A New Route Guidance Method Considering Pedestrian Level of Service using Multi-Criteria Decision Making Technique

Yong Jin Joo* Soo Ho Kim**

Abstract The route finding analysis is an essential geo-related decision support tool in a LBS(Location based Services) and previous researches related to route guidance have been mainly focused on route guidances for vehicles. However, due to the recent spread of personal computing devices such as PDA, PMP and smart phone, route guidance for pedestrians have been increasingly in demand. The pedestrian route guidance is different from vehicle route guidance because pedestrians are affected more surrounding environment than vehicles. Therefore, pe- destrian path finding needs considerations of factors affecting walking. This paper aimed to extract factors affecting walking and charting the factors for application factors affecting walking to pedestrian path finding. In this paper, we found various factors about environment of road for pedestrian and extract the factors affecting walking. Factors affecting walking consist of 4 categories - traffic, sidewalk, network, safety facility. We calculated weights about each factor using analytic hierarchy process (AHP). Based on weights we calculated scores about each factor's attribute. The weight is maximum score of factor. These scores of factor are used to optimal pedestrian path finding as path finding cost with distance, accessibility.

Keywords : LBS(Location Based Service), Route Guidance, Route Finding, Pedestrian, AHP

1. Introduction

Since 1990s, the vehicle navigation market has been grown continuously. Such a growth of market has led to an advancement of related technologies. Technologies related to vehicle navigations may be divided into a hardware part such as terminals, storage media etc., data part such as road networks, background, POI, and a software part to utilize data stored. Among them, the software part responsible for a functional part is basically developed for vehicles so that data used by it has been also developed in a field related to a vehicle drive. Examining the path finding which is a typical function, technologies have been emerged beginning with the shorted path finding considering an initial distance, the fastest path finding considering speed limits and classes of roads, the free road path finding considering a toll, and the optimum path finding with the real-time traffic information of TPEG(Transport Protocol Experts Group.)

Recently, demands to not only functions to guide roads for vehicles but also services to guide roads for pedestrians are increasing due to the popularization of portable mobile devices such as smartphones, PDA, PMP.

The portable mobile devices could provide a location based service(LBS) through a GPS receiver and a variety of application programs. Map services based on road data is the most typical LBS

† This research was supported by a grant (07KLSG B01) from Cutting-edge Urban Development - Korean Land Spatialization Research Project funded by Ministry of Land, Transport and Maritime Affairs.

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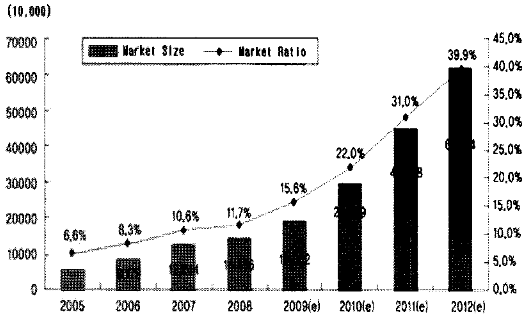

Figure 1. Trends and changes of smart phone market(2009, Gartner)

and companies having navigation map data for vehicles provide applications developed themselves to use in the mobile devices by converting navigation data for vehicles. The navigation system for vehicles, however, is difficult to reflect properties of pedestrians using mobile devices. Therefore, it is required data and application programs specialized for pedestrian services.

This study aims to suggest the methodology which is able to calculate pedestrian path considering walk environments and level of service of pedestrian by using Multi-Criteria Decision Making Technique. In order to achieve this goal, we design factors having an influence on walking for data of road network constructing up to alleys where vehicles could pass through, and selects factors to be used for finding costs. Then, weights are assigned to the selected factors through the AHP(Analytic Hierarchy Process) method, and a path finding score is calculated using them. The path finding score is used to calculate a final path finding score for pedestrians through operations with a distance which is the existing finding cost.

Next, we derives factors having an influence on walking through an analysis on the existing studies. Next, we calculates finding costs for pedestrians by assigning weights and scores for the derived factors, and carries out an experiment for some areas. Last but not lest, we discusses about conclusions and the future study subjects.

2. Design Path Cost Considered Walk Environment

2.1 Literature Review

The walking factors are divided into physical environmental elements and human subjective elements. The physical environmental elements are the ones for walking facilities, which are used as indexes for evaluating the walking environment, and the human subjective elements are ones that could be differently represented depending on individual preferences and walking purposes etc. Handy S. proved that the physical environment was an influence factor of walking by conducting a survey targeting pedestrians in different areas after classifying the walking purposes into leisure and movement means[7], and Moudon A. V. analyzed on an influence factor of walking and cycling with evaluation indexes used in each field[14]. And Lee C. derived the importance of elements evaluating the walking affinity through a statistical analysis[13]. Seo. H. L. classified elements having an influence on walking into street environment, network environment, and regional environment to analyze them[17], and Park S. H. carried out a study to make them as indexes[19]. Hieronymus C. Borst classified elements having an influence on walking of the elderly and infirm into 25 items to make them as indexes and used them in path finding[9], Lee J. E. classified the walking influence elements into physical environmental elements, changes of direction, visual field and accessibility to use for path finding through arbitrary weights[12].

2.2 Development of Factors related to Walk Environment

In Chapter 2.1 we searched about factors affected walking. Through these existing studies, this study carries out classification for traffic, sidewalk, network, and safety facilities etc. as physical environmental elements having an influence on walking, and finally derived factors are as follows(Table 1).

Table 1. Factors having influences on walking

Division	Items
Traffic	velocity
	traffic lights
	traffic calming facilities
	crosswalk
	traffic dencity
Sidewalk	width
	impediments
	curve
	vehicle entry into sidewalk
	Street trees
	garden
	seat
	hate facilities
	slope
Network	Accessibility
Safety facilities	Light
	CCTV
	construction area
	buffer facilities

2.2.1 Traffic environment

Traffic environment is a factor for driveways adjacent to a footpath. The fact that is adjacent to a driveway may affect pedestrian's safety. A speed limit is a factor giving the most significant influence to the extent of pedestrian's injuries in the event of a traffic accident with them, and traffic lights, crosswalk, traffic tranquilization facilities could call a driver's attention to increase safety for pedestrians. The traffic density is a traffic volume comparing to the road capacity, which pedestrian's signal wait time may be changed according to the extent of traffic volume, and it may affect the emission extent of exhaust gases.

2.2.2 Sidewalk environment

The sidewalk environment is a factor for geometrical structures and facilities on the road where pedestrians are personally walking. The walking impediments and the vehicle entry into a sidewalk affect pedestrian's safety and convenience, and the footpath width, street trees, seats, gardens, unpleasant facilities etc. affect the comfort of walking. Curves of sidewalk interfere with pedestrian's securing a clear view, and the slopes have a significant influence on pedestrian's view and walking fatigue degree.

2.2.3 Network environments

The network environment is a factor for accessibility of roads. This study would like to use local integration's numerical values of the Space Syntax theory. The Space Syntax is a methodology to quantitatively calculate the extent of each space's accessibility into other space by analyzing a mutual structure between spaces. This theory has been used for studies to mainly calculate the accessibility of buildings or roads and represent it visually, and is recently applied also to a study analyzing correlation between accessibility and actual traffic volume. According to results of the study, it is proved that the local integration of the Space Syntax theory has a positive correlation with actual traffic volume[2] as well as accessability for pedestrian[10][11].

2.2.4 Safety facilities

The safety facility is a factor for safety accidents or crime occurrences that could be arisen when pedestrians are walking. Lighting prevents pedestrians from safety accidents by securing a clear view when walking in the night times, and CCTV could prevent from crimes. The construction area is a factor threatening pedestrian's safety, and the buffer facilities could protect pedestrians from unexpected threats of vehicles.

3. Calculate path finding cost at each link using AHP method

3.1 Calculation of weights for each element

Every factor derived above has a qualitative property. In order to approach as the GIS methodology when utilizing them in path finding, however, a quantitative analysis is needed. This study uses the AHP method for such a quantitative analysis.

The AHP is a method that Thomas L. Satty devised in 1980, which is a multi-criteria decision making technique to select the optimum alternative by understanding the evaluation criteria and the alternative as a hierarchical structure. This AHP was developed based on the fact that the brain uses gradual or hierarchical analysis process when human beings make decision. According to results of the study, it is said that human beings follow three rules (setting of a hierarchical structure, setting of relative importance, maintenance of logical consistency) when they solve a problem. The following is a procedure to assign weights for each element according to three rules above.

3.1.1 Building a Hierarchical Structure

Factors having an influence on walking are derived in the section 2. Representing them hierarchically, they are as follows.

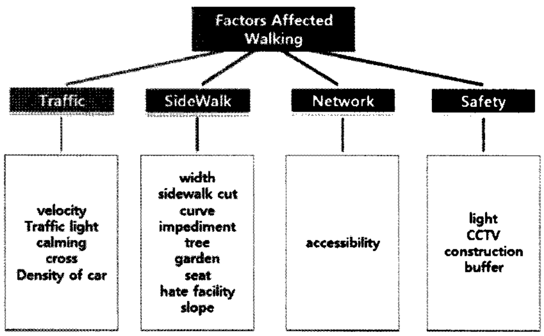

Figure 2. Hierarchical representation of walking factors

3.1.2 Building relative importance

Weights for each hierarchy are calculated through the dual comparison matrix for each factor proposed by the AHP. This study uses the Expert Choice tool. Weights for each factor calculated through the AHP method are as follows.

3.1.3 Maintenance of logical consistency

The AHP derives a non-consistency index in the integration process of 1:1comparison results utilizing the main eigen vector of comparison matrix, and logical consistency of the decision-maker could

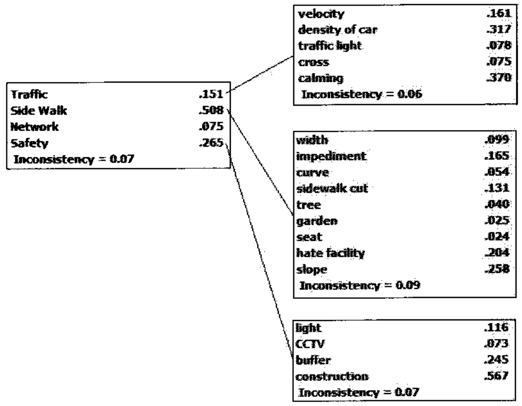

Figure 3. Weights for each hierarchy

Table 2. Ranking of factors weight

No.	Factor	Weight
1	construction	0.150
2	slope	0.131
3	hate facility	0.104
4	impediment	0.084
5	accessibility	0.075
6	vehicle entry into sidewalk	0.067
7	buffer facilities	0.065
8	traffic calming facilities	0.056
9	width	0.050
10	traffic dencity	0.048
11	light	0.031
12	curve	0.027
13	velocity	0.024
14	tree	0.020
15	CCTV	0.019
16	garden	0.013
17	seat	0.012
18	traffic light	0.012
19	crosswalk	0.011

be judged using it. It is an important advantage of the AHP method, which could increase rationality and logicality of decision making. The consistency indexes for weight selection of walking factors are 0.07, 0.06, 0.09, 0.07, and they are numerical values less than 0.1 that is the reference of logical consistency, which it could be found that the logical consistency is maintained.

3.2 Assigning scores for each attribute of factors

The previous stage calculates weights for each factor through the AHP method, and the result being logically right is obtained because weights determined through the non-consistency analysis keeps the logical consistency. At this time, total sum of weights for each factor is 1. But each factor does not always keep the optimum condition in actual road situations. For example, driving speeds of vehicles exist differently from 10 to 110, and these values are needed to be distinguished. Therefore, this study assigns scores based on the weights for each attribute of each factor. The maximum value of scores for each attribute becomes the calculated weight, and it means that total sum of road scores becomes 1 when the road becomes the optimum condition for pedestrians.

$$S_a = (N_a + 1 - R_a)(W_f \div N_a) \qquad (1)$$

S_a is score of each attribute, R_a is ranking of attribute, W is weight of factor and N_a is number of factor's attributes. $(N_a + 1 - R_a)$, because highest rank is 1, but score of rank 1 is same of W_f, so we multiply $N_a + 1 - R_a$ by $W_f \div N_a$.

3.3 Calculation of a Path cost

The finding cost considered first was the distance for the vehicle navigation. In other words, it was based on an assumption that a path with the shortest moving path is most rapidly arrived. However, actual road situation is very different from it. The required time basically becomes different depending on the speed limit, and actual required time may become different depending on the number of lanes, curved section, bottleneck state etc. In addition, recently, the optimum path finding techniques have been emerged considering a traffic volume etc. In order to find the optimum path considering factors having an influence on walking like this, a variety of factors were defined earlier, and weights for each factor and scores for each attribute were assigned. The finding cost finally utilized for walking path finding is calculated as the product with the distance which is the most fundamental finding cost.

$$Cost = Distance \times (\sum Score)^{-1} \qquad (2)$$

At this time, since the score for each attribute is advantageous for walking as its value becomes larger but the distance is disadvantageous for walking as its value becomes larger, it is calculated with the distance after taking an inverse number of the score for the reference is adjusted.
We developed optimum path finding algorithm with the help of designed score based on Dijkstra algorithm (fig 4). In addition, we used formula (2) instead of distance as a path finding cost.

```
Algorithm for optimum path finding;
begin
  S:= 0; _S:=N;
  d(i) : = ∞ for each i ∈ N ;
  d(s) : = 0 and pred(s) : = 0;
  while |S|<n do
  begin
     let i ∈ _S be a node for which d(i)=min(d(j) : j ∈ _S);
     S := S U{i};
     _S := _S-{i};
     for each (i, j) ∈ A(i) do
           if d(j) > d(i) + c_ij then
           d(j) : = d(i) + c_ij;
           pred(j) : = i;
  end;
end;
```

S : result set of node that have shortest path
Pred(node) : predecessor index
d(node) : smallest cost to node
C_{ij} : path cost to node j from node i

Figure 4. Optimum path finding algorithm

4. Case Study

The finding cost for walking path finding described earlier is applied to actual road network. The study area is a road around the Sadang station where the No.2 subway line crosses the No.4 line in Seoul, Korea. This region is the downtown area and busy street intersected by two sections of subway, where is the place with large pedestrian volume of people using surrounding facilities and willing to use public transportation.

Figure 5. Aerial photo and road network of study area

The number of links are 993, and the vehicle density, traffic lights, crosswalks, slopes, CCTV are excluded from constructed items. Results of assigning scores for the target roads show 0.48~0.69 of values of a range, and these are added with the distance to calculate the final finding cost. It is considered that the range of score values narrowly represented is because scores of items excluded from constructed items are not applied.

Figure 6. Path Cost assigned by Pedestrian Quality on Networks

Table 3. Cost value of case study

	Path1		Path2	
	Length	Cost	Length	Cost
Shortest	2.254km	3.744	0.827km	1.436
Optimum	2.257km	3.745	0.841km	1.373

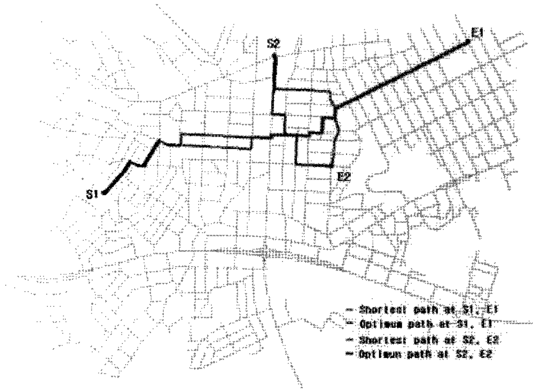

Figure 7. Result of Path Finding based on assigned path cost

As a result of carrying out the shorted path finding using only distance for arbitrary two locations and the optimum path finding using the finding cost calculated from this study, different paths are represented for some paths.

Optimum path is more far than shortest path but it is good condition for buffer facility, garden and seat that positive factors for walking. And there is no construction area, hate facility, impediment that negative factors for walking.

On the contrary of this optimum path, shortest path has some buffer facility and traffic calming facility, but there are some impediments, hate facility, and construction area that is the most affective for walking. So in spite of shortest distance, it is different from optimum path.

It is more suitable walking path that was presented considering a variety of factors having an influence on walking.

5. Conclusion

This study extracted a variety of factors having an influence on walking in order to present a path finding method suitable to pedestrian path guidance which is recently issued. In addition, weights were calculated using the AHP to calculate the importance between the extracted factors, and these weight were used to assign scores of factors for each score. The logical validity was also proved

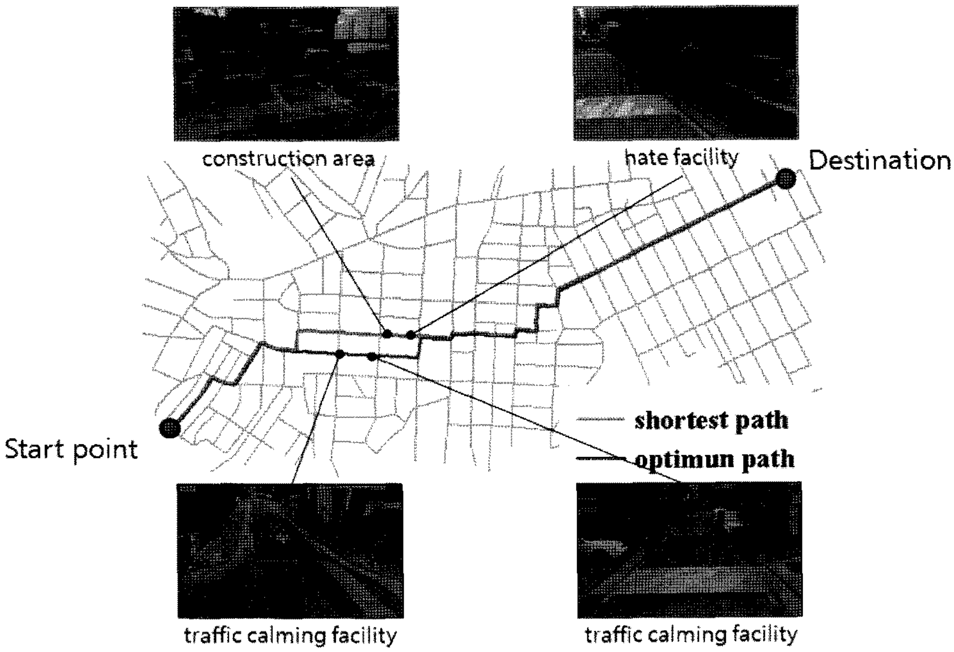

Figure 8. Comparison with Result of Route Guidance in Path1

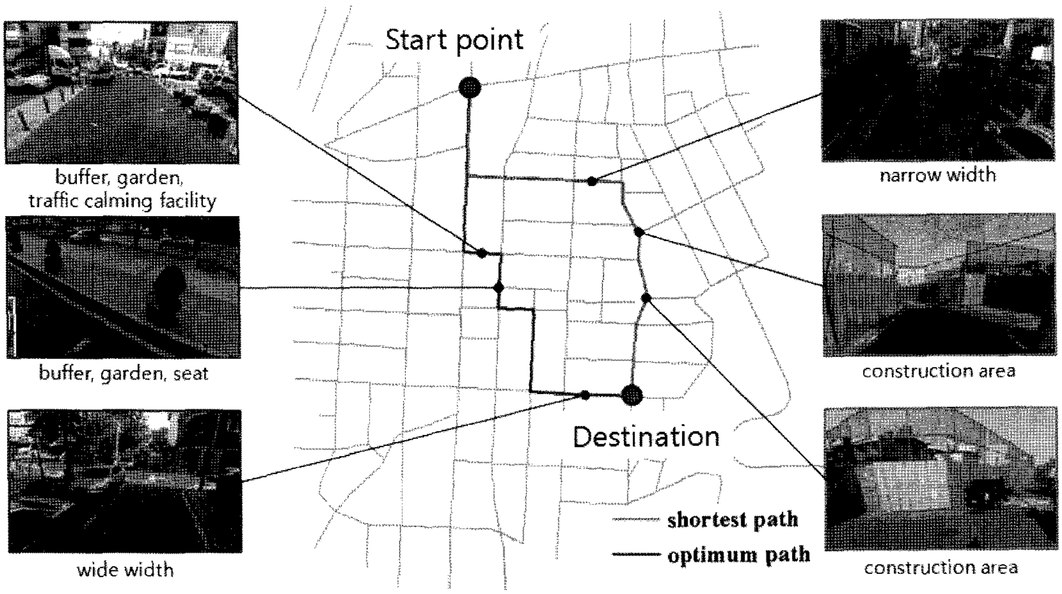

Figure 9. Comparison with Result of Route Guidance in Path2

using the consistency index when calculating weights for each factor through the AHP method. Finally, the finding cost was calculated for the pedestrian path finding by calculating these scores with distance values of the road network. The calculated finding cost applied to the road network in downtown's busy street with large pedestrian volume, as a result, it was represented the result different from the path finding through a simple distance. It is analyzed because more suitable walking path was presented considering a variety of factors having an influence on walking. However, a quantified verification for this is needed because it is only subjective view. In addition, a detailed study is needed for the criteria to distinguish attributes and the assigned scores also in the score assigning process.

The main cause affecting pedestrians in walking has many subjective elements. In other words, some people want a path having poor walking environment but faster way, on the other hand, some people want a walking path with longer way around but comfortable environment. Children and women want a walking path having safety facilities, lighting, or crime prevention facilities. The AHP method presented in this paper could be utilized for such personalized services. The AHP for decision making of public purposes should gather the major opinion, but for personal purpose such as walking, it is because weights could be calculated according to a personal preference. Therefore, it could be utilized for personalized location based services through personal computing devices.

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Manuscript received : 2011.01.10
Revised : 2011.02.18
Accepted : 2011.02.24

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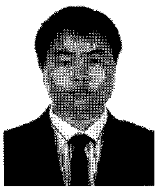

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