Pedestrian Level of Service at Signalized Intersections in China Using Contingent Field Survey and Pedestrian Crossing Video Simulation

By

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Abstract

As China motorizes, the number of motorized vehicles and non-or semi-motorized vehicle conflicts is increasing. Pedestrians are the most vulnerable users of signalized intersections in urban areas and context sensitive methods are required to improve their experience.

This study proposes a reliable and convenient investigation method to estimate pedestrian level of service (LOS) based on Chinese traffic environments and Chinese pedestrians’ perceptions. A modified method of pedestrian simulation was developed, Pedestrian Crossing Video Simulation (PCVS) and the reliability and validity of the method was corroborated with Contingent Field Survey (CFS) analysis.

The LOS estimation methods were conducted on 12 selected crosswalks. Experimental results showed that PCVS has the characteristics of immersion and reality based on consistent perceptions of pedestrian LOS between the two methods.

Factors influencing pedestrian LOS were investigated using two approaches, Pearson correlation analysis and stepwise regression analysis. The regression analysis ($R^2=0.65$) revealed intuitive signs and magnitudes of significant variables that influence LOS; increases in delay, turning traffic, mixed two-wheeler volume, and pedestrian delay have negative impacts to LOS. Pedestrian volume and the presence of a refuge island enabling a two-step crossing both improve pedestrian LOS.
INTRODUCTION

As a healthy and sustainable trip mode, walking is an important part in urban traffic. Pedestrians are among the most vulnerable road users, particularly with increasing car and motorized two-wheeler traffic. According to the Chinese Ministry of Public Security (2011), 62,387 people died and 237,421 injured in the traffic accidents, about 25% were pedestrians. As intersections expand, it is becoming more difficult to traverse the roadway. There are several possible factors leading to the high ratio of pedestrian involved accidents in China: 1) right-of-way encroachment from cars while pedestrians are in crosswalk during pedestrian crossing phase (2); 2) road users breaking traffic rules, and priority rules are often not well obeyed (2,3); 3) researchers and management departments prioritize motorized vehicles, which result in many problems to pedestrians crossing (3,4,5,6) (e.g. Cherry (6) found the hostile intersection environment can lead to illegal midblock crossing).

Successful strategies to protect pedestrians and promote a pedestrian-friendly environment require an understanding of pedestrians’ altitude and perceptions while crossing, which is reflected by Pedestrian Level of Service (LOS).

Recent advances in pedestrian LOS place emphasis on pedestrian perceptions, in addition to objective measures of infrastructure, represented in the Highway Capacity Manual and Florida Department of Transportation (FDOT) LOS model (7,8). These approaches highlight the importance of perceived barriers to walking. But the LOS standards available were developed for the traffic conditions in the western countries. A significant feature of pedestrian travel environment in China is mixed traffic where pedestrians, cars and non-or semi-motorized two-wheelers (i.e. traditional bicycles and electric bikes) share the same road space (4,5,9). The applicability of western pedestrian LOS models to Chinese road conditions may not accurately represent pedestrians’ perception LOS. The different social cultures could also cause different effects to the pedestrian’s perception of pedestrian LOS. This paper proposes an approach to pedestrian LOS in the Chinese context.

In order to collect reliable data and create a pedestrian LOS model, numerous methods have been used for determining how pedestrian perceive their level of accommodation while crossing. However, the pedestrian crossing perception includes complex of psycho-physical factors. It is difficult to use a field survey and intercept survey while controlling for the actual conditions. Some researchers proposed simulation methods using still pictures, videos and animations to replace the actual transportation environment. Schwebel (10) proposed that this kind of methods should satisfy requirements of immersion and reality. But many existing studies rely on non-immersive techniques or the traffic environments applied in the experiment are simplistic.

How can we propose a reliable and convenient investigation method? Is there any difference between the pedestrian perception of LOS in a simulation environment and in the actual roadway environment? How could we evaluate pedestrian LOS based on the Chinese traffic environment and Chinese pedestrian’s perception of LOS? This paper aims to answer these questions. A new video simulation method, Pedestrian Crossing Video Simulation (PCVS) was developed, tested and compared to a field survey. Then a statistically reliable pedestrian LOS model was developed for signalized intersections. The remainder of this paper is organized as follows. A literature review of pedestrian LOS models and pedestrian LOS investigation methods to collection pedestrian response to traffic environment are given.
Ling, Ni, Cherry and Li

in the next session, followed by methodology, result and discussion, finally conclusions.

BACKGROUND

Pedestrian LOS model at signalized intersections

Many efforts have been devoted to development of a reliable and quantifiable pedestrian LOS measure, especially in western countries. Research on pedestrian LOS could be described in three stages. In the first stage, the most notable is HCM2000 (11). It provides two methods for calculating pedestrian LOS at signalized intersections: pedestrian delay and pedestrian space. In the second stage, many researchers attempted to include the environmental factors. Lautso and Murole (12), Sarkar (13), Khisty (14), Miller (15), Dixon (16) and others put forward numerous qualitative and quantitative measures that included many possible environmental factors. The third stage began to discuss pedestrian LOS based on pedestrians’ perception of safety and comfort, which is represented by the HCM2010 pedestrian LOS model at intersections (7). The methodology proposed by HCM2010 provides a variety of measures for evaluating pedestrian LOS. Each measure describes a different aspect of the pedestrian trip through the intersection. A study from China using intercept survey investigated pedestrian LOS at intersections from pedestrians’ perceptions of comfort and safety (17). However, the accuracy of that model may need to be improved.

Pedestrian LOS investigation methods

Numerous data collection methods have been used to obtain the pedestrians’ responses to the intersection environment stimuli and to determine what factors pedestrians view as significantly important when evaluating pedestrian LOS. According to the subjects and study locations, collection methods were mainly classified into five categories (18).

The Observational Method calculates the pedestrian LOS based on the observation of the crossing process of in-situ pedestrians. The factors were easily captured, such as pedestrian density, delay and so on. Hubbard (19) proposed an evaluation method of pedestrian LOS according to the result of observing the yielding behavior of turn vehicles and pedestrian.

Using an Intercept Survey (18) to interview people after they have traversed a crosswalk at intersection and asking them to grade the crossing. Bian et al. (17) used this method to estimate the pedestrian’s perception of comfort and safety of signalized intersections in China. She also used this method to develop a model to evaluate pedestrian LOS for sidewalks in China (20).

A Contingent Field Survey (CFS) involves walking with subjects on a course and grading each crosswalk on scale immediately after they have traversed the intersection. Usually this method is designed to elicit responses of subjects walking individually, not in pairs or groups. This method was used by Petritsch et al. (8) and FDOT to develop the pedestrian LOS and bicycle LOS models for intersections and segments.

Controlled Field Valuation involves taking subjects to different intersections and letting surveyors observe then grade the crosswalk without actually making the crossing. FDOT used this method in developing a LOS model for pedestrian mid-block crossings (18). some methods were used to indicate crossing behavior, such as two-step technique and shout technique where the subjects should walk two steps or shout to instead of real crossing (14, 21, 22), though pedestrians made no real crossing.

Laboratory/Simulation Studies involve having the subjects view a representation (a
video or photo or virtual reality) of the pedestrian environment. The subjects then grade crosswalks based on the presentation. While the other methods usually involve independent evaluations by individual participants, this method allows surveyors to discuss in groups (18).

Although each method has its advantages and drawbacks, there are no advanced pedestrian LOS studies in China. This study combines a contingent field study and laboratory/simulation studies in China. The intent of the current paper is to add the growing body of literature on data collection methods of pedestrian LOS.

LEVEL OF SERVICE INVESTIGATION DESIGN

Pedestrians typically express their opinions of how well a particular intersection by referring to the perceived safety and comfort when crossing at a signalized intersection (8). As a result, the pedestrian LOS in this study reflects pedestrians’ perception of crossing in safety and comfort two aspects, which is identical to the concept used by HCM2010(7), Petritsch (8) and so on. Two methods were created to obtain the pedestrians’ response to the traffic environment when crossing at signalized intersections. One is Contingent Field Survey (CFS) (8), and the other is Pedestrian Crossing Video Simulation (PCVS).

Contingent Field Survey

CFS placed participants on a roadway course and through various crosswalks at signalized intersections. The purpose was to obtain the pedestrians’ real-time perceived LOS at crosswalks and to create and test a mathematical relationship of quantifiable factors to reflect pedestrian LOS. Participants should go cross streets individually, rather than in pairs or in groups formed by the recruited participants. But they can cross streets with other pedestrians, which are not recruited by researchers. Participants were encouraged to mix into the general population. All experiments were conducted in natural crossing situation. The survey was held on Monday, April 9th and Wednesday, April 25th, 2012 in Shanghai, China from 12:30 to 17:00. Both days were sunny and warm.

Participants

To ensure a large participant for data analysis purposes, the study team sought both volunteer and paid participants through on-line notices. 44 respondents were selected, including students, company staff, workers and retired people. The participants ranged in age from 12 to 75. Over half (57%) of participants live in downtown Shanghai and the others live in Shanghai’s suburbs. Demographics of the participants are shown in Table 1.

<table>
<thead>
<tr>
<th>TABLE 1 Basic Information of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>48%</td>
</tr>
</tbody>
</table>

Site Selection

To cover the typical traffic and roadway conditions in Chinese metropolitan areas, 12 intersection crossings (from 6 intersections) were selected, showed in Figure 1. These
Intersections ran through a broad spectrum of land uses, including shopping centers, residential districts, Tongji University, hospitals and offices. These selected intersections have a variety of configuration and traffic conditions. The main characteristics of the 12 crosswalks are presented in Table 2.

**FIGURE 1 Selected Sites for Survey**

**TABLE 2 Main Characteristics of the 12 Crosswalks**

<table>
<thead>
<tr>
<th>NO.</th>
<th>Site</th>
<th>Crossing distance/Lane to cross</th>
<th>Signal phase/ Cycle time/ Pedestrian red phase</th>
<th>Safety island(Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Siping Rd &amp; Zhangwu Rd</td>
<td>34m/6 lanes</td>
<td>3 phase /140s/83s</td>
<td>Y</td>
</tr>
<tr>
<td>2</td>
<td>Siping Rd &amp; Zhangwu Rd</td>
<td>25m/4 lanes</td>
<td>3 phase /140s/123s</td>
<td>N</td>
</tr>
<tr>
<td>3</td>
<td>Quyang Rd &amp; Yutian Rd</td>
<td>40m/5 lanes</td>
<td>3 phase /220s/160s</td>
<td>N</td>
</tr>
<tr>
<td>4</td>
<td>Quyang Rd &amp; Yutian Rd</td>
<td>17m/2 lanes</td>
<td>3 phase /220s/114s</td>
<td>N</td>
</tr>
<tr>
<td>5</td>
<td>Dalian Rd &amp; Feihong Rd</td>
<td>42m/10 lanes</td>
<td>3 phase /210s/126s</td>
<td>Y</td>
</tr>
<tr>
<td>6</td>
<td>Dalian Rd &amp; Feihong Rd</td>
<td>22m/5 lanes</td>
<td>3 phase /210s/90s</td>
<td>N</td>
</tr>
<tr>
<td>7</td>
<td>Zhoujiazui Rd &amp; Dalian Rd</td>
<td>45m/10 lanes</td>
<td>4 phase /205s/138s</td>
<td>Y</td>
</tr>
<tr>
<td>8</td>
<td>Zhoujiazui Rd &amp; Dalian Rd</td>
<td>52m/10 lanes</td>
<td>4 phase /205s/157s</td>
<td>N</td>
</tr>
<tr>
<td>9</td>
<td>Sichuan Rd &amp; Haining Rd</td>
<td>40m/10 lanes</td>
<td>3 phase /210s/143s</td>
<td>Y</td>
</tr>
<tr>
<td>10</td>
<td>Sichuan Rd &amp; Wujin Rd</td>
<td>14m/4 lanes</td>
<td>2 phase /200s/88s</td>
<td>N</td>
</tr>
</tbody>
</table>
Investigation Design

The CFS included three parts: preparation process, experiment process and data collection shown in Figure 2. Each participant was provided a scorecard and a questionnaire to carry during his or her individual walk. On the left side of the score card was maps with the numbered crosswalks and crossing direction shown, on the right side, participants would score crosswalks from 1-5. On the questionnaire, there are questions related to factors on pedestrian LOS. The researchers led participants to the intersection and let them cross the intersection randomly. To make sure the investigation reliable and practical, the number of participant pedestrians of every contingent was less than 5. They were forbidden to chat or change their opinions during the whole crossing process. Focusing on designing for desirable behavior, participants were told to obey the traffic signals when crossing the intersections. Since the pedestrians crossed streets with motorized vehicles (e.g. Right-turn-on-red), a degree of risk was involved. This was explained to the participants during recruitment and training.

Extensive video data were collected at each crosswalk. A digital video camera was installed above observation area. The pedestrian waiting area, crosswalk, signal and central safety island (if present) were visible in the video. If the camera could not be set above the observation, the appropriate placement was chosen far enough from the crosswalk to prevent any possible influence on pedestrian behavior. A total of 413 experimental observations were...
collected, among which 383 responses were effective.

**Pedestrian Crossing Video Simulation (PCVS)**

Field study can get the real-time response of pedestrian. However it requires extensive resources for the data collection process. According to the characteristics of pedestrian crossing, this paper proposed Pedestrian Crossing Video Simulation (PCVS). The core concept of PCVS is to utilize video simulation technology to present a virtual pedestrian crossing environment through a group of screens to participants with video and audio inputs to enhance immersion and reality.

There are two primary purposes of PCVS. One purpose was to develop a reliable lab method to evaluate pedestrian LOS for existing or planned environments. Participants were able to view and rate complex intersections with high traffic volumes that would have imposed higher risk if experienced in field. An additional purpose was to enhance the comparison of various pedestrians’ attitudes to a same traffic environment and allow researchers to exert more experimental control of the pedestrian environment.

To ensure a consistent recording methodology, and one which reflects typical pedestrians’ scanning behavior, we test several styles of videos which were recorded from different angles. Using Corel Video Studio, videos were edited into different styles, such as simultaneously viewing a scene from above and standing still while scanning horizontally, to walking while scanning horizontally while simultaneously seeing the scene from above. Eight graduate students from the department of transportation engineering in Tongji University were recruited to test the feasibility of PCVS' immersion and reality in different styles. After they finished the feedback questionnaire, a focus group was conducted to discuss the improvement of PCVS. Based on comments received during the pilot survey and discussion, the researchers revised the video protocol and investigation.

**Creation of the video**

Videotaping was performed using three cameras of the same type. To simulate pedestrians’ vision during the whole crossing process, a continuous image was recorded from pedestrians’ left, ahead and right perspective in eye level (in China, average eye level is about 1.55m), shown in Figure 3(a). The three cameras were placed at the same level and in the same focal distance to assure a consistent experience across the screens. The field of view of the three cameras was aligned to assure a consistent wrap-around image. The similar traffic environment with contingent field study was chosen to record for three signal cycles of every crosswalk.

**Experiment scenario**

In order to match visual angle to the real-traffic environment, three videos were played synchronously in three computers, whose three respective screens were arranged in a semi-circle representing one continuous image to the participant from his/her left, ahead and right perspective (see Figure 3(b), (c)). The position and angel of each screen can also be adjusted adapting for individual participants.

Because we hope to develop PCVS as a replaceable method of field study, it was critical to index the sound level of PCVS to the physical environment. The sound was set so it matched the sound in real traffic by stereo speakers.

**Investigation Design**

The investigation process is shown in Figure 4. To ensure that the participants have a
Ling, Ni, Cherry and Li

To ensure a comprehensive understanding of the experiment and assure the accuracy of collected data, the PCVS experiment requires the following three steps.

**Step 1:** Introduce experiment’s purpose. A presentation should be shown to the participants regarding the viewing procedure, assessment of intersections, and the corresponding grading instructions.

**Step 2:** PCVS experiment. After being briefed, participants were directed to the video room themselves. During the experiment, participants are expected to become immersed (to the extent possible) in the traffic environment and judge their perceptions of the intersection crossing.

**Step 3:** Questionnaire. Participant should grade the each crosswalk after viewing.

(a) The picture of video recording  
(b) PCVS work scenario

(c) The crossing Scenario Participant Viewed

**FIGURE 3 PCVS Work Scenario**

**FIGURE 4 The Work Flow of PCVS**
PCVS’s Reliability and Validity

To judge whether an experiment is scientific and reasonable, it is necessary to analyze the experimental results, but also to test the whole process from a systems point of view as well (23). Reliability and validity calibration were used to test the effectiveness of PCVS.

To this end, 19 participants ages 20-55 were recruited from Tongji University and Yangpu district in Shanghai (7 male, 12 female). The sample included individuals from different backgrounds of income, education and occupation. Six crosswalks were tested (No.1-4, 11-12), 114 observations were collected and test questionnaires were finished.

In this study, the Cronbach’s coefficient was applied to evaluate internal consistency of the crossing distance and the waiting time, focusing on reliability between the two methods. According to previous research, Cronbach’s coefficient > 0.65 will be acceptable (24). The reliability analysis result is shown in Table 3(a).

Validity refers to the extent to which a concept, conclusion or measurement is well-founded and corresponds accurately to the real world. In the field of behavioral science, from the 1990s many validity models have been developed, including Content Validity (including Face Validity), Criterion-Related Validity, and Construct Validity (19-20). In this experiment, Face Validity refers to the participants’ intuitive judgment of the reality and sickness of the experiment environment. This research used five-grade marking to grade each answer of questions. “5” stands for very well, and “1” stands for very bad. A questionnaire on the above two aspects of questions was carried out after each participant completing the experiment to measure the Face Validity. The result of Face Validity is shown in Table 3(b). According to the results of reliability and Face Validity analysis, PCVS has a good effectiveness.

### TABLE 3 PCVS’s Reliability and Validity

<table>
<thead>
<tr>
<th>(a) PCVS Reliability Analysis</th>
<th>(b) PCVS Face Validity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cronbach’s Alpha</strong></td>
<td><strong>Items</strong></td>
</tr>
<tr>
<td>Crossing distance</td>
<td>Definition of video</td>
</tr>
<tr>
<td></td>
<td>Ave. 4.50 Std. 0.70</td>
</tr>
<tr>
<td>Waiting time</td>
<td>The sound’s influence to the immersion</td>
</tr>
<tr>
<td></td>
<td>Ave. 4.10 Std. 0.63</td>
</tr>
<tr>
<td></td>
<td>Simulation sickness, such as nausea and disorientation</td>
</tr>
<tr>
<td></td>
<td>Ave. 3.98 Std. 0.57</td>
</tr>
</tbody>
</table>

RESULT ANALYSIS

Comparison of two survey methods

Consistency of two survey methods analysis

Participants were the 44 recruited people of contingent field study. The selected crosswalks were the same as contingent field study except crosswalk No. 9. Following the process above, 358 samples of participants’ perceived pedestrian LOS were collected.

During PCVS experiment, participants were asked whether the traffic environment is
different from real field. 5 possible answers were provided in the questionnaire: “very different”, “a little different”, “generally consistent”, “relatively consistent”, and “very consistent”. The result shown in Figure 5 illustrated that only 9% participants thought the PCVS was “a little different” from the reality and 2% thought it was “very different” from reality. PCVS could reflect pedestrian crossing reasonably well. According to the feedback from these participants, the conflicts between non-motorized vehicles and pedestrians were different from reality. The main cause is the randomness of traffic flow.

**FIGURE 5 The Consistency of PCVS and CFS**

**Comparison of two survey methods’ grading results**

Figure 6 shows the result of two survey methods’ grades of 12 crosswalks. The horizontal axis represents the crosswalk number and vertical axis represents the average grade of every crosswalk. Independent-Samples t-test was used to calibrate the difference of two survey method’s grading results. It turns out that only No.10 crosswalk’s results have significant difference between CFS and PCVS ($P$ value=0.000). The main reason is that the traffic flow recorded in PCVS is quite different from that when CFS conducted.

**FIGURE 6 Comparison of Two Survey Methods’ Grading Results**

Note: No.9 crosswalk did not grade with PCVS method

There are 6 crosswalks’ where grades of PCVS are lower (though insignificant) than those of CFS. According to the discussion and suggestion from participants, there are two
potential reasons for this. One reason was that in PCVS participants saw the whole process of
conflicts between pedestrians and vehicles and non-motorized vehicles. However, in the field
survey pedestrians usually cross in groups and do not have as much individual interaction
with non-motorized and motorized vehicles. So participants were inclined to grade the same
crosswalk of PCVS lower than that of CFS. An additional reason was that participants focus
on the traffic environment on screens more explicitly so that they had less distracting sensory
inputs than in the field survey. The intersections were analyzed under representative
pedestrian and auto-traffic conditions. It is possible that different traffic conditions could yield
disparity between PCVS and CFS. It is important to schedule testing in such a way to limit
this disparity.

Factors of pedestrian LOS

Pedestrians’ perceived factors

After the CFS, participants were asked to subjectively choose important factors of pedestrian
LOS among 17 possible factors. Participant also ranked the importance of the six most
important factors that influence LOS on a scale of 1-6 (6 is the most important and 1 is least
important). “Pedestrians mixed with cyclists” means cyclists who cross street riding bicycles
or motorized two wheeler during pedestrian green time.

Figure 7 (a) lists eight important factors each chosen by more than 50% of participants.
Participants perceived important factors of pedestrian LOS includes: crossing distance, the
existence of refuge island, pedestrians crossing mixed with cyclists, pedestrian red time,
pedestrian flashing green time, conflict with turning motorized vehicles, conflict with turning
non-motorized vehicles, and turning vehicles’ speed.

Figure 7 (b) shows the rating of intersection attributes and that existence of refuge island,
whether the pedestrian red time is too long and whether there are conflicts with turning
motorized vehicles are the most important factors chosen by the participants, and they are the
primary consideration of more than 50% participants when crossing. The existence of refuge
islands is chosen as the most important factor by 80% participants. Therefore, refuge islands
are suggested to be planned when the distance of the crosswalk is quite long.

Pedestrians mixed with two-wheeler traffic, whether there are conflicts with vehicles,
and the pedestrian flashing green time are the top three among the relatively important factors.
Three factors chosen by most participants as the fifth and sixth important ones are whether
there is conflict with non-motorized vehicles, turning vehicle speed, and crossing distance.

Relevant factors of pedestrian LOS

Using data from the CFS, we investigate factors important to pedestrian LOS from literature
(Table 4(a)) and compare to data from the CFS by estimating Pearson correlation and factor
analysis, shown in Table 4(b). Other factors were dropped from further consideration because
of their poor correlation with the dependent variable, LOS score for the pedestrians crossing
at signalized intersections. Pedestrians’ perceived factors are largely consistent with the
results from Pearson Correlation analysis except turning vehicles’ speed. Moreover, all of the
relevant factors of pedestrian LOS could be reflected in PCVS, which shows PCVS can be an
effective investigation approach to assess pedestrian LOS.
FIGURE 7 Pedestrians’ Perceived Factors of Pedestrian LOS

TABLE 4 Relevant Factors of Pedestrian LOS

(a) Possible factors influencing pedestrian LOS at signalized intersections

<table>
<thead>
<tr>
<th>Possible factors</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waiting for crossing</td>
<td>Motorized vehicle volume</td>
</tr>
<tr>
<td></td>
<td>1. Left turning, straight, right turning</td>
</tr>
<tr>
<td></td>
<td>2. Entering and leaving intersection</td>
</tr>
<tr>
<td></td>
<td>(pcu represents “passenger-car unit”)</td>
</tr>
<tr>
<td></td>
<td>(Entering vehicles are those in approaches which mean they will go across the stop line. Leaving vehicles are in the opposite direction of entering vehicles.)</td>
</tr>
<tr>
<td></td>
<td>3. Entering and leaving intersection</td>
</tr>
<tr>
<td></td>
<td>(pcu represents “passenger-car unit”)</td>
</tr>
<tr>
<td></td>
<td>(Entering vehicles are those in approaches which mean they will go across the stop line. Leaving vehicles are in the opposite direction of entering vehicles.)</td>
</tr>
</tbody>
</table>
| Non-motorized vehicle volume | 1. Left turning, straight, right turning veh/cycle  
| Motorized vehicle volume | 1. Left turning, straight, right turning pcu/cycle  
| Non-motorized vehicle volume | 2. Entering and leaving intersection veh/cycle  
| U turning Motorized vehicle volume | pcu/cycle  
| During crossing | Mixed cyclist volume | Cyclists mixed with pedestrians veh/cycle  
| Presence of refuge island | 0/1: 0 no island, 1 has island  
| Presence of two-step crossing | 0/1: 0 single step, 1 two-step  
| Pedestrians volume at the beginning of green time | One-side  
| Lanes to cross | Number  
| Pedestrian delay | In seconds (including waiting time and the time lapse since conflict with vehicles)  
| Crossing distance | In meters  

### (b) Pearson Correlations of key factors

<table>
<thead>
<tr>
<th>Factors</th>
<th>N</th>
<th>Pearson Correlation</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Waiting for crossing</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaving straight motorized vehicles</td>
<td>383</td>
<td>-0.226**</td>
<td>0.000</td>
</tr>
<tr>
<td>Entering straight motorized vehicles</td>
<td>383</td>
<td>-0.229**</td>
<td>0.000</td>
</tr>
<tr>
<td>Entering straight non-motorized vehicles</td>
<td>383</td>
<td>-0.131*</td>
<td>0.038</td>
</tr>
<tr>
<td><strong>During crossing</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaving left-turning motorized vehicles</td>
<td>383</td>
<td>-0.181*</td>
<td>0.040</td>
</tr>
<tr>
<td>Leaving left-turning non-motorized vehicles</td>
<td>383</td>
<td>-0.336**</td>
<td>0.000</td>
</tr>
<tr>
<td>Entering right-turning motorized vehicles</td>
<td>383</td>
<td>-0.299**</td>
<td>0.000</td>
</tr>
<tr>
<td>Entering right-turning non-motorized vehicles</td>
<td>383</td>
<td>-0.316**</td>
<td>0.000</td>
</tr>
<tr>
<td>Pedestrians volume at the beginning of green time</td>
<td>383</td>
<td>0.0205**</td>
<td>0.001</td>
</tr>
<tr>
<td>Lanes to cross</td>
<td>383</td>
<td>-0.042*</td>
<td>0.038</td>
</tr>
<tr>
<td>Mixed cyclists volume</td>
<td>383</td>
<td>-0.205**</td>
<td>0.001</td>
</tr>
<tr>
<td>U turning Motorized vehicle volume</td>
<td>383</td>
<td>-0.401**</td>
<td>0.000</td>
</tr>
<tr>
<td>Pedestrian delay</td>
<td>383</td>
<td>-0.700**</td>
<td>0.000</td>
</tr>
<tr>
<td>Presence of refuge island</td>
<td>383</td>
<td>0.169**</td>
<td>0.008</td>
</tr>
<tr>
<td>Presence of two-step crossing</td>
<td>383</td>
<td>0.169**</td>
<td>0.008</td>
</tr>
</tbody>
</table>

Note: *p<0.05; **p<0.01
MODEL DEVELOPMENT AND DISCUSSION

Model development

A pedestrian LOS model was developed using 383 samples from the CFS. Relevant factors of pedestrian LOS were taken into account in the successive transformation test and stepwise regression analysis. Finally, integrating the results of Pearson correlation analysis and stepwise regression analysis, the relevant variables were estimated (Table 5). The coefficient signs and magnitudes are intuitive, where LOS starts at approximately A (constant=5.3) and reducing with delay, turning traffic, mixed two-wheeler volume, and pedestrian delay have negative impacts to LOS. Pedestrian volume (safety in numbers) and the presence of a refuge island enabling a two-step crossing both improve pedestrian LOS.

\[
\text{LOS}_{\text{ped}} = \alpha_0 + \alpha_1 J^M_L + \alpha_2 C^B_L + \alpha_3 N_{\text{ped}} + \alpha_4 N^{B}_{\text{mixed}} \\
+ \alpha_5 T_{\text{delay}} + \alpha_6 \left( S_t + S_c \right)
\]

<table>
<thead>
<tr>
<th>Relevant variables</th>
<th>Model Terms</th>
<th>Coefficients</th>
<th>T-statistics</th>
<th>Significance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entering right-turning motorized vehicles (pcu/cycle)</td>
<td>$J^M_L$</td>
<td>-0.080</td>
<td>-4.789</td>
<td>0.000</td>
</tr>
<tr>
<td>Leaving left-turning non-motorized vehicles (veh/cycle)</td>
<td>$C^B_L$</td>
<td>-0.079</td>
<td>-4.479</td>
<td>0.000</td>
</tr>
<tr>
<td>Pedestrians volume at the beginning of green time (ped/cycle)</td>
<td>$N_{\text{ped}}$</td>
<td>0.023</td>
<td>2.332</td>
<td>0.021</td>
</tr>
<tr>
<td>Mixed cyclists volume (veh/cycle)</td>
<td>$N^{B}_{\text{mixed}}$</td>
<td>-0.075</td>
<td>-9.438</td>
<td>0.000</td>
</tr>
<tr>
<td>Pedestrian delay (s)</td>
<td>$T_{\text{delay}}$</td>
<td>-0.021</td>
<td>-16.472</td>
<td>0.000</td>
</tr>
<tr>
<td>Presence of refuge island (0/1)</td>
<td>$S_t$</td>
<td>0.468</td>
<td>5.232</td>
<td>0.000</td>
</tr>
<tr>
<td>Presence of two-step crossing (0/1)</td>
<td>$S_c$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>$\alpha_0$</td>
<td>5.337</td>
<td>44.816</td>
<td>0.000</td>
</tr>
</tbody>
</table>

$N=383 \quad R^2=0.652$

The following shows pedestrian LOS classifications, where $Y$ is the model’s numerical result. According to the perception responses, the medium LOS was 2.5, considering its symmetry, the scale was determined to be:

- LOS A: $Y \geq 4.5$
- LOS B: $3.5 < Y \leq 4.5$
- LOS C: $2.5 < Y \leq 3.5$
- LOS D: $1.5 < Y \leq 2.5$
- LOS E: $0.5 < Y \leq 1.5$
Analyzing the model with consideration of independent variables, we conclude that:

1) Refuge islands and the control of two-step crossing considerably influence LOS. Include refuge islands and two-step crossing will improve pedestrian perceived LOS, equal to more than 20 seconds of reduced delay.

2) LOS rises with increase of the pedestrians' number at the beginning of green light. It indicates that the individual safety and comfort of pedestrians are fairly high when pedestrians cross in groups. Since motorized vehicles often find it difficult to push through groups, they tend to yield to pedestrians.

3) LOS decreases when volume of leaving left-turning non-motorized vehicles and that of entering right-turning motorized vehicles increase. Both of them conflict directly with pedestrians, which influenced pedestrians' safety and comfort. Therefore, these vehicle flows should be isolated from pedestrians in time or space in the intersection design and management, in order to provide pedestrians better crossing environments.

4) Cyclists riding with non- or semi-motorized two-wheel vehicles interfere pedestrians' crossing and influence pedestrian LOS when those cyclists cross street with pedestrians (in the crosswalk).

5) Pedestrians' delay time includes both their waiting time and the time during which they are blocked in the crosswalks. Pedestrians' LOS reduces as the delay time increases, as expected.

6) HCM2010 did not take the influence of non- or semi-motorized vehicle conflicts on pedestrians' perception. However, the result indicates both leaving left-turning non-motorized vehicles and mixed cyclists volume are relevant variables of pedestrian LOS.

CONCLUSION

The purposes of this study was to develop a cost-effective approach to assess pedestrian LOS in a new environment using cultural and geography-specific attributes, and attempt to develop a pedestrian LOS model in China whose transportation environment is quite different from developed countries.

Pedestrian Crossing Video Simulation (PCVS) was developed and the reliability and validity were corroborated using CFS data. Experimental results show that PCVS has the characteristics of immersion and reality. The PCVS design employed for this study is described in this paper. Also, this method would be useful to other countries more than China.

Of the 12 selected crosswalks, all but one shows no statistically significant difference in the respective ratings of pedestrian LOS. However participants were inclined to grade the same crosswalk of PCVS slightly lower than that of CFS, in part because of the more controlled experimental environment and the wide-angle vision.

Pedestrians' perceived factors are largely consistent with the results from Pearson Correlation analysis except turning vehicles' speed. What’s more, all of the relevant factors of pedestrian LOS could be reflected in PCVS which shows that PCVS can be an effective tool to investigate pedestrian LOS.

Integrating the results of Pearson correlation analysis and stepwise regression analysis, the relevant variables were determined to be: entering right-turning motorized vehicles,
leaving left-turning non-motorized vehicles, pedestrians volume at the beginning of green
time, mixed cyclists volume, pedestrian delay, presence of refuge islands and presence of
two-step crossing. The resulting general model for the Pedestrian LOS at signalized
intersections is reliable, with a high goodness-of-fit ($R^2=0.65$). Many of the variables are
similar to western pedestrian LOS approaches (HCM 2010), but this study finds some factors
more relevant to China. The researchers will validate and improve the pedestrian LOS model
with more intersections and pedestrians.

This paper outlines a replicable approach to investigate pedestrian LOS and presents
results from a study in Shanghai, providing researchers, planners and engineers with
China-specific tools and results to improve the pedestrian experience at intersections.

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