Sarkar proposed a qualitative method to compute pedestrian LOS based on six factors: safety, security, convenience and comfort, continuity, system coherence, and attractiveness (Sarkar, 1993). Qualitative attributes of pedestrian environments are described, but not quantified, in Sarkar's work. Since it is a qualitative method, the measurement of each factor is not easy in reality and also most of the factors are linked with each other. Later Khisty developed a quantitative method to determine the pedestrian LOS based on almost same criteria proposed by Sarker (Khisty.C.J, 1994). Although Khisty's method provides a quantitative measure of pedestrian LOS on a point scale, the results from this scale is not easy to interpret. A fundamental question remains as whether these scaling systems really address the pedestrian facilities, i.e. do pedestrians agree with these scaling systems. Miller et al (Miller *et al*, 2000) also proposed a scale method for pedestrian LOS assessment. Alternatives were introduced to improve the existing conditions and the proposed model was calibrated by using 3-D visualization. Dixon proposed a pedestrian LOS evaluation criterion which involves the provision of basic facilities, conflicts, amenities, motor vehicle LOS, maintenance, and travel demand management, and multimodal provisions (Dixon, 1996). A study proposed "overall LOS" as an index that combines the factors and indicates an overall value for the pedestrian LOS. Conjoint technique was used to combine the factors affecting pedestrian LOS (Muraleetharan *et al*, 2004). A mathematical model was proposed by Landis et al based on five variables: lateral separation of pedestrians from motor vehicle traffic, presence of physical barriers and buffers, outside lane traffic volume, motor vehicle speed, and vehicle mix (Landis *et al*, 2001). Although this mathematical model evaluates a roadway segment, it does not include intersections. However, they believe that intersection conditions have a significant bearing on pedestrians and a measure must be developed that includes conditions at intersections. Also this model is limited with environmental factors only and does not include other factors such as flow rate of path users, and space requirements. Some studies use pedestrian signal delay to define a pedestrian LOS (Joseph *et al*, 1999). The delay at intersection is an important indicator of the efficiency of an intersection. A pedestrian LOS criterion for signalized/unsignalized intersection is defined in terms of time delay in the Highway Capacity Manual 2000 (HCM, 2000). Although HCM describes LOS criteria for pedestrian at intersections based on pedestrian delay, it does not include the other factors such as crossing facilities, turning vehicles, and pedestrian-bicycle interactions at crosswalks, etc. Recent researches on pedestrian LOS indicate that there are also some other factors that affect pedestrian LOS. Therefore a method is needed to include the factors into the computation of pedestrian LOS at intersection. Based on literature review, much of the works dealing with pedestrian is limited to pedestrian facilities on uninterrupted sidewalks. On the other hand, there are a few studies dealing with pedestrian facility issues at intersections. Usually accidents in non-motorized transport modes occur when it is difficult for the user to cross an intersection (Fugger *et al*, 2000). This indicates that a reliable measure is needed to describe the pedestrian environment at intersections. Therefore the attempt of this research is to solve intersection LOS issues connected with pedestrians. The research will provide a method to

assess the degree of difficulty a user will experience crossing an intersection. Development of pedestrian LOS measure for intersection is intended to indicate the level of difficulty in crossing intersections.

2. DATA COLLECTION

2.1 Factors Affecting Pedestrian LOS at Intersections

It is important that right factors should be included in the design process. We established the factors by referring previous research works. The factors such as space at corners, crossing facilities, turning vehicles, delay at signals, and pedestrian-bicycle interaction were identified as the factors affecting crosswalk LOS. The space at corner includes both hold area and circulation area. HCM describes circulation area and temporary holding area as two main parts of pedestrian areas at street corners. Circulation area is necessary for moving pedestrians, and hold area is necessary to accommodate waiting pedestrians. Based on this description, space at corner was classified into three levels as both circulation area and hold area are large enough to accommodate the people, only the hold area is wide enough to accommodate the people, and both areas are too small and not enough to accommodate the people.

Crossing opportunities at intersections are indicated by crossing facilities. Crossing facilities include high visibility ladder style cross markings, well-designed curb ramps, detectable pathfinder tiles, separate path for bicycles, and raised median protection or pedestrian refuge islands (if the street is too wide to cross in a single signal phase). Three levels of crossing facilities were determined on the basis of research works done in the past (Miller *et al*, 2000 and Middleton, 1981). Level 1 contains excellent crossing facilities. Level 2 indicates that standard facilities are provided but more facilities are needed. Level 3 means that facilities are lacking and it is difficult to cross.

The potential for pedestrian-vehicle conflict is represented by the turning vehicles. HCM explains the effect of turning vehicles on the LOS for pedestrians crossing during a given green phase. But it does not define the exact relationship between the number of turning vehicles and pedestrian LOS. Therefore we defined the levels according to the signal system installed at a particular crosswalk. Level 1, 2, and 3 were defined as no turning vehicles, left turning vehicles, and left turning and right turning vehicles respectively.

The total time spent by pedestrians waiting to cross the street is expressed as delay. Cycle length and effective green time (for pedestrian) can be measured in seconds at the signalized intersections. The average delay at a signalized intersection is calculated by the Eq.1 given in HCM.

$$\text{Average delay} = 0.5(C-g)^2/C \quad (1)$$

Where C = Cycle length (in seconds); g = Effective green time for pedestrian (in seconds). Volume of pedestrians and cyclists was defined based on the freedom to walk freely without congestion. By counting the number of passing and opposing pedestrians and bicycles for a particular time period we could calculate the total number of bicycle passing and opposing events per hour.

2.2 Site Selection

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 4 or 5 crosswalks. The first location includes five crosswalks. Since this location was near the Kita-12 subway station, a high pedestrian flow rate was observed in the morning rush hour. The second location was adjacent to first location. The third location was near to Sapporo railway station. 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.

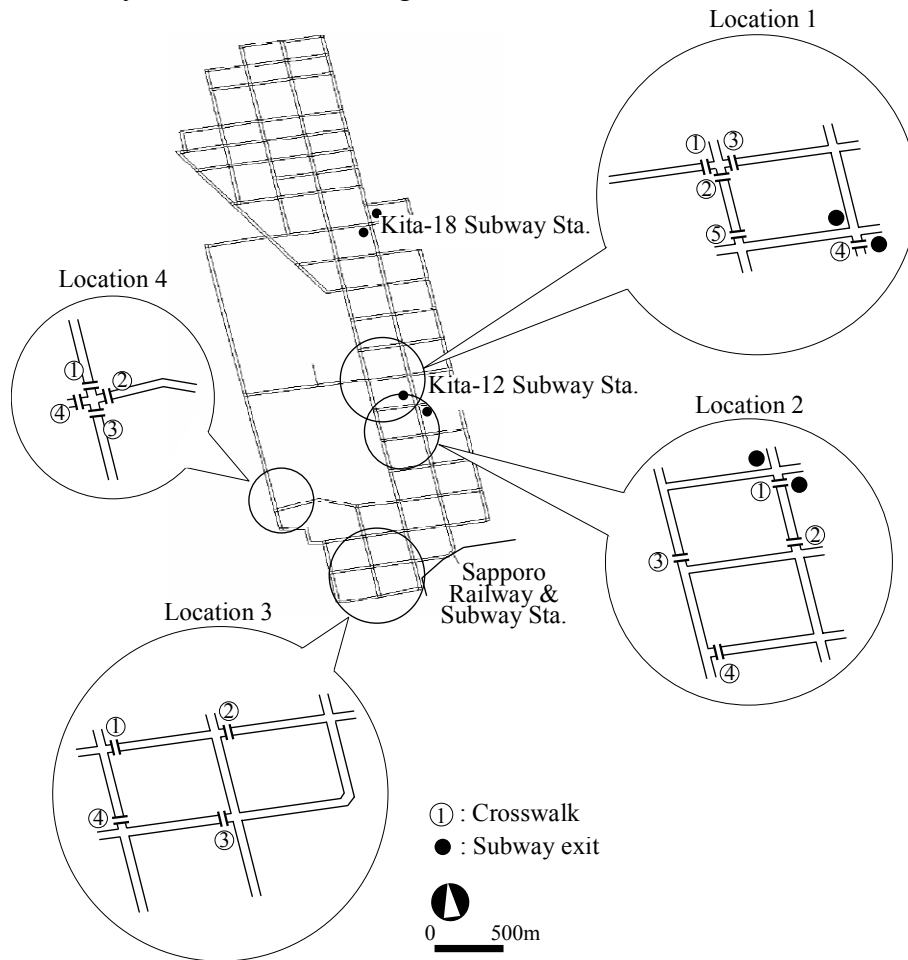


Figure 1. Selected locations for the survey

2.3 Collecting Geometric and Operational Characteristics

Geometric and operational aspects of the crosswalks were examined by conducting a field survey. All characteristics of factors affecting LOS were collected for each crosswalk in an area within and surrounding of Hokkaido University. The numbers assigned to each crosswalk are also indicated in Figure 1. In the field measurement process, we were able to introduce measurement methods for each of the factors considered in this study. Some of these factors are not easy to define and measure. But a considerable number of factors are clearly defined in HCM 2000. Therefore HCM was used to define and measure those factors. In addition to HCM past research papers were referred to define some other factors which are not defined in HCM. Geometric and operational characteristics of selected crosswalks are shown in Table 1.

Table 1. Geometric and Operational Characteristics of the Selected Crosswalks

Loca- tion	Cross- walk	(1) Level of space at corner		(2) Crossing facilities*						(3) Turning Vehicles	(4) Delay			(5) Pedestrian-Bicycle interaction			
		Corner 1	Corner 2	VC	SB	PT	CR	L	RI		C	g	Delay	Pedestrians		Cyclists	
													->	<-	->	<-	
1	1	2	3	0.5	0	0	1	4	0	Left turn only	120	65	13	29	5	9	30
1	2	3	2	1	0	0	1	2	0	Left turn only	110	50	16	0	4	1	11
1	3	3	3	1	0	0	1	2	0	Left and right	120	32	32	9	2	6	5
1	4	1	1	1	1	1	1	4	0	No turn	120	32	32	1	17	19	6
1	5	2	2	1	0	1	1	4	0	Left turn only	94	54	9	10	10	5	2
2	1	1	1	1	1	1	1	4	0	Left turn only	120	32	32	0	5	1	6
2	2	1	1	1	0	0	0	4	0	Left turn only	110	50	16	17	5	3	2
2	3	2	3	1	0	0.5	1	4	0	Left turn only	120	47	22	0	5	1	6
2	4	3	2	0	0	0	1	4	0	Left and right	Unsignalized		5	4	10	4	20
3	1	2	2	0.5	0	0	1	4	0	No turn	120	38	28	17	5	3	2
3	2	2	2	1	0	1	1	4	0	Left turn only	120	32	32	7	4	13	8
3	3	1	1	1	0	1	1	4	0	Left and right	120	50	20	6	0	5	0
3	4	1	1	0.5	0	0	1	4	0	Left and right	120	65	13	6	10	10	13
4	1	2	1	1	0	0	1	2	0	Left and right	Unsignalized		5	75	1	25	1
4	2	3	2	1	0	0	1	2	0	Left and right	Unsignalized		5	0	0	9	2
4	3	2	3	1	0	0	1	4	1	Left and right	Unsignalized		5	6	1	5	2
4	4	3	2	1	0	0	1	2	0	Left and right	Unsignalized		5	6	6	5	18

* VC: Visible cross markings

SB: Separate bicycle path

PT: Pathfinder tiles

CR: Curb ramps

L: Number of lanes

RI: Refuge islands

2.4 Stated Levels of Crossing Difficulties by the Respondents

In this approach photos of crosswalks were used and the locations of crosswalks were indicated on maps. Figure 2 shows sample questionnaire sheet used for the survey.

Approximately how many times do you cross this crosswalk?

1. Almost every day 2. Few times a week 3. Few times a month 4. Few times a year

Imagine that you are crossing at this crosswalk on a weekday in the morning.

How do you feel when you use this crosswalk?

Difficult to cross Comfortable to

Figure 2. Sample Questionnaire Sheets used for the Survey

Questionnaires were distributed to the pedestrians who crossed the crosswalks. Instructions and explanations of LOS were given in the first few pages of questionnaire in order to clear what was expected from them. It was emphasized to respondents that this study needs their perception of the level of difficulty if they were to use the particular crosswalk. Respondents were requested to record their perception on a scale how comfortable they felt as they crossed that crosswalk. The major advantage of this approach is that perceptions are based on crossing experiences in real situations. Also respondents were given enough time to answer. To simplify the matter of providing an assessment, the scale was made ranging from 0 to 10. Score 10 means very comfortable to cross and score 0 means extremely difficult to cross. In addition to their perceived LOS of the indicated location, the respondents would also be asked to indicate how often they use that path. These intersections were a mix of both signalized and unsignalized intersections. Pedestrians expressed their ratings of how well a particular intersection accommodates their travel by referring to the intersection's perceived safety or comfort. The scores given by the pedestrians were considered as the dependent variables for the analysis.

3. RESULTS

3.1 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 or older. As can be seen in Table 2, 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 fourth 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%

3.2 The Averaged Users' Scores

As shown in Table 3 the averages of users' scores were computed for each crosswalk using the answers of respondents. Responses from persons unfamiliar with the location and only using a few times per month or year were not considered. Responses from frequent users were only taken into the analysis.

Table 3. Average User Scores

Location	Crosswalk	Number of Participants	Average Users' Score	Std Dev
1	1	50	3.34	2.77
	2	53	4.79	2.87
	3	45	4.20	2.65
	4	50	6.28	2.84
	5	41	6.27	2.33
2	1	34	5.53	5.57
	2	10	6.10	2.02
	3	3	6.67	3.21
	4	3	5.00	2.65
3	1	19	4.89	2.69
	2	26	5.46	2.37
	3	38	4.18	2.52
	4	21	4.62	2.25
4	1	32	5.50	2.49
	2	40	5.83	2.83
	3	27	5.37	2.44
	4	27	6.81	2.08

4. STATISTICAL APPROACH

4.1 Regression Analysis

A stepwise multi-variable regression analysis was performed using the observed data of various types of intersections. Regression analysis was used to translate respondents' answers into numerical values. Each of the factors was weighted by coefficients derived by stepwise regression modeling importance. The weighted coefficients of each factor and the corresponding t-statistics are shown in Table 4.

Table 4. The weighted coefficients of each factor and the corresponding t-statistics

Parameter	Coefficients	Std. Error	t-value	Significance level
Constant	7.8420	0.197	39.894	0.000
Space at corner (Level 2)	-0.2420	0.122	-1.985	0.082
Space at corner (Level 3)	-1.4080	0.212	-6.640	0.000
Crossing Facilities (Level 2)	-1.1870	0.105	-11.358	0.000
Crossing Facilities (Level 3)	-1.4130	0.219	-6.440	0.000
Turning Vehicle (Level 2)	-0.7920	0.099	-8.026	0.000
Turning Vehicle (Level 3)	-1.6930	0.236	-7.175	0.000
Delay	-0.0370	0.006	-5.827	0.000
Bicycle Events	-0.0031	0.001	-2.375	0.045

4.2 Calculating Categorical Scores

The regression analysis requires that independent variables to be numerical variables. However, in this analysis categorical variables are included as independent variables. There

are 3 categorical variables; space at corner, crossing facilities and turning vehicles and each categorical has 3 categories (levels). Table 5 shows the categorical scores of each level.

Table 5. The Categorical Scores

Parameter	Partial Correlation Coefficient (PCC)	Frequency (f)	(PCC)×(f)	Summation for each categorical variable	Average	Categorical Score
Space at corner (Level 1)	0.000	190	0.000			$D_{11} = 0.2545$
Space at corner (Level 2)	-0.242	284	-68.728			$D_{12} = 0.0125$
Space at corner (Level 3)	-1.408	45	-63.360	-132.088	-0.2545	$D_{13} = -1.1535$
Crossing facilities (Level 1)	0.000	416	0.000			$D_{21} = 0.2369$
Crossing facilities (Level 2)	-1.187	100	-118.700			$D_{22} = -0.9501$
Crossing facilities (Level 3)	-1.413	3	-4.239	-122.939	-0.2369	$D_{23} = -1.1761$
Turning Vehicles (Level 1)	0.000	84	0.000			$D_{31} = 1.2645$
Turning Vehicles (Level 2)	-0.792	89	-70.488			$D_{32} = 0.4725$
Turning Vehicles (Level 3)	-1.693	346	-585.778	-656.266	-1.2645	$D_{33} = -0.4285$

4.3 Pedestrian LOS Model

A stepwise multivariable regression analysis was used to express the mathematical equation for pedestrian LOS. The collections of factors with the statistical reliability were used to form a mathematical expression. This measure evaluates the conditions of crosswalks at intersections. The pedestrian LOS at crosswalk can be expressed in an equation format as shown below.

$$\text{Pedestrian LOS at crosswalk} = 7.842 + \sum_{i=1}^3 \sum_{j=1}^3 D_{ij} \delta_{ij} - (0.037 \times \text{pd}) - (0.0031 \times \text{pb}) \quad (2)$$

Where

D_{ij} = Categorical score associated with j^{th} level of the i^{th} attribute

δ_{ij} = 1 if the j^{th} level of the i^{th} attribute is present

pd = Pedestrian delay in seconds

pb = Number of pedestrian-bicycle interactions

5. DISCUSSIONS AND CONCLUSIONS

The study revealed that the factor 'turning vehicle' has greater influence on pedestrian LOS than other factors. When the number of turning vehicles increases, the result shows a corresponding decrease in the perceived safety to the pedestrian. Therefore it can be recommended that at intersections the signal systems must be designed to minimize the pedestrian-vehicle interaction because pedestrians feel discomfort due to the conflicts with vehicles. Furthermore, the factors 'delays at signals' and 'pedestrian-bicycle interaction' were also found to be significant factors in determining pedestrian LOS at intersections. Both

waiting area (hold area) and the space for moving (circulation area) should be wider than the standard size because the categorical score for level 2 has a negative value. In case of crossing facilities, we observed that pedestrians prefer design improvements, such as high visibility zebra style cross markings, separate path for bicycles, and well-designed curb ramps. Also it has been found that the importance between levels of crossing facilities was similar to a research work done in the past (Miller *et al*, 2000). Another interesting observation regarding intersections is that pedestrians prefer pedestrian-priority-crossings and they do not accept long delays at signalized intersections. Both HCM 2000 and other researches (Kaiser, 1994) indicate that pedestrians become impatient when they experience long delay, and they engage in risk-taking behaviors.

Pedestrian LOS model for crosswalk provides a measure of a crosswalk's performance with respect to pedestrians' safety and comfort. Using the value of pedestrian LOS at crosswalk, roadway designers can determine how well a particular intersection accommodates pedestrian travel. In other words, pedestrian LOS measures can provide an easy understanding about the condition of a crosswalk. Such a measure would help in evaluating and prioritizing the needs for pedestrians on existing intersections. Pedestrian LOS at crosswalk can be used to develop a minimum LOS standard which could prescribe the minimum acceptable LOS for the adequate accommodation of pedestrians. Crosswalks at urban intersections should be targeted to maintain a minimum pedestrian LOS in order to provide a minimum level of accommodation for pedestrians. Pedestrian LOS models could also be used to support the development of pedestrian facility improvements. Roadway designers can use the pedestrian LOS model to test alternative intersection designs by iteratively changing the independent variables to find the best combination of factors to achieve the desired LOS. The method proposed in this study provides not only the pedestrian LOS at intersection but also the factors contributing to low and high LOS.

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