Roadside Walking Environments and Major Factors Affecting Pedestrian Level of Service in South Korea

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Abstract: This paper provides study results of pedestrian level of service (LOS) within roadside walking environments. Comfort needs of pedestrians and the multimodal level of service are the main issue of the study. The approach applied in the research includes a literature review, pedestrian intercept survey, and multiple regression analysis. Major findings include: (1) current measure of effectiveness for determining pedestrian LOS in the KHCM (Korean Highway Capacity Manual) should be replaced with a more realistic measure of effectiveness, such as the level of pedestrian satisfaction, (2) perception of pedestrian LOS within roadside walking environments was successfully captured in a model developed in this study, and (3) the impact of adding automobile related variables to explanatory variables was statistically significant. Cross-section design elements affecting the perception of pedestrian LOS were also identified. It is hoped that this research will provide engineers with a starting point for understanding more pedestrian-friendly strategies of urban arterial designs.

KeyWords: Multimodal Level of Service, Pedestrians, Roadside, Pedestrian Intercept Survey, Multiple Regression

1. INTRODUCTION

1.1 Research Background and Objective

In the past, transportation engineers who were responsible for sidewalk designs only needed to examine pedestrians' interest for their designs. Similarly, those responsible for automobile lane design only cared for auto drivers' interest. It was rare to see the two groups cooperate and provide their designs based on the concept of the multimodal level of service. As a result, the urban arterial, which consists of travel lanes, sidewalks, etc., in its right-of-way space, seemed to serve too much for auto drivers and lacks a balanced level of service for all street users: auto drivers, transit riders, cyclists, and pedestrians. Non-motorized users were neglected (Choi, 2011; Lee, 2012; Kim, 2012; Kim, 2013; Choi, 2010; Tay, 2011), and recently studies were called to deal with this problem (Rouphail, 1998; Landis 2002; Elias, 2011). In this respect, transportation engineers are now fascinated by the novel idea of the multimodal level of service. This method is designed for evaluating "complete streets" context-sensitive design alternatives, and smart growth from the perspective of all users of the street (Landis 2002; Bian 2007; Dowling 2008). They all share the same concept and put their emphasis on the idea that urban streets are for everyone. Although being very simple, it is considered that this idea provides a starting point for having an increased understanding of safe, attractive, and comfortable access and travel for all users (Crider, 2001; Dowling, 2001; Winters, 2001; Landis 2002; Winters, 2004; Perone, 2005; Hiatt, 2006).

However, although applied successfully in some countries (TRB, 2010), the multimodal level of service method has never been applied in South Korea. It is only after years of neglect that this method starts to gain considerable support from the public, i.e., this method becomes applied when non-motorized transportation designs are in discussion. Today, engineers agree on the importance of the multimodal level of service. Regardless, in South Korea, there still is a key challenge in multimodal level of service practice. That is, pedestrian needs in roadside walking environments are yet to be understood. Traditionally, pedestrian studies are very limited, as opposed to auto driver studies, and pedestrian needs studies in conjunction with the multimodal level of service method is particularly limited. In this regard, this study is eager to put an effort into better explaining pedestrian needs and to transfer the result to more efficient pedestrian designs.

The objective of this research paper is to detail how pedestrians perceive roadside walk environments, such as sidewalk pavements, and to provide useful insights of major factors affecting pedestrian level of service with a view from applying the multimodal level of service in South Korea, as well as a model describing their relationships.

1.2 Scope, Approach, and Contribution of the Research

The research is committed to best practice of the multimodal level of service method, with a purpose that a safer and more comfortable urban arterial design can be offered to pedestrians or other non-motorized users. In this regard, particular respect is given to identifying major factors affecting pedestrian levels of service in roadside walking environments. The comfort need of pedestrians is more outspoken in urban areas, so rural roads are precluded here. Further, current pedestrian level of service methods prescribed in the KHCM is not heavily consulted since its theory is mostly derived from vehicular traffic flow theory.

The research approach applied includes: (1) literature review, (2) pedestrian intercept surveys, (3) statistical analyses in the quest for identifying major factors affecting pedestrian levels of service, and (4) model development to explain how pedestrian perceptions vary according to different roadside walking environments.

As stated earlier, there are successful applications of the multimodal level of service method in some countries, but no such application was made in South Korea. Therefore, the main contribution of the research is to capture local characteristics of pedestrian needs. It is equally important that the research contributes to our extended understanding for contemporary methods of pedestrian levels of service.

2. LITERATURE REVIEW

It is stated that the current pedestrian level of service procedure prescribed in the KHCM includes several limitations. The overarching key issue is the use of pedestrian density as a measure of effectiveness. Since its first introduction by Fruin in the 1970s, this means has been used extensively to explain how pedestrians would feel at each given walking condition. This method is very useful in describing the impact of pedestrian volume increase to pedestrian levels of service. Pedestrian malls, sidewalks adjacent to commercial buildings, and pedestrian facilities along urban streets are nicely designed by adopting its concept. However, with the sustainable transportation topic emerging recently, this concept becomes less appealing to engineers. It is realized that there exists a huge difference between the vehicle and pedestrian flow. As Goffman states (Goffman, 1971), "pedestrians can twist, duck, bend, and turn sharply and therefore, unlike motorists, can safely count on being able to extricate themselves in the last few milliseconds before impending impact." He also notes that if two pedestrians collide, damage is not likely to be significant. In essence, while vehicle density is important to explain vehicle flow and its effects on motorists' perception for the flow, a quite different means is required to explain comfort needs of pedestrians. Hence, it is advised in this paper that pedestrian density should be replaced with a more realistic measure of effectiveness, such as the level of pedestrian satisfaction. Several other measures of effectiveness of pedestrian LOS were similarly proposed by such studies as Landis 2002(Landis, 2002; Shaker, 2002; Petritsch, 2006; Bian, 2007; Dowling, 2008).

It is also indicated that pedestrians discern between acceptable and unacceptable levels of service quite differently from auto drivers. For example, LOS D or LOS E is acceptable from an auto driver's point of view, but LOS C is already unacceptable for pedestrians. This results from pedestrians' being very sensitive to the presence of other pedestrians, which is not so important in the case of auto drivers. In other words, comfort needs of pedestrians are volatile and degrade very rapidly when given conditions change. It is for this reason that the US hurriedly adopted the multimodal level of service procedure (Dowling, 2008). A similar action is required in South Korea, i.e., we need to fit the KHCM to provide level of service equally across modes. Considerable research point out that pedestrian LOS determined with the KHCM generally overestimates, resulting in much higher LOS values than pedestrians actually perceive (Ji, 2009; Lee, 2011; Choi, 2012).

Last, in the process of applying the KHCM's pedestrian LOS, engineers evaluate the pedestrian facility separately from traffic lanes, assuming that pedestrian LOS is developed for pedestrian facilities and auto driver LOS is for traffic lanes. No interaction is considered between the two. In the real world, however, pedestrian and vehicular areas usually sit together in urban areas, with or without separations. As a result, in spite of the separations, users in the two areas may actually interact. Traffic noise, high speed, and careless parking on sidewalk pavements involve a noticeable degradation of pedestrian LOS. Therefore, it is advised here that the effect of interaction between travel modes must be considered to better explain pedestrian LOS.

3. ARGUMENTS AND EVIDENCE

3.1 Pilot Study and Congruency Test

Without being aware that the KHCM produces unrealistic pedestrian LOS, engineers keep applying the KHCM to evaluate pedestrian facility designs. As a result, their duty of fulfilling best practical designs is sometimes in question and the public is not content with urban sidewalk conditions. Academically, researchers have pointed out this troubling problem for a long time (Choi, J; Lee, S.; Kim, 2012; Kim, 2013; Choi, 2010; Tay, 2011).

Authors start to deal with it by conducting a pilot field study before doing a main field test, where the congruency among pedestrian levels of service as prescribed by the KHCM, the multimodal LOS method being applied in the US, and actual pedestrian surveys are tested. In the actual pedestrian surveys, which was conducted in urban street sections in Seoul, selected pedestrians were approached by survey crew members and asked to state their actual perceptions of pedestrian level of service for the street sections that they have walked a short while ago. As a follow-up analysis, the study determined pedestrian levels of service for the same street sections with prescribed procedures stated in the current KHCM and the multimodal LOS method being applied in the USHCM (United States Highway Capacity Manual). Three different results were compared to determine whether the current KHCM's pedestrian LOS would indeed need an improvement.

3.2 Test Result

From Figure 1, it is apparent that the congruency rates of perceived pedestrian LOS with the levels of service of the KHCM and the multimodal LOS method are not very high. To be detailed, it is captured that the KHCM produced a correct pedestrian LOS only for 5 sites out of 16 total, recording 31% in congruence, and that the multimodal LOS method gave 6 correct answers with a congruency rate of 38%. Although the multimodal LOS method produces a slightly better result, the improvement is not considerable. This is discouraging because, at the onset of the study, we expected a considerable improvement. This may result from model transferability, i.e., the multimodal LOS model applied in this analysis is intended to represent demographical, traffic, and cultural characteristics of the US. Thus, we understand that each country needs its own modeling effort. Only with detailed local characteristics of pedestrian behaviors, reliable models of pedestrian perception may be developed.

Upon completion of this test, we wanted to reinforce our findings, so a survey crew was sent one more time to the test sites to gather their unique characteristics in the walking environments. As a result, we discovered that there often occur several conditions onerous to comfortable walking, such as parked vehicles on sidewalk pavements and half hidden driveways penetrating sidewalk pavements. Thus, it was realized that operating conditions of the roadside walking facilities should be considered when examining comfort needs of pedestrians.

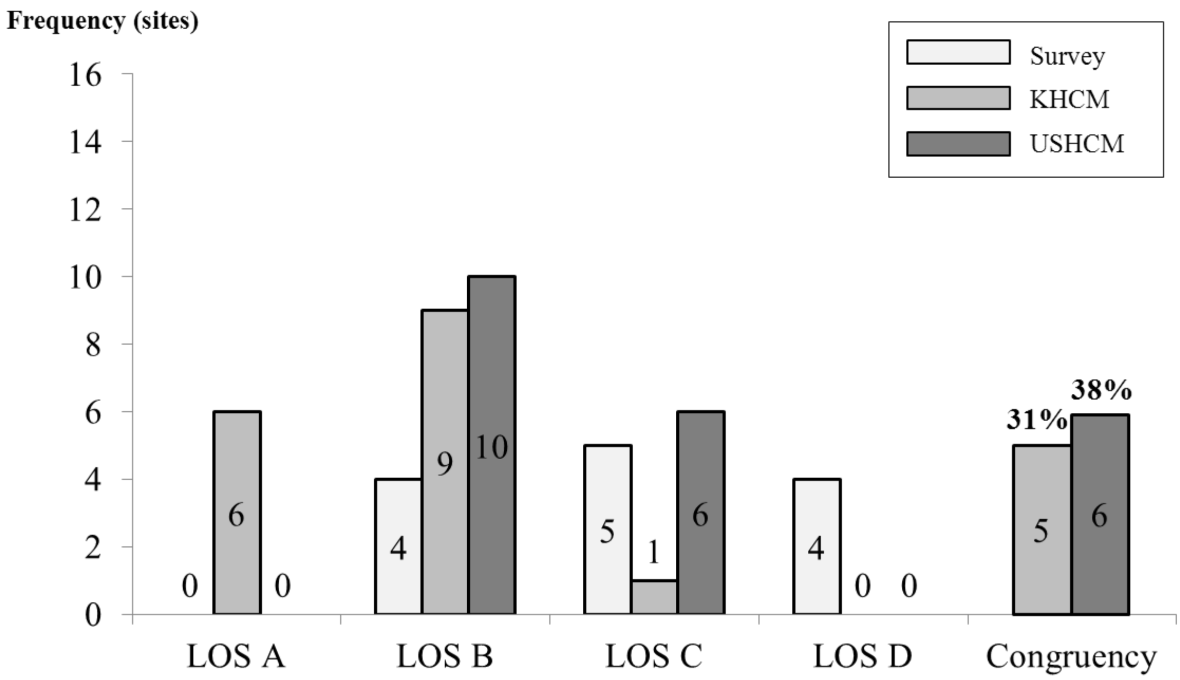

Figure 1. Three Different Pedestrian Levels of Service Resulting from the Pilot Study

4. IMPROVEMENT METHODOLOGY

4.1 Multimodal LOS Method in the USHCM

This study proposes to apply the multimodal LOS method in an effort to improve the KHCM's pedestrian LOS procedure. As mentioned in NCHRP 3-70, which is the main source of the multimodal LOS in the USHCM, LOS should be comparable across modes. In other words, it is required for the multimodal LOS method that, if LOS for pedestrians is C, levels of service for all other modes must be at most C. As a result, when the cross-section design of an urban street include traffic lanes, sidewalks, bike lanes, and bus lanes, design levels of service for motorized traffic modes shall not be lopsidedly better than the one for the pedestrian level of service. Therefore, a street with a low traffic volume but a heavy pedestrian volume (or vice versa) may have a well balanced level of service when the multimodal level of service is applied.

Individual components of the pedestrian LOS in the USHCM include segment experience, travel along segment, mid-block crossing, intersection experience, and pedestrian density. The USHCM explains segment experience by considering various factors, such as vehicle volume in shoulder lanes, vehicle speeds, lateral separation between vehicles and pedestrians, barriers (trees, bushes, or barricades), on-street parking, and the presence and width of sidewalks (Dowling, 2008). We are concerned with roadside walking environments and their impact on the multimodal LOS, so we put our effort into the first component, which is segment experience. Besides, it is considered that pedestrian LOS should be the central mode of investigation, because it represents the non-motorized transport.

4.2 Field Study

After realizing the importance of the impacts on the perception of pedestrian LOS of operating conditions in vehicle lanes, we decided to conduct a modeling work. This task requires a field survey of geometric design features including sidewalks and traffic lanes, a pedestrian intercept survey, and a statistical analysis to develop pedestrian LOS models.

4.2.1 Data Collection

A total of sixteen test sites were selected. Collected data include pedestrian volume, geometric features, vehicle speed and volume. Excluding rainy days, the pedestrian intercept survey was conducted in November 2012 during peak hours of 8:00-9:00 A.M. and 6:00-7:00 P.M. A total of 30 pedestrians were queried for 1-2 minutes period at each site, providing the sample size of 480. It is noted here that sometimes the level of pedestrian volume was excessive, which would make pedestrians walk in a forced flow, i.e., pedestrian LOS would be more influenced by pedestrian density than by pedestrian comfort needs. Therefore, in that case, field surveys were suspended. In fact, the novel element we are contributing by the research is a subjective assessment by pedestrians about a specific level of service, i.e., a satisfaction level experienced by pedestrians. In that sense, pedestrians' changing sense of satisfaction due to congestion must be excluded in further analyses. Hence, our field studies were conducted only with light levels of pedestrian volume. With this treatment, we could successfully equate pedestrians' assessment of "walking quality" on the footpath to "satisfaction".

A pedestrian intercept survey was carried out to examine perceived levels of service by participating pedestrians immediately downstream of the test sites as depicted in Figure 2.

This is one of the historical methods for measuring traveler perception of satisfaction (Creasey, 2008) and has advantages including: (1) direct measurement of LOS perception, (2) vivid memory due to mid-trip intercepts, (3) large sample, and (4) trip or facility specific information per one data. In conducting the survey, survey crew provided participating pedestrians with both a scoring sheet and a graphical representation of pedestrian levels of service. With the graphical representation, pedestrians are advised to give LOS designations A"-"B"-"C"-"D"-"E"-"F" to describe "Open"- "Unimpeded"- "Impeded"-"Constrained"- "Crowded"- "Congested"- "Jammed". This expression was originally developed by Pushkarev and Zupan and still is appropriate for practical applications. As a follow-up, the survey crew offered 1-6 marks to pedestrian levels of service A-F (A being the most favorable walking condition and F the worst) , listed in this order.

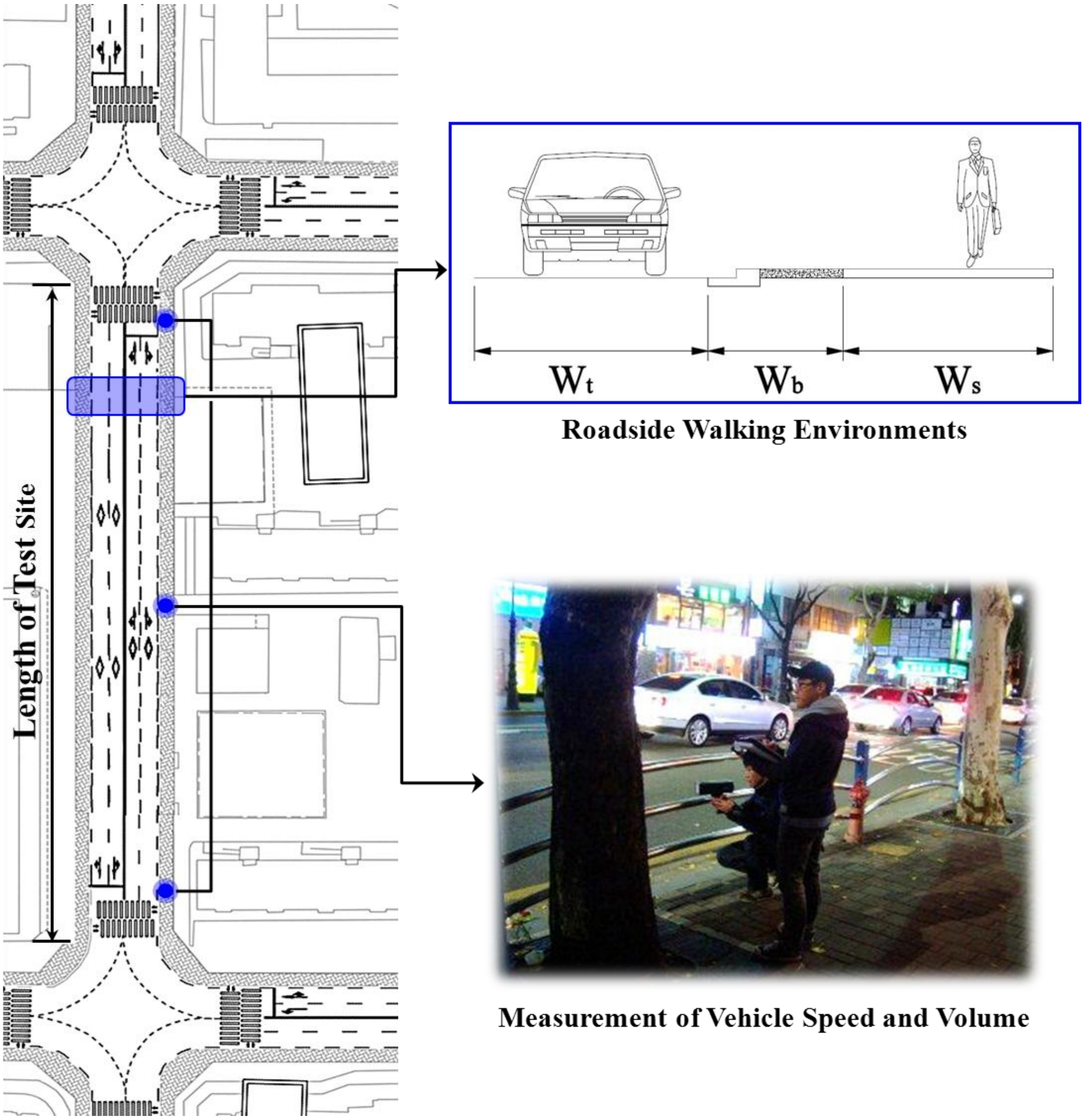

Figure 2. Typical Horizontal Plan of Test Sites, Sidewalks, and Pedestrian Intercept Survey

In broad terms, geometric design features cover cross-section elements, such as sidewalk width, separation width, and the width of the shoulder lane. Measurements are made at 10 m intervals and their average values are applied in the modeling process.

Automobile related information includes vehicle speed and volume. This measurement is also made during the pedestrian intercept survey, so that automobile impact may be captured in pedestrian answers. Similarly, vehicle speed and volume are collected during the pedestrian intercept survey. It is clear that pedestrian perceptions will be more sensitive to the level of pedestrian volumes than to the walking environment. Therefore, the survey was carried out at urban streets with favorable pedestrian levels of service such as A or B. A summary of the field survey sites and collected data are given in Table 1.

Table 1. Summary of Field Survey Sites and Collected Data

ID	Street Name	Ped Volume (ped/min)	Width of Lane (m)	Number of Lanes (N)	Sidewalk Width (m)	Width of Separation (m)	Vehicle Speed (km/h)	Vehicle Volume (veh/hr)
1	Dongjak-daero	66	3.8	4	2.2	2.0	52.6	691
2	Nambusunhwan-ro	79	4.0	4	3.5	1.2	58.9	590
3	Nambusunhwan-ro	97	3.7	4	4.5	1.0	46.4	547
4	Hyoryeong-ro	61	3.5	3	2.8	0.5	53.4	295
5	Bangbae-ro	39	4.0	3	2.0	0.8	48.1	404
6	Bangbae-ro	69	4.0	3	3.3	1.5	46.9	383
7	Seocho-daero	58	4.0	3	3.1	0.5	52.7	559
8	Seocho-daero	56	3.6	3	3.0	0.7	44.8	487
9	Changgyeonggung-ro	72	4.0	3	2.8	1.2	42.2	605
10	Insadong-gil	60	4.1	3	2.4	1.5	31.4	378
11	Cheonggyecheon-ro	86	3.7	3	3.0	1.0	44.7	433
12	Samil-daero gil	93	3.6	4	3.5	2.5	49.0	578
13	Jong-ro 41-gil	35	3.3	2	2.0	1.1	37.0	156
14	Kimsangok-ro	28	3.5	2	2.7	0.8	34.0	279
15	Daehak-ro	65	3.5	3	2.8	1.0	33.6	295
16	Daehak-ro	54	3.5	3	4.5	1.1	40.0	253
Average		63.5	3.74	3.13	3.01	1.15	44.7	433.3

5. PEDESTRIAN LEVEL OF SERVICE MODEL

5.1 The Model

There are many geometric features and operating conditions that can affect the perception of pedestrian LOS. We used a multiple regression model to include all potential explanatory variables. The model structure has two separate parts, one related to cross-section geometric elements and the other related to automobile movement. Eqn. (1) gives the model.

$$Y = \beta_0 + \beta_1 f(\text{lateral separation fators}) + \beta_2 (\text{traffic fators}) \cdots + C \qquad \text{Eqn. (1)}$$

5.2 Variables

5.2.1 Dependent Variable

Results from the pedestrian intercept survey are applied as the dependent variable in this analysis. Since the perception of pedestrian LOS is marked with integers in a range of 1-6, the dependent variable also has such a range.

To apply the multiple regression analysis, it is required to do the normal distribution test for the dependent variable. This study applies the Kolmogorov-Smirnov (K-S) test for this purpose. The hypotheses are as follow:

H_0 : The data follow a specified distribution

H_1 : The data does not follow the specified distribution

From Table 2, it is apparent that the null hypothesis cannot be rejected at a confidence level of 95%. This implies that distribution of the dependent variable follows normal distribution. Hence, we decide to apply the multiple regression analysis to explain the perception of pedestrian LOS.

Table 2. Statistics of Kolmogorov-Smirnov Test

Average	Min.	Max.	Standard Deviation	Sample Size	P-value
2.679	1	6	0.950	480	0.119

5.2.2 Independent Variables

We make iterations to identify statistically significant independent variables and finally select six independent variables including the effective width of sidewalks, the width of separation, the width of shoulder lanes, vehicle speed, and vehicle volume. A follow-up analysis is also made to apply them to regression analysis. Table 3 lists the statistical summary.

Table 3. Statistical Summary of Independent Variables

Variable Name	Variable Description	Unit	Min.	Max.	Average	Standard Deviation
X_1	Width of Lane	m	3.3	4.1	3.7	0.2
X_2	Number of Lanes	N	2.0	4.0	3.1	0.6
X_3	Sidewalk Width	m	2.0	4.5	3.0	0.7
X_4	Width of Separation	m	0.5	2.5	1.2	0.5
X_5	Vehicle Speed	km/h	19.6	77.5	44.7	12.4
X_6	Vehicle Volume	Veh./5min	11.0	91.0	43.3	18.0

5.3 Developed Model

The intent of this analysis is to develop a model that can reliably explain perception of pedestrian LOS based on geometric conditions of cross-section and automobile related variables. Therefore, efforts are made to increase the reliability of the model by examining various combinations of independent variables. We first apply variable transformations with logarithm and choose a combination with high explanatory power. Next, we add automobile related variables, such as vehicle speed and vehicle volume. This step is particularly important because the inclusion of automobile related variables may bring a significant amount of increase in explanatory power (an assumption underlying the multimodal LOS method). Last, we make another variable selection and reach the final model. From Table 4, it is demonstrated successfully that the perception of pedestrian LOS changes greatly with the inclusion of automobile related variables to sidewalk variables.

Table 4. Candidate and Final Model of Pedestrian Level of Service

Classification			Model 1	**Model 2**	**Model 3**	Model 4	**Final Model**
Constant			-1.391 (0.012)	**-3.629 (0.000)**	**-2.523 (0.000)**	-8.965 (0.000)	**-2.485 (0.000)**
Cross-Section Related	X_i	X1	1.083 (0.000)				
		X2	0.898 (0.000)				
		X3	-0.630 (0.000)				
		X4	-0.773 (0.000)				
	Ln(X_i)	Ln(X1)		**4.356 (0.000)**	**3.074 (0.000)**	2.567 (0.000)	**3.001 (0.000)**
		Ln(X2)		**2.241 (0.000)**	**0.125 (0.395)**	0.152 (0.333)	
		Ln(X3)		**-1.769 (0.000)**	**-1.398 (0.000)**	-1.513 (0.000)	**-1.438 (0.000)**
		Ln(X4)		**-0.878 (0.000)**	**-0.528 (0.000)**	-0.492 (0.000)	**-0.544 (0.000)**

Automobile Related	X_{i-n}	X5			**0.046 (0.000)**		**0.045 (0.000)**
		X6			**0.018 (0.000)**		**0.017 (0.000)**
	Ln(X_{i-n})	Ln(X5)				1.953 (0.000)	
		Ln(X6)				0.745 (0.000)	
R^2			0.439 (0.000)	**0.445 (0.000)**	**0.835 (0.000)**	0.817 (0.000)	**0.833 (0.000)**

Eqn. (2) gives the final model.

$$PS=2.485+3.001Ln(W_t)-1.438Ln(W_b)-0.544Ln(W_s) +0.045SPD_5+0.017Vol_5 \quad \text{Eqn. (2)}$$

where,

PS : Perception of pedestrian LOS
W_t : Width of Lane
W_b : Width of Separation
W_s : Sidewalk Width
SPD_5 : Vehicle Speed
Vol_5 : Vehicle Volume

Applying the developed model, we estimate the perception of pedestrian LOS and compare it with the one from the pedestrian intercept survey. Figure 3 depicts the comparison. In this comparison, it is clear that the model produces realistic, consistent results.

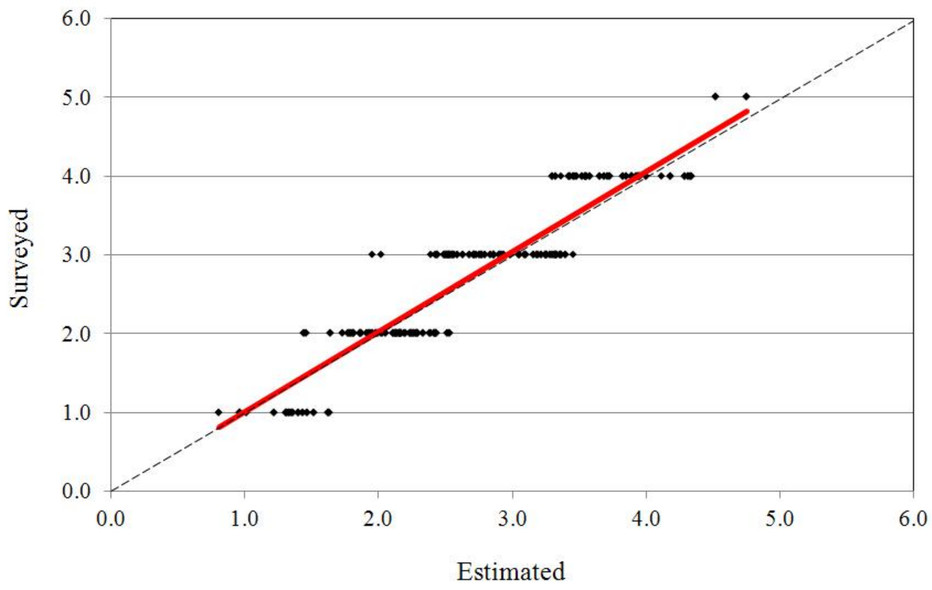

Figure 3. Estimated vs. Surveyed Perception of Pedestrian LOS

6. RESULTS AND DISCUSSION

In this section, the result of the perception of pedestrian LOS will be discussed along with key challenging issues. Atop the discussion list is the impact of including automobile related variables on the explanatory power of model. From Table 4, it is found that R^2 has increased sharply from 0.445 to 0.835, implying that pedestrian LOS is closely related to automobile variables. It is for this reason that the KHCM's pedestrian LOS procedure would not produce realistic results when comfort needs of pedestrians are the main issue of analysis.

According to the KHCM, pedestrian LOS is determined based on pedestrian density. However, a pedestrian LOS model in this study includes such independent variables as the width of shoulder lanes, the width of separation, the width of sidewalks, vehicle speed, and vehicle volume. The regression coefficients associated with each variable were in good agreement with existing research results (McLeod, 2000; Dowling 2008; Bian 2007). In the case of the USHCM, pedestrian LOS is expressed in multimodal perspective and pedestrian LOS in urban arterial is determined with a relatively complicated procedure. However, this paper demonstrates that a simple pedestrian LOS model is equally valuable.

In the quest for evidence that would demonstrate the level of model reliability, we undertook a separated pedestrian intercept survey at 10 field sites, which are different from the main field survey sites. At this time, pedestrian LOS is determined in three different ways including: (1) pedestrian intercept survey, (2) the KHCM method, and (3) the model as shown in Eqn. 2. As displayed in Figure 4, assuming that the pedestrian intercept survey provides true values, the KHCM's pedestrian LOS procedure provides only 30% accuracy in contrast with the result from the model, which approximately reaches a 70% accuracy. Hence, we come to a conclusion that an increased amount of the perception of pedestrian LOS within roadside walking environments is captured in this model.

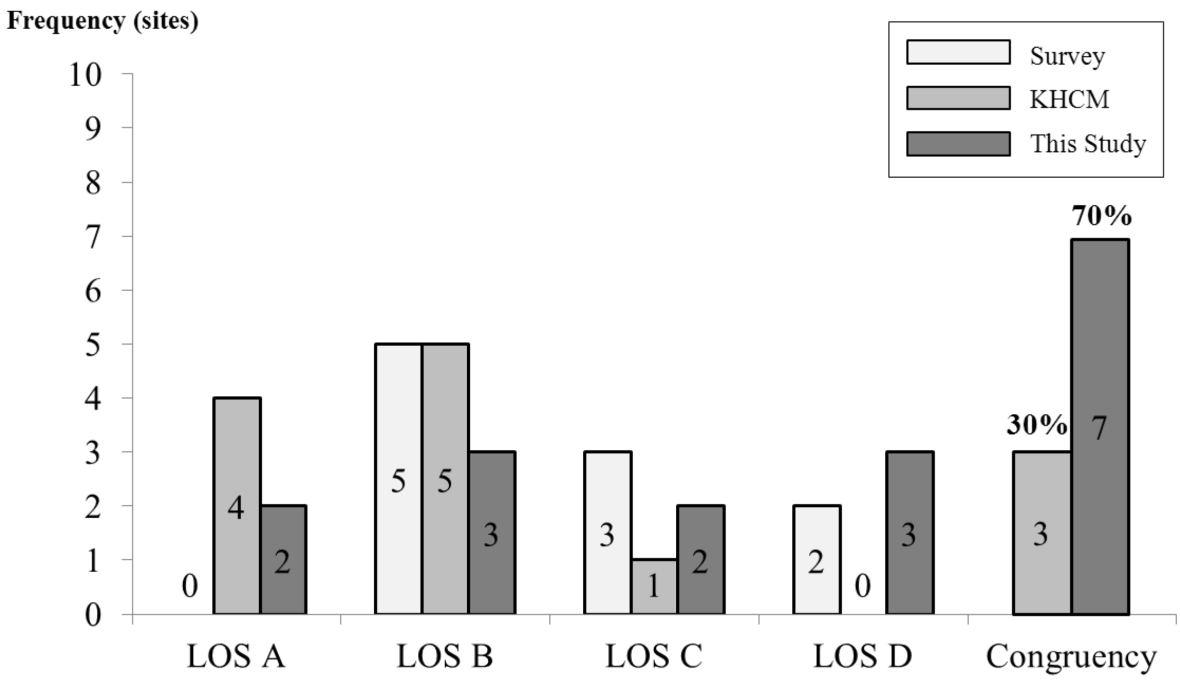

Figure 4. Verification of Model Reliability

7. FINDINGS AND CONCLUSIONS

With the primary purpose of applying the concept of the multimodal level of service to urban street designs, we investigated the perception of pedestrian level of service in roadside walking environments. The conclusions and findings in this paper are based on pedestrian intercept survey and can be summarized as follow:

- Current measure of effectiveness for determining pedestrian level of service in the KHCM is pedestrian density and this measure should be replaced with a more realistic measure of effectiveness, such as the level of pedestrian satisfaction.
- The impact of including automobile related variables on the explanatory power of the pedestrian LOS model is statistically significant.
- The perception of pedestrian LOS within roadside walking environments can be successfully captured in such a model as developed in this study

This result is by no means comprehensive, and we hope that this research will provide a starting point for understanding more pedestrian-friendly strategies of urban arterial designs.

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