Assessment of Quality Level of Service of Pedestrian Sidewalk

Tien-Pen Hsu  
Associate Professor  
Civil Engineering  
National Taiwan University  
No. 1, Sec. 4, Roosevelt Road, Taipei 106-17, Taiwan (R.O.C)  
Fax: +886-2-363-1558  
E-mail: hsutp@ntu.edu.tw

Yu-Chu Yang  
Research Assistant  
Civil Engineering  
National Taiwan University  
No. 1, Sec. 4, Roosevelt Road, Taipei 106-17, Taiwan (R.O.C)  
Fax: +886-2-363-1558  
E-mail: r98521508@ntu.edu.tw

Yi-Ting Lin  
Research Assistant  
Civil Engineering  
National Taiwan University  
No. 1, Sec. 4, Roosevelt Road, Taipei 106-17, Taiwan (R.O.C)  
Fax: +886-2-363-1558  
E-mail: r97521518@ntu.edu.tw

Pei-Ju Wen  
Research Assistant  
Civil Engineering  
National Taiwan University  
No. 1, Sec. 4, Roosevelt Road, Taipei 106-17, Taiwan (R.O.C)  
Fax: +886-2-363-1558  
E-mail: r99521512@ntu.edu.tw

Abstract: To provide high quality walking space for pedestrian is one of the most important measures to achieve a sustainable urban living environment. A good pedestrian space has to fulfill the multi-objective requirements of road users. Therefore, this paper presents a comprehensive assessment model for pedestrian space. The assessment model is established by using Fuzzy classification method based on a survey of pedestrian perception on service quality of pedestrian space in comparison with the field observed value of evaluation criteria. The assessment results using the model developed in this study are proven consistent with the perception of the pedestrian. The model is then practically useful. The model is applied to assess the streets in Taipei city center. The results reflex the sidewalk quality level in Taipei is needed to be improved. The model is then a useful tool to assess the quality of sidewalk.

Key Words: Pedestrian sidewalk, multi-criteria evaluation, Level of service, Fuzzy classification

1. INTRODUCTION

In recent years, pedestrian space has gradually been concerned seriously. The assessment of the quality of pedestrian space contains a lot of different assessment methods, basically by measuring the capacity for level of service assessment, for example, the method from the Highway Capacity Manual (HCM, 1985). However, this method is only capacity-based, not considering factors like the comfort and safety in pedestrian space. By various requirements of the public for the level of service in pedestrian space, it is necessary to conduct the multi-criteria evaluation. The assessment should take into account with multiple objectives (Yeh, 1997), for example, considering the subjective experiences with the pedestrian, including the comfort, convenience, safety and security, aesthetics, the effectiveness of capacity (HCM, 1985).

A fully user-friendly transportation system has an integrative quality of friendly sidewalk and pedestrian plaza with good pavement quality, high accessibility, beautiful landscape, comfortable and convenient environment (Hsu, 1994). Assessment of the level of service for
pedestrian space can be conducted directly by asking for the satisfaction of the public. However, for investigating the improvement need for pedestrian facilities, the provision quality of the pedestrian facility should be explored. Therefore, this paper combined these two concepts. A series of evaluation criteria are created firstly, and then execute the classification of the level of service according to the pedestrian satisfaction degree. Through the comparison with the existing facility level, a comprehensive level of service evaluation model is then established. As a result, if the location has the poor level of service, through checking the score of evaluation criteria, the improvement countermeasures can be identified through enhance the score of the evaluation criteria.

To integrate multiple criteria into a comprehensive index, an expert questionnaire survey is conducted to obtain subjective weight value by using Analytic Hierarchy Process (AHP), and another objective weight value of the criteria is created by using the Entropy Method basing on the facility provision situation using the relative difference level between the investigated sidewalks. The weight value of the evaluation criteria is obtained by average of the subjective weight value and objective weight value. Thereafter, by using the Fuzzy Classification Method, the comprehensive assessment index is divided into six categories of quality level of service, which becomes an integrated assessment system finally.

2. ASSESSMENT MODEL OF PEDESTRIAN SPACE

2.1 The structure of assessment model

A high quality and comfortable pedestrian space should provide three basic functions simultaneously, which are transport probability, user friendliness and social sustainability. First, transport probability function is to provide pedestrian a good walking environment as the basic requirement, including accessibility, safety, convenience, continuity, and disaster prevention for pedestrian etc. Second, the user friendliness means that a pedestrian space should be able to meet various objectives such as comfort, simplicity, accessible information, and more convenient by means of technology for users. Third, Social sustainability is to supply pedestrian space for communication, leisure and activity for encouraging the elderly people and children to enjoy the convenience and comfort of transport services. Therefore, the evaluation model of pedestrian sidewalk should consider many aspects. The evaluation criteria, i.e. indexes in this paper come out from the concept of human friendly environment and providing a public transportation-oriented of urban development to achieve walkable city. Through a searching for all of the factors that may affect the quality of pedestrian sidewalk, a framework of evaluation criteria is then organized. Basing on the three functions mentioned above, seven criteria are selected by expertise discussion and questionnaire survey to be seen as the most important factors are selected to establish the comprehensive assessment model, which are shown in Table 1. The criteria include effective width of the pedestrian space, the quality of pedestrian space pavement, barrier-free level of pedestrian space, the proportion of obstructions on pedestrian space, landscape order index, the ratio of with-sidewalk street length, and the ratio of facilities for disables. The seven evaluation criteria are summarized in Table 1 based on functions, objectives and the criteria.
Table 1 Comprehensive assessment model of pedestrian space

<table>
<thead>
<tr>
<th>Function</th>
<th>Objective</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessibility</td>
<td>Transport Probability</td>
<td>Effective width of the pedestrian space (EW)</td>
</tr>
<tr>
<td>Safety</td>
<td>Safety</td>
<td>The quality of pedestrian space pavement (QP)</td>
</tr>
<tr>
<td>Continuity</td>
<td>Continuity</td>
<td>The ratio of barrier-free facility of pedestrian space (BF)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The proportion of obstructions on pedestrian space (PO)</td>
</tr>
<tr>
<td>User Friendliness</td>
<td>Simplicity</td>
<td>Landscape order index (LI)</td>
</tr>
<tr>
<td>Social Sustainability</td>
<td>Equity</td>
<td>The ratio of with-sidewalk street length (RS)</td>
</tr>
<tr>
<td></td>
<td>Affordability</td>
<td>The ratio of facilities for disabilities (RO)</td>
</tr>
</tbody>
</table>

3.2 Criteria and Quantitative Approach

The pedestrian space of the comprehensive assessment in this study is defined as net width of the walking space for pedestrian with pavement. Each indicator in comprehensive assessment model has different investigation approach by its own definition. Both sidewalks on a street are counted together with each section of street. The definitions of the criteria, survey approach, and their quantitative methods are as following:

- The ratio of with-sidewalk street length (RS): the length of sidewalks along the roads or alleys with the proportion of street length:
  \[
  RS = \frac{\text{The length of sidewalk}}{\text{The length of road}}
  \]

- Effective width of pedestrian space (EW): Total width (m) of the pedestrian space subtracts the width of barriers on the sidewalk.

- The quality of pedestrian space pavement (QP): A simple measurement is adopted for assessing the quality of pavement. Investigating the pavement of sidewalks on the basis of whether there is damage, cracks, and unevenness on pedestrian space or not. If there is any flaw part on the pavement, the section of the sidewalk is considered as incompleteness. The section is defined the segment from intersection to intersection.
  \[
  QP = \frac{\text{The total length of sidewalk with incomplete pavement}}{\text{The total length of street}}
  \]

- The ratio of barrier-free facility of pedestrian space (BF): The ratio of established barrier-free ramps to non-established but there should be set barrier-free ramps for pedestrian crossing at junction.
  \[
  BF = \frac{\text{The number of constructed barrier-free ramps for pedestrian}}{\text{The number of locations where ramp should be constructed}}
  \]

- The proportion of obstructions on pedestrian space (PO): The length of the section with obstructions existing on pedestrian space accounted for the length of the total length of pedestrian space:
\[ \text{PO} = \frac{\text{The length of the section with obstructions}}{\text{The length of sidewalks}} \]  

- Landscape order index (LI): the level of separate facilities and public facilities to clarify the space for different functional activities at pedestrian space. This index is the sum of evaluation value of separate facilities with green fence and other public art facilities. For separate facilities with green fence, in accordance with greening refuge island, traffic markings, curbs, balustrades, and traffic markings, the value is graded as +2, +1, 0, -1, -2 in order. The value of +2 will be graded if the public facilities is green and in orderliness. The range of the evaluated value of public art facilities is also from best with +2 to the worst with -2. The total score of the road section is the sum of evaluated value of separate facility and public facility, and the average value of both sides of street. Therefore the value of LI is between +4 and -4.

- The ratio of facilities for disables (RD): The ratio of established facilities for disables to non-established but there should be set facilities for disables. It should be provided with audible traffic signals at the intersection, and at each approach of an intersection should be located at least two audible traffic signals.

\[ \text{RD} = \frac{\text{The number of constructed audible traffic signals}}{\text{The number of locations where audible traffic signals should be established}} \]  

3.3 Standardized of Score of Evaluation Criteria

For evaluating the pedestrian space in an area or a road section, a standardized value with ranking process is used to classify the score of each evaluation criteria into the score between 0 and 10, because each of the criteria has different from unit or scale. This is a simple standardization method to divide the value from best with 10 score to the worst with 0 score. The values converted to a standardized value between 0 and 10 grade is shown in Table 2.

<table>
<thead>
<tr>
<th>Evaluation Value</th>
<th>10</th>
<th>9</th>
<th>8</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective width of pedestrian space (EW)</td>
<td>&gt; 4.0</td>
<td>3.5–4</td>
<td>3.0–3.5</td>
<td>2.5–3.0</td>
<td>2.0–2.5</td>
<td>1.5–2.0</td>
<td>1.2–1.5</td>
<td>0.9–1.2</td>
<td>0.65–0.9</td>
<td>0.5–0.65</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>The quality of Pedestrian pavement (QP)</td>
<td>&lt;0.05</td>
<td>0.05–0.1</td>
<td>0.1–0.15</td>
<td>0.15–0.2</td>
<td>0.2–0.25</td>
<td>0.25–0.3</td>
<td>0.3–0.35</td>
<td>0.35–0.4</td>
<td>0.4–0.45</td>
<td>0.45–0.5</td>
<td>&gt;0.50</td>
</tr>
<tr>
<td>The ration of barrier-free facility of pedestrian space (BF)</td>
<td>&gt;0.95</td>
<td>0.9–0.95</td>
<td>0.8–0.9</td>
<td>0.7–0.8</td>
<td>0.6–0.7</td>
<td>0.5–0.6</td>
<td>0.4–0.5</td>
<td>0.3–0.4</td>
<td>0.2–0.3</td>
<td>0.1–0.2</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>The proportion of obstructions on pedestrian space (PO)</td>
<td>&lt;0.05</td>
<td>0.05–0.1</td>
<td>0.1–0.2</td>
<td>0.2–0.3</td>
<td>0.3–0.4</td>
<td>0.4–0.5</td>
<td>0.5–0.6</td>
<td>0.6–0.7</td>
<td>0.7–0.8</td>
<td>0.8–0.9</td>
<td>&gt;0.90</td>
</tr>
<tr>
<td>Landscape order index (LI)</td>
<td>=4</td>
<td>3.5–4</td>
<td>3–3.5</td>
<td>2–3</td>
<td>1–2</td>
<td>0–1</td>
<td>=0</td>
<td>0–1</td>
<td>-1–2</td>
<td>-2–3</td>
<td>=4</td>
</tr>
</tbody>
</table>
3.4 Weight Value of Criteria

This paper used a combination of Analytic Hierarchy Process (AHP) with the Entropy Weight to be a average weight as the weight value of the evaluation criteria. Through the questionnaire survey to the expertise, the weight value is calculated using AHP. The weight value is called a subjective weight value. On the other hand, for considering the significance of comparison, the difference of the evaluation value of the different location should be considered, therefore, the Entropy weight method is used, called objective weight value. Combining these two weight value, the paper adopted the average weight of subjective weight and objective weight as the evaluation criteria weights.

Analytic Hierarchy process (AHP) was developed by Thomas L. Saaty in the 1970s. It must meet the requirements of assumptions in hierarchy structure to apply AHP to decision making process, those requirements are as follows: independence, transitivity as well as consistency. The procedure for using the AHP can be summarized as:
1. Define the unstructured problem and decompose the problem into a systematic hierarchical structure.
2. Estimate the relative weights for the components of each level of the hierarchy.
3. Carry out the consistency measure
4. Calculation of the Subjective weigh

The weight values come out from AHP are listed in Table 3.

In the entropy weight method, the word Entropy comes from the Greek, the original "change" or "conversion". Entropy can explained degree of surprise when someone knows something suddenly in probability theory. When Entropy value is large, the objective weight of deliver of the message is also relatively small. Entropy weight method is a concept of entropy to calculate the relative weight between criteria. Entropy weight method can be eliminated subjective of valuator when calculated the criteria weight. Entropy weight method in process of calculated the objective weight need to performance value of the assessment criterion. The step of objective weight of the calculation of entropy weight method as follow:
1. Consideration the m assessment criteria and n evaluation of alternative of matrix, identify different measured value Xij of each criteria.
2. Calculated the close level between each assessment criteria of matrix, based on all of the maximum survey value, got the close level Dij between each survey value with datum point.
3. Transform close level of distance into probability of something happened, and then standardized.
4. Transform probability into entropy, and then got entropy weight, also was relative weight of each criterion. Final objective weight value of the assessment criteria, as shown in Table 3.

By means of the expert questionnaire upon Analytic Hierarchy Process (AHP), the subjective weights are obtained, and together with the objective weights via Entropy Method, the average weight of each criterion is able to be calculated, as shown in Table 3.
### Table 3 Weight Value of Criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>AHP Weight</th>
<th>Entropy Weight</th>
<th>Average Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>The ratio of with-sidewalk street length (RS)</td>
<td>0.1834</td>
<td>0.1242</td>
<td>0.1538</td>
</tr>
<tr>
<td>Effective width of the sidewalk (EW)</td>
<td>0.1458</td>
<td>0.1758</td>
<td>0.1608</td>
</tr>
<tr>
<td>The proportion of obstructions on pedestrian space (PO)</td>
<td>0.1618</td>
<td>0.1242</td>
<td>0.1430</td>
</tr>
<tr>
<td>The ratio of facilities for disabled (RD)</td>
<td>0.1750</td>
<td>0.1624</td>
<td>0.1687</td>
</tr>
<tr>
<td>The ration of barrier-free facility (BF)</td>
<td>0.1502</td>
<td>0.1624</td>
<td>0.1563</td>
</tr>
<tr>
<td>The quality of pedestrian space pavement (QP)</td>
<td>0.0977</td>
<td>0.1255</td>
<td>0.1116</td>
</tr>
<tr>
<td>Landscape order index (LI)</td>
<td>0.0861</td>
<td>0.1255</td>
<td>0.1058</td>
</tr>
</tbody>
</table>

#### 3.5 Classification of Quality Level of Service by Comprehensive Evaluation Value

Fuzzy Set Theory is adopted to classify the objects based on fuzzy membership function established by comparing questionnaire survey on perceived level of service and the supply situation of pedestrian space. Membership function is built using following steps:

1. **Principle of Mode:** list the levels of service which corresponds to that of pedestrian in order, the value with highest frequency is defined membership as 1.
2. **Fuzzy Statistical Analysis:** the relative frequency of other values in the same grade which present their similar degree with the mode can be calculated through dividing values by mode; linking each value under the same grade make original membership function graph.
3. **Fit Optimal curve:** trend line can be drawn by finding the highest $R^2$ value to fit original membership function graph.
4. **Get $\alpha$-intercept of membership function:** $\alpha$-intercept is used to restrict fuzzy set in a certain range. This study adopt $\alpha=0.9$ as the threshold.

For classifying the level of quality level of service of pedestrian sidewalk, this method of assessment divides the satisfaction degrees into six grades by utilizing the concept of Level of Service (LOS). The six grades are following: Great (Level A), Good (Level B), Better (Level C), Normal (Level D), Bad (Level E) and Awful (Level F). Based on the Fuzzy classification method (Kristy 1992), subjective perceptions through asking pedestrians to evaluate the experienced quality walking on the sidewalk by filling in questionnaires can be gathered, then using Fuzzy classification method to decide the threshold value of every level of service grades in pedestrian space; by this process, the comprehensive evaluation value (CW) of evaluation criteria mentioned previously can be easily transformed to the basis that used to evaluate level of service, and the model of evaluating level of service in pedestrian space can be built. The table below presents the values of service intervals graded by fuzzy classification method of each Quality Level of Service. The calculation of CW is as follows:

$$CW = \sum Wi \cdot ECi$$

Where CW: Comprehensive evaluation value,
- $Wi$: Weight of criterion, according to Table 3,
- $ECi$: Standardized evaluation value, according to Table 2.
4. THE EVALUATION RESULTS OF TAIPEI CITY

The comprehensive Evaluation Value of each street can be gotten through calculating and evaluating the data which got by field survey, and then, the status of level of service of sidewalks in Taipei City can be classified according to Table 4. Seven districts of central area in Taipei City are taken as example to assess the sidewalk. The area is 67.8 Km², as shown in Figure 1. The results of Quality Level of Service of pedestrian space are illustrated in Table 5.

There are 330 arterials and secondary roads in the areas divided into in 1441 sections with boundary of the intersection, and the total length is about 323 kilometers. There is no street graded at the A class and 269 road sections belong to the worst class F, accounting for 18.67%. It shows the quality of pedestrian space in Taipei City still need to be improved.
<table>
<thead>
<tr>
<th>Quality Level of Service for pedestrian</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>The number of road sections</td>
<td>0</td>
<td>128</td>
<td>243</td>
<td>596</td>
<td>205</td>
<td>269</td>
<td>1441</td>
</tr>
<tr>
<td>(percentage)</td>
<td>(0.0%)</td>
<td>(8.9%)</td>
<td>(16.9%)</td>
<td>(41.4%)</td>
<td>(14.2%)</td>
<td>(18.7%)</td>
<td>(100%)</td>
</tr>
<tr>
<td>Total length of roads (km)</td>
<td>0</td>
<td>32.73</td>
<td>60.08</td>
<td>124.01</td>
<td>41.46</td>
<td>64.69</td>
<td>322.97</td>
</tr>
<tr>
<td>(percentage)</td>
<td>(0.0%)</td>
<td>(10.1%)</td>
<td>(18.6%)</td>
<td>(38.4%)</td>
<td>(12.8%)</td>
<td>(20.0%)</td>
<td>(100%)</td>
</tr>
</tbody>
</table>

Take the highest living quality district, Shin-Yi district, as the example. The reason for its higher living quality with the better pedestrian space is the establishment of green region shrunken back from road boundary and the pedestrian zone. The level of service of the quality of pedestrian space on arterials and secondary roads in Shin-Yi district are presented in Figure 2. It shows various levels of service of pedestrian space marked in different colors. The streets locate near central business area are almost at better level of service, while the peripheral roads surrounding this have the worse situation of class E or F. Focus on the roads at class E or F in Shin-Yi district, the worst criterion is lack of facility for helping the disable people, i.e. with the lower ratio of facilities for disables (RD), and the second worse point is the higher proportion of obstructions on pedestrian space (PO). As a result, the improvement of the quality of pedestrian space should be strengthened on continuity and facilities for disables.

5. CONCLUSIONS AND SUGGESTIONS

Through a process of getting comprehensive evaluation weight value, the assessment model of level of service of quality of pedestrian space is established in this paper. The model is applied and proven practically useful. This assessment model can be adopted as a basis for creating improvement countermeasures and used to evaluate the effect of countermeasures. For being more accurate in evaluating the service quality of pedestrian space, to develop database for the evaluation criteria is recommended and which can used as a basis of planning in the future by combining with the comprehensive evaluation model developed in this paper.

REFERENCES

Taiwan Highway Capacity Manual(2001), Institute of Transportation, MOTC.
Figure 2 The quality of pedestrian space in Shin-Yi district