A DEVELOPMENT OF INTEGRATED EVALUATION CRITERIA FOR QUALITY OF SERVICE ON PEDESTRIAN NETWORKS BY USING MULTI-CRITERIA DECISION ANALYSIS

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ABSTRACT: This paper proposes more accurate methods for estimating the quality of service (QOS) in the pedestrian movement space by developing composite indicators that integrate both quantitative and qualitative factors affecting pedestrian satisfaction, rather than simply relying on quantitative measures like pedestrian flow rate and pedestrian delay, which has been a major approach to the level of service (LOS) evaluations. To achieve this aim, we firstly conduct questionnaire surveys and record image in order to investigate perceived level of service (PLOS), considering the land use pattern of the survey areas. Then, we set up a new list of evaluation criteria based on survey results obtained in the previous step and to provide an evaluation framework by analyzing the degrees of importance and repetition existing on the criteria. Next, we consider pedestrians' complex judgment processes through multi-criteria decision analysis such as Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP). Finally, we select a case study area and apply the evaluation criteria in order to assess the developed evaluation framework, testing its applicability. The main results show that: first, ANP is better analytic methods than AHP due to the fact that pedestrians feel repetition when they judge level of service. Second, qualitative factors such as pedestrian behaviors, maintenance, scenery for pedestrians and environments should be considered. Importance of qualitative factors is higher in residential area than other areas. We expect that using qualitative indicators is appropriate in order to estimate pedestrians' QOS.

Keywords: *Multi-Criteria Decision Analysis, Pedestrian, Quality of Service, Analytic Network Process (ANP), Analytic Hierarchy Process (AHP)*

1. INTRODUCTION

The moving spaces of pedestrians are facilities that have very important functions for urbanities' comfortable traffic and resting. In particular, their importance is being enhanced with the advent of the new plan paradigm of the 21st century termed *Sustainable Development*. In spite of such importance, pedestrians in Korea have been living in a car first society where none of safety, convenience and comfort is guaranteed in roads that have become asphalt jungle. Advanced countries that have experienced the popularization of cars much earlier than Korea have already perceived many problems and are attempting accurate evaluation of pedestrians' moving spaces in order to recover pedestrians' safety, convenience and comfort.

However, the present pedestrians' moving space evaluation in Korea is focused on mobility oriented quantitative indexes(Pedestrian Flow Rate, Pedestrian Delay) and does not reflect the Perceived Level of Service (PLOS) actually perceived by pedestrians while they are moving through walking spaces. In this respect, this study is intended to seek ways to consider qualitative variables and reveal the relationships between variables and the characteristics of diverse forms of pedestrian services in order to develop new pedestrian service level evaluation indexes that can adapt to be changed walking environments.

Major contents of this study were divided into the following five stages and detailed contents and methods are as follows. First, examine existing quantitative

pedestrian service level evaluation methods and previous studies of pedestrian service levels to select evaluation items to be used in this study. Second, conduct expert questionnaire surveys regarding the selected evaluation items on walking related experts in diverse classes to select final evaluation items. Third, in order to make the complicated thoughts of humans such as pedestrians into evaluation structures, review the levels of importance of different indexes and establish evaluation structures through the Multi-Criteria Evaluation Method(MCE). Fourth, compare and analyze the established results of pedestrian service quality evaluation indexes by analysis method and land use type. Last but not least, draw conclusions and present implications using the results of comparison and analysis of evaluation indexes.

2. Design of Evaluation Items and the expert questionnaire surveys

2.1 Recent Trends on Pedestrian Evaluation Items

In this section, the viewpoints of the study were presented based on existing pedestrian service level calculation methods and domestic/foreign previous studies. Studies by Kim Gyeong-Hwan·Kim Jong-Bok[3], US Highway Capacity Manual [6], studies by Landis et al[1] and Martin Guttenplan et al(2003), Korean Highway Capacity Manual [6], a study by Jonathan Byrd and Sisiopiku[8] and New York City Pedestrian Level of Service Study Phase [7] used walking densities utilizing walking amounts and effective widths which are representative quantitative indexes as an evaluation index presented service levels divided into A(a level where pedestrians can move ideal paths wanted by them)~F(a level where pedestrians frequently come contact with other pedestrians). These quantitative methods enable simple calculations of the levels of service (LOS). However, they apply a logic that the levels of service (LOS) of walking environments will come down if walking speeds are reduced or walking densities are increased because the service levels of motor roads were applied and thus, distorted results will be drawn if they are applied to 'streets where people want to walk' where walking densities are increased because satisfaction with walking is high in practice or station impact areas where convenience

facilities are concentrated. Therefore, in the case of specialized streets or station impact areas, rather than focusing on mobility to determine the level of service for pedestrians, new approaches to the calculation of pedestrian service levels and indexes that can synthesize diverse factors (safety, comfort and environments) are necessary. To review analytic methodologies for developing indexes, in studies [4, 5], there were some attempts to integrate quantitative and qualitative indexes by utilizing multi-criteria evaluation (MCE : analytic hierarchy process(AHP)). However, they have limitations in conceptualizing the complicated thought of humans such as pedestrians. Therefore, in this study, the Anlytic Network Process (ANP) that can consider (Indirect Effect) the complicated thoughts of pedestrians is applied and comparison and analysis are conducted in relation to duplicity.

2.2 The 1st Selection of Evaluation Items

In order to secure the reliability of evaluation indexes, initial evaluation items were arranged mainly with variables used in previous studies and examinations.

The initially selected evaluation indexes were tentatively divided in relation to mobility, safety and comfort (including environments) and detailed evaluation items are presented in Table 1 shown below.

Table 1. Initial evaluation items selected through examinations of previous studies

Tentative division	Impact factor (Evaluation Index)
Mobility	- Visibility of traffic lights, (blinking) time (sec.) of green lights for walking, existence of no-signal crossroads, crosswalk width(m), crosswalk length(m), sidewalk width(m), degree of separation between sidewalks and bike roads, number of obstacles to pedestrians(degree), number of facilities supporting the movements of the traffic weak, degree of entrance roads(access roads), consistency of walking speeds, continuity of walking speeds, walking traffic(person/hour, person/15 min.), walking density(person/m^2), walking speed(m/min.), occupying space(m^2/person), pedestrian delay(sec./person), other pedestrians direction changes, continuity of sidewalks
Safety	- Form of signals(signal/no signal crossroads), suitability of walk signal time, whether walking time of the traffic weak is considered, existence of pedestrian evacuation islands, existence of bus stops, existences of cars parked on the roads, existence of walk safety facilities, existence of safety facilities for the traffic weak(lowered thresholds), level of brightness of lighting(streetlight), existence of roads

	dedicated to right turns(turns), degree of sight distances at crossroads, vehicle traffic(including turns and going straight), vehicle speeds, heavy vehicle ratio, car drivers' observance of the law, ratios of non-pedestrian (motorcycles, bikes) traffic, non-pedestrian (motorcycles, bikes) observance of the law, degree of conflicts with pedestrians
Comfort (environment)	- Degree of maintaining free walking(desired) speeds, landscapes around walking paths, state and existence of street trees, state of development of roadsides, state of cleanness of sidewalks, state of pavement of walking spaces, maintenance of walk facilities, convenience of using walking plazas(resting facilities), noise level around walking spaces, smoke level around walking spaces, level of vibrations around walking spaces), provision of public transportation information, walk moving space construction work information(including buildings), visibility of walking related signboards, whether remaining signals have been installed

2.3 Final Evaluation Item Selection

1) Analysis of the expert questionnaire surveys

Based on the initially selected evaluation items, expert questionnaire surveys (including preliminary surveys) for selecting final evaluation indexes were conducted during March 15 through 29, 2008. The detailed numbers of expert questionnaires distributed and collection rates are shown in Table2 below.

Table 2. Numbers of questionnaires distributed and collection rates

Division	No. of questionnaires distributed	No. of collected questionnaires	Collection rates(%)
Academia	30	25	83
Specialized research institutes	30	25	83
Civil servants	10	5	50
Engineering Co.	25	18	72
Others	5	2	40
Total	100	75	75

Evaluation items were selected using Multi-Frequency Analyses based on the expert questionnaire surveys and results down to ranking three that are considered to be answers from the experts with some consistency were organized. Selected evaluation indexes were accumulated and those within around 85-Percentile(%) were selected as final evaluation indexes; provided that, it was decided that, of the initially selected evaluation indexes, those with four or less sub evaluation elements should be applied regardless of the accumulation of evaluation indexes (85-Percentile(%)). Examples of the analysis of the expert questionnaire surveys are shown in Table 3 and of the

seven sub evaluation indexes for walking landscapes, surrounding landscapes, the level of brightness of lighting, the state of development around sidewalks and the state of street trees were finally selected based on the levels of importance indicated by the experts.

Table 3. Example of the results of analysis of the expert questionnaire surveys

Division	Frequency (no. of times)			Composition ratio(%)		
	1	2	3	1	2	3
Landscapes around walking paths	35	15	16	47	20	21
Level of brightness of lighting	12	28	13	16	37	17
State of development around sidewalks	8	10	22	11	13	29
State of street trees	7	9	7	9	12	9
Existence of street trees	5	7	9	7	9	12
No. of obstacles to pedestrians	4	4	3	5	5	4
Level of noises in walking spaces	4	2	5	5	3	7
Total	75	75	75	100	100	100

2) Selection of final evaluation items

Based in the initially selected evaluation indexes, expert questionnaire surveys were conducted to draw sub evaluation elements with which final evaluation items can be composed and measured as shown in Figure 1.
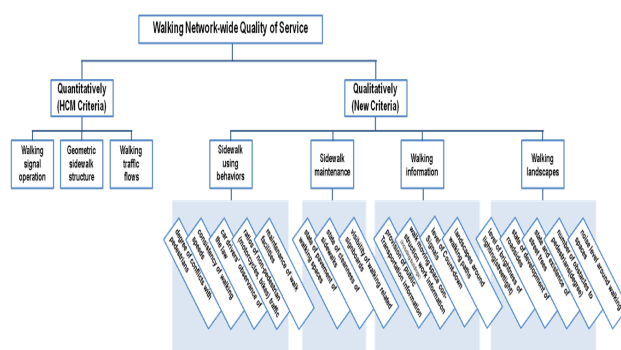

Fig. 1   Hierarchy structure of finally selected evaluation items

Quantitative elements were grouped into three intermediate categories and qualitative elements were grouped into four intermediate categories. As quantitative indexes, walking traffic flows, walking signal operation and geometric structures of sidewalks which are reflected in the existing highway capacity manual(KHCM) to some extent were drawn. As qualitative indexes, sidewalk using behaviors,

walking landscapes, sidewalk maintenance and walking information which are not reflected in the existing highway capacity manual(KHCM) were drawn.

3. Development of Pedestrian Service Quality Evaluation Indexes

3.1 Evaluation index structures by methodology

The hierarchy structure of the evaluation that were initially divided into large categories(Quantitative, qualitative indexes) and intermediate categories(walking signal operation, geometric structures of sidewalks, walking traffic flows, sidewalk using behaviors, sidewalk maintenance, walking information, walking landscapes) is divided. Then, considering the interdependency and correlations between the evaluation items, the following network structure of the evaluation indexes was established as shown in Figure 2.
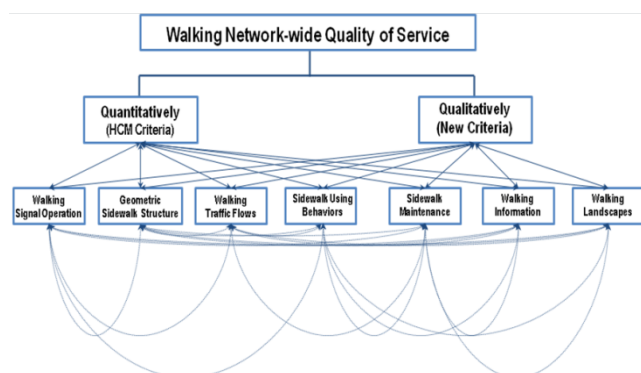

Fig. 2   Evaluation index structure for ANP analysis

3.2 Comparison of the results of development of evaluation indexes

1) Comparison of the results in commercial regions and business regions

Weight values in commercial regions and business regions were compared and it was indicated that the results varied with duplicity. First, the results drawn using the analytic hierarchy process(AHP) that did not consider duplicity were identified to be as follows; walking traffic flows(0.5216), geometric structures of sidewalks(0.1643), sidewalk using behaviors(0.1094), walking signal operation(0.0690), walking landscapes(0.0630), sidewalk maintenance(0.0432), walking information(0.0296).

Second, he results drawn using the analytic network process(ANP) that considered duplicity were identified to be as follows; walking traffic flows(0.3056), sidewalk using behaviors(0.2370), walking landscapes(0.1362), geometric structures of sidewalks(0.1275), walking signal operation(0.0839), walking information(0.0684) and sidewalk maintenance(0.0415).

Table 4. Comparison of priorities by AHP and ANP : Commercial, business regions

Evaluation item	AHP weight value	Priority	ANP weight value	Priority
Quantitative factors	0.7548	1	0.5125	1
Qualitative factors	0.2452	2	0.4875	2
Geometric sidewalk structure	0.1643	2	0.1275	3
Sidewalk maintenance	0.0432	6	0.0415	7
Sidewalk using behaviors	0.1094	3	0.2370	2
Walking landscapes	0.0630	5	0.1362	3
Walking traffic flows	0.5216	1	0.3056	1
Walking signal operation	0.0690	4	0.0839	5
Walking information	0.0296	7	0.0684	6

As shown in Table 4, for commercial and business regions, in the case of the analytic hierarchy process (AHP), the weight values of quantitative items and qualitative items were shown to be 0.7548 and 0.2452 respectively and thus it can be seen that these regions are more heavily affected by quantitative evaluation items. In the case of the analytic network process (ANP), the weight values of quantitative items and qualitative items were shown to be 0.5125 and 0.4875 respectively and thus it can be seen that the importance of quantitative items is lower compared to the analytic hierarchy process (AHP). It can be seen that in the raking of importance of evaluation indexes, the ratios of sidewalk using behaviors and walking landscapes that are qualitative items were enhanced to raise the importance of qualitative items. This result is drawn because sidewalk using behaviors and walking landscapes have high duplicity with quantitative evaluation items too. In the case of walking traffic flows that were shown to be the most important factor in the analytic hierarchy process(AHP) and the analytic network process(ANP) as a quantitative item, it can be seen that, since it is highly correlated with

geometric sidewalk structures in practice, its level of importance decreased by 0.2160 in the analytic network process(ANP).

2) Comparison of results in residential regions

Weight values in residential regions were compared and results in a form similar to that in commercial and business regions were shown. First, the results obtained using the analytic hierarchy process(AHP) were identified to be as follows; walking traffic flows(0.3078), geometric structures of sidewalks(0.2220), sidewalk using behaviors(0.1969), walking signal operation(0.1067), sidewalk maintenance(0.0830), walking landscapes(0.0603) and walking information(0.0233).

Second, weight values obtained using the analytic network process(ANP) were identified to be as follows due to duplicity between the evaluation items; walking traffic flows(0.2522), sidewalk using behaviors(0.2221), geometric structures of sidewalks(0.1563), walking landscapes(0.1135), walking signal operation(0.1068), sidewalk maintenance(0.0819) and walking information(0.0671).

As shown in table 5, for residential regions, in the case of the analytic hierarchy process (AHP), weight values of quantitative items and qualitative items were shown to be 0.6366 and 0.3635 respectively, and thus it can be seen that quantitative evaluation items have larger effects. In the case of residential regions, it can be seen that, the importance of qualitative items is clearly high and of them, sidewalk using behaviors are established as an important factor. Consequently, unlike commercial and business regions where service levels are greatly affected by quantitative (walking amount) factors of walks, it can be said that, for service levels in residential areas, the effects of qualitative items are more important. In the case of the analytic network process (ANP), the weight values of quantitative items and qualitative items were shown to be 0.4997 and 0.5003 respectively and thus it can be seen that the evaluation scores were lower compared to the analytic hierarchy process(AHP). It could be seen that, the ratios of sidewalk using behaviors and walking landscapes which are qualitative items were enhanced in the importance

rankings of evaluation indexes and thus the levels of importance of qualitative items were raised. It is considered that this result was drawn because sidewalk using behaviors and walking landscapes are highly correlated with not only qualitative items but also quantitative evaluation items. Given the high correlations between evaluation elements, it can be seen that, in residential regions, the level of importance of qualitative items is as high as that of quantitative items.

Table 5. Comparison of priorities by AHP and ANP : residential regions

Evaluation item	AHP weight	Priority	ANP weight	Priority
Quantitative factors	0.6366	1	0.4997	2
Qualitative factors	0.3635	2	0.5003	1
Geometric sidewalk structure	0.2220	2	0.1563	3
Sidewalk maintenance	0.0830	5	0.0819	6
Sidewalk using behaviors	0.1969	3	0.2221	2
Walking landscapes	0.0603	6	0.1135	4
Walking traffic flows	0.3078	1	0.2522	1
Walking signal operation	0.1067	4	0.1068	5
Walking information	0.0233	7	0.0671	7

4. Conclusion

In this study, new evaluation indexes for evaluating the quality of walking movement space (general sidewalks and signal crosswalks) services from the viewpoint of pedestrians were reestablished through previous study examinations, user perception surveys and expert questionnaire surveys. Based on established evaluation items, the levels of importance by evaluation element were calculated through the analytic hierarchy process(AHP) and the analytic network process(ANP) which are multiple criteria decision making methods. In this study, the correlations between newly reestablished evaluation elements were revealed through several sessions of expert discussion and the analytic network process(ANP) and the analytic hierarchy process(AHP) that can calculate importance considering the correlations were applied to draw results.

First, the results obtained by the analytic network

process(ANP) were compared with the results obtained by the analytic hierarchy process(AHP) to review the degrees of changes in priorities and the levels of importance and based on the results, the results obtained by the AHP method that considers that evaluation elements are mutually independent and the results obtained by the ANP that considers correlations between evaluation elements were different by land use type(commercial and business, residential). It can be seen that in the case of humans such as pedestrians, decisions are made after associating general situations with each other (refer to attached data 1). Therefore, it is considered that when studying matters related with complicated and synthetic judgments such as pedestrians, applying the analytic network process(ANP) would be practical.

Second, to review priorities in commercial and business regions in detail, in the case of AHP, walking traffic flows, geometric structures of sidewalks and sidewalk using behaviors were shown to be numbers 1, 2 and 3 respectively indicating that walking amounts and geometric structures which are existing quantitative items had important effects. In the case of ANP, sidewalk using behaviors were shown to be number 2 and walking landscapes were shown to be number 3 and thus it could be seen that the levels of importance of sidewalk using behaviors and surrounding environments were enhanced. As explained earlier, this means that pedestrians' surrounding situations and pedestrians' use behaviors in relation to each other have some correlations (duplicity) with walking traffic flows which is a quantitative evaluation item.

Third, to review priorities in residential regions in detail, in the case of the analytic hierarchy process (AHP), walking traffic flows, geometric structures of sidewalks and sidewalk using behaviors were shown to be high with number 1, 2 and 3 respectively and thus it can be seen that the levels of importance of walking amounts and geometric structures which are quantitative items were high as with commercial and business regions.

In the case of the analytic network process (ANP), walking traffic flows, sidewalk using behaviors and geometric structures of sidewalks were shown to be number 1, 2 and

3 respectively indicating that walking amounts and signal operations had relatively smaller effects compared to commercial and business regions.

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