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COMBINED AHP AND GIS METHOD TO ENHANCE ROAD MAINTENANCE BUGET USE

Sungpil Shin[1] and Inchul Yang [2,*3]
[1] Korea Institute of Civil Engineering and Building Technology, 10223, Korea
[2] Korea Institute of Civil Engineering and Building Technology, 10223, Korea
[*3] Korea University of Science and Technology (UST), 10223, Korea, Corresponding author

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ABSTRACT
More than 7 billion US dollars are spent for the national highway system every year in Korea. Due to the budget limit it is crucial to establish an efficient road maintenance budget execution plan (RMBEP) on how and where to allocate the budget so as to maximize the nation highway system performance. For this reason we propose a methodology to find an efficient RMBEP based on GIS (Geographic Information System) and AHP (Analytic Hierarchy Process). The resultant RMBEP designates which regions must be placed a priority in the road maintenance investment problem. The proposed scheme is able to minimize the possibility of mixed personal decision in decision-making process and help road managers to make the most effective BEP based on the scientific and reliable method. AHP coupled with GIS which is a powerful combination as a rational and objective approach in a location choice problem was used to make an efficient RMBEP. First, road related variables such as traffic volume (AADT, Annual Average Daily Traffic), pavement condition (MCI, Maintenance Control Index), cut-slope density, and the safety index of cut-slope were selected as criteria for AHP analysis, and the weight for each criterion was calculated through a survey from road managers at each regional road management center. GIS layers for each criterion were constructed, and then the weighted normalized criterion maps were made for establishing the decision index through linear scale transformation. GIS overlay analysis was adopted to calculate the priority of investment. The outcome from a case study for select regions shows that the pavement condition and the safety index of cut-slope are crucial elements of the decision making from the point of view on disaster management

INTRODUCTION
A huge amount of money has been spent for regional road maintenance as part of disaster management for road facilities for a long time in Korea. However, recent increasing public interest on welfare policies in Korea leads to a decrease of budget on road maintenance, and thus it is crucial to establish an efficient budget plan on how and where the cost should be used first so as to maximize the effect of preparedness to an unpredictable incident and to keep the road network system performance.

For this reason proposed is a methodology which adopts Geographic Information Systems (GIS) and Analytic Hierarchy Process (AHP) to establish an efficient road maintenance budget execution plan (RMBEP) designating which region should have priority for road maintenance investment.

RELATED WORK
Many studies have been conducted to find the optimal solution for location finding problems using GIS and multi-criteria decision making method (MCDM). In 2012, Othman et al. [1] developed a MCDM method capable of identifying the high landslide risk areas using GIS tool, and ten significant elements causing negatively a landslide were selected to calculate the weights through AHP. Moradi et al. [2] also adopted GIS based AHP method to identify a landslide susceptibility spot in Iran, and variables such as rainfall, earthquake, slope gradient, land coverage, distance to river were selected to calculate the weights. Safian [3] conducted a study on evaluation of the regional features for purpose-built offices in Malaysia. Yang et al. [4] studied on the selection of the best geographical site of a deicing material storage facility in which the AHP model weights for each variable such as population density, snowfall and total highway length by region were calculated and the optimal locations as well as the building priority of the facilities were determined. Hong et al. [5] proposed an efficient process for land acquisition priorities in stream corridors that would ultimately be vegetated for riparian buffer zones.

The criteria of land acquisition priority were driven through experts` advice. The relative weights of their value and priorities for each criterion were computed using the AHP method. The previous effort in finding the

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optimal location or risky area, however, has not been applied to the road maintenance arena where the preparedness like pavement repairs should be done to keep the road safe for drivers under some bad environments such as rainfall and snowfall. Thus the combined GIS and AHP method was applied to a real-world case in Korea in this study so as to find the most effective RMBEP for road managers.

METHODOLOGY

The establishment of budget execution plan (BEP) in road maintenance includes finding the spatial investment priority of limited budget to maximize its efficiency. MCDM deals with the selection of the optimal one among many alternatives based on the predefined multiple conflicting criteria, and it can be definitely applied to BEP making process where several variables should be considered at the same time so as to keep the road authorities from wasting its budget and to help maintain the road system safe and sustainable.

While MCDM is a useful tool in decision-making process, it is a non-spatial analysis method, which means it's unable to cope with a location problem. The BEP making problem in road maintenance is inherently a location finding, and thus GIS must play a key role. It is imperative to employ both MCDM and GIS for solving RMBEP establishment problem in this study, and thus the combined GIS and MCDM model is adopted. AHP is chosen as an MCDM tool which is capable to analyze specific criteria quantitatively based on the human thinking process.

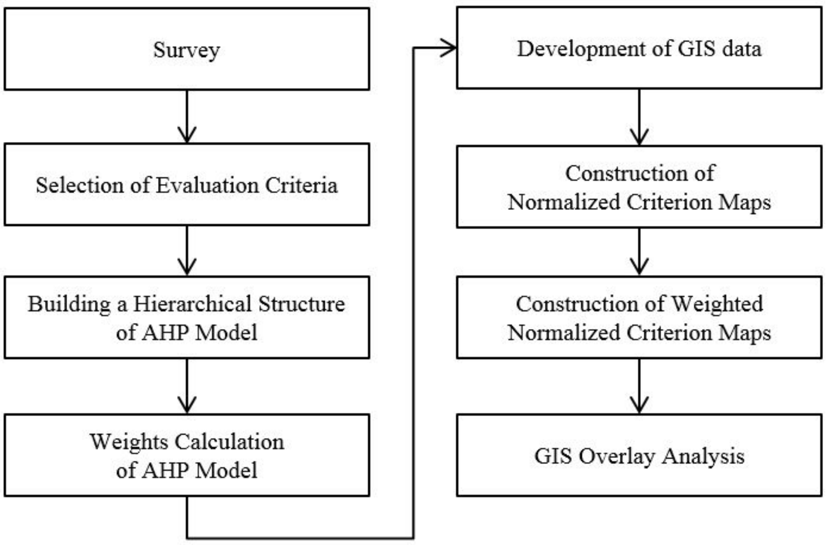

Fig. 1 Analysis Process

The proposed analysis process is as shown in Fig. 1. The multiple evaluation criteria were selected through a survey of experts, and then the hierarchical structure of AHP model was developed. The weights of AHP model representing the relative significance of criteria were calculated based on the survey results. Data for each criterion were collected from Highway Management System which is a GIS based road maintenance database system for national highway network in Korea. The data were then converted to GIS-type data, followed by the construction of normalized criteria maps. The weighted normalized criteria maps were developed by multiplying the AHP model weights and the normalized value of evaluation criteria. Finally, the optimal BEP was established through GIS overlay analysis of the weighted normalized criteria maps. The detail of each process will be described in the next section together with a numerical example.

APPICATION

Selection of Evaluation Criteria and AHP Hierarchy

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In this section was selected multiple criteria for the budget investment priority as disaster preparedness under two conditions:

(1) whether an element has effective numerical values,
(2) usefulness of the element in the decision making.

An interview with road managers and experts was performed to find appropriate criteria, and four variables were chosen including (1) traffic volume, (2) pavement condition, (3) density of cut-slope, and (4) safety index of cut-slope. The traffic volume represents how many vehicles run on the road for an hour, and the pavement condition represents the road comfortability and safety including the number of road cracks and pot-holes. The cut-slope density is the number of cut-slopes in a road section, and the safety index of cut-slope represents the level of collapse possibility of a cut-slope. The traffic volume and the pavement condition are critical values to assess the road condition. Also the density and safety index of cut-slopes represents the potential risk of the road. Thus these four items are typically used when the road maintenance job plan is made. Those items are being monitored on a regular time basis or sometimes on a real-time basis for the successful road maintenance in Korea.

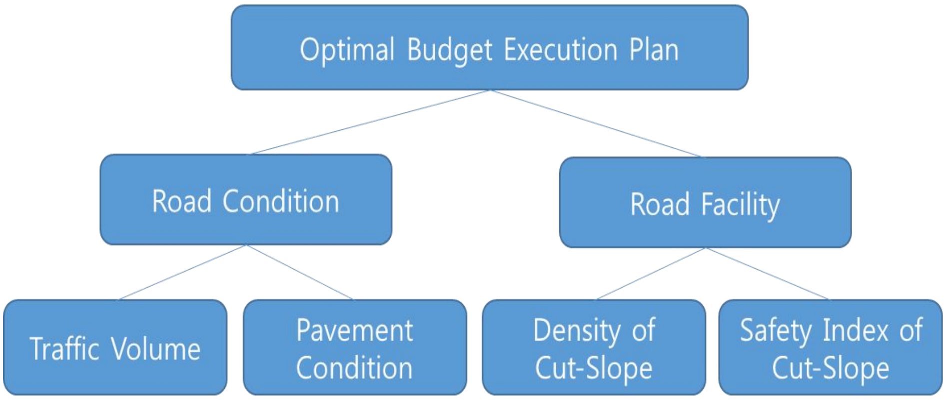

FIG. 2. AHP Hierarchy

After the selection of criteria, AHP hierarchical structure was made to resolve unstructured problems easily. As shown in FIG. 2, the goal was placed at the top level followed by two criteria at the second level. Finding an efficient BEP is the ultimate goal in this study, that the region with a high investment priority should be assigned first a portion of budget to conduct the road maintenance job such as re-pavement and repair work of cut-slope. Then two criteria were selected for the second level. One is road condition with sub-criteria of traffic volume and pavement condition, and the other road facility with sub-criteria of cut-slope density and safety index of cut-slope.

Weight Calculation of AHP Model

Based on the survey results the prioritization was performed to calculate the weights representing the relative significance of the criteria. First, a pair-wise comparison matrix was built as shown in Table 1. Then, the final weights were calculated and the criteria were prioritized as shown in Table 2. From the results it is found that the elements of road condition (=0.564) are more significant in road maintenance budget execution plan than those of road facilities (=0.436). It is because traffic volume and pavement condition are more safety-related variables and road managers are more interested in road safety than any other elements related to road maintenance. In addition, people on the road can easily find the pavement problem immediately leading to civil appeals, and thus the road managers cannot help being interested in those problems.

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In addition, the consistency ratio (CR) is usually adopted to check if the answers of the interviewees are consistent, and every CR in this study was less than 0.1 which shows that the estimated weights can be deemed logical and rational.

Table 1. Pair-wise Comparison Matrix

Decision elements	Traffic Volume	Pavement Condition	Density of Cut-Slope	Safety Index of Cut-Slope
Traffic Volume	1.000	1.482	1.031	1.748
Pavement Condition	0.675	1.000	0.334	0.690
Density of Cut-Slope	0.970	2.990	1.000	1.319
Safety Index of Cut-Slope	0.572	1.449	0.758	1.000

Table 2. Weights and Priorities

Classification		Weights		Priority
Road Condition	Traffic Volume	0.564	0.186	4
	Pavement Condition		0.378	1
Road Facility	Density of Cut-Slope-	0.436	0.170	3
	Safety Index of Cut-Slope		0.266	2

GIS Data Collection

The study site is the jurisdictional area of Uijeongbu Regional Construction Management Administration (RCMA) as shown in Fig. 3. The site has both some flatlands of urban area such as the city of Paju and Yangju and mountainous terrain like the city of Gapyeong and Yangpyeong. Heavy traffic is observed in the area near the Seoul Metropolitan Area, and light traffic in the other area. The Uijeongbu RCMA is in charge of the vast area of eight cities, among which the city of Yangju has the heaviest traffic with few cut-slopes.

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The city of Pochun, however, has many cut-slopes with lighter traffic and bad condition of pavement. For the study site GIS-based data of the four evaluation criteria were collected based on which the criteria maps were constructed.

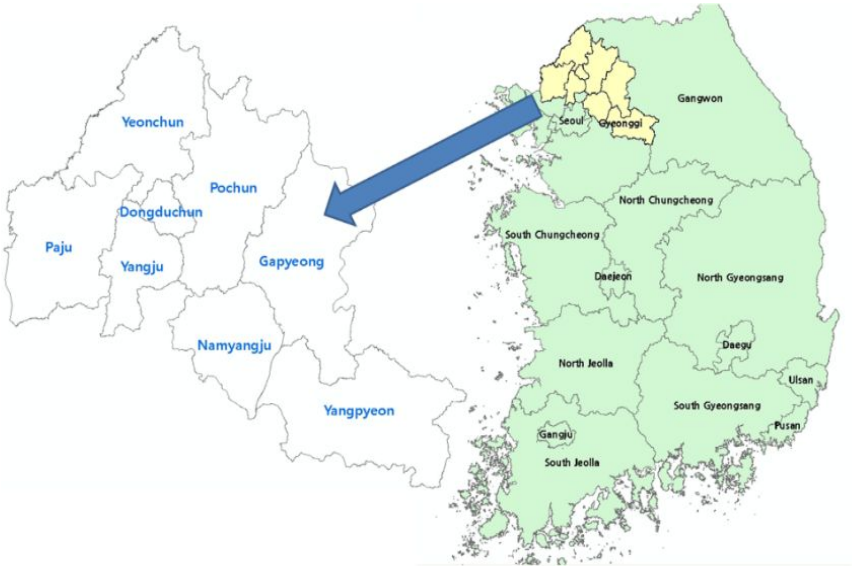

Fig. 3. Study Site

a) Traffic Volume

From the perspective of disaster management the area of heavy traffic is generally considered to have high B/C (Benefit to Cost) ratio since it is subject to the critical damage for humans when a crisis happens. In order to find the traffic volume in each city, the annual average daily traffic (AADT) was investigated and mapped into road links as shown in Fig. 4-(a). However, AADT itself cannot explain the representative feature of each city's level of traffic, the value of vehicle mile travelled (VMT) is instead used by multiplying AADT and the total road length in each city. As shown in FIG. 4-(b), Gapyeong and Yangju have the highest VMT followed by Pochun.

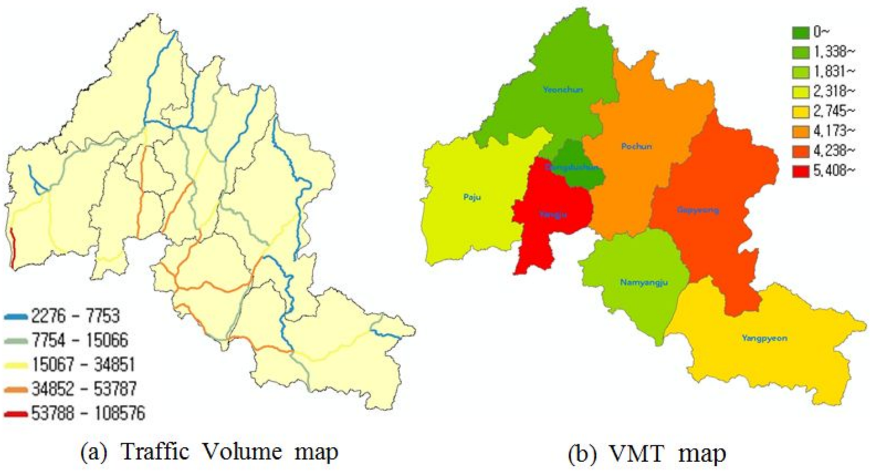

Fig. 4. Evaluation Criteria Map 1(Traffic Volume)

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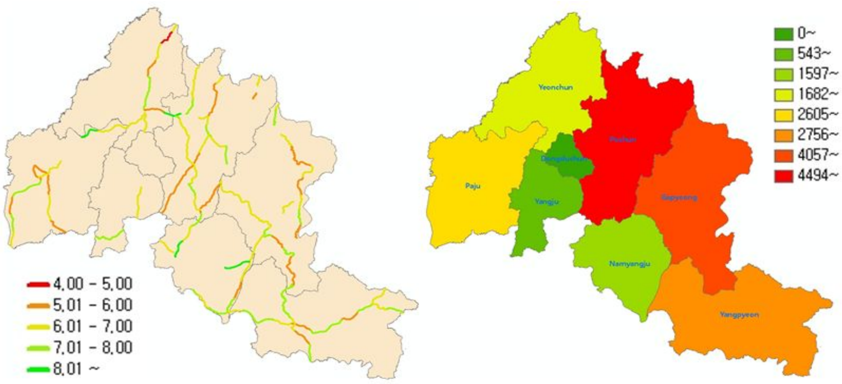
b) Pavement Condition

Recent heavy snowfalls in Korea have caused the increasing amount of deicing material usage such as calcium chloride, which increases the number of road cracks and pot-holes leading to significant property and human damages. Pavement conditions along a roadway should be an important factor for road managers to decide which part of road should be repaired first. So the MCI (Maintenance Control Index) is adopted for the third evaluation criterion which is a comprehensive index to evaluate the pavement condition considering the surface cracks, rutting, and longitudinal road profiles. Usually the value of MCI less than 3.0 means the pavement should be repaired as soon as possible. Higher MCI value indicates the pavement condition is better. In order to make high values of MCI indicating bad condition and to use the representative index for a city we proposed the modified MCI (mMCI) as equation (1). The maximum of MCI (K) in the study is set to 10. Fig. 5-(a) represents the distribution of MCI, and Fig. 5-(b) shows the modified MCI map according to which Pochun is the worst city and Dongduchun is the best.

$mMCI = (K - MCI) \times (\text{Total Road Length})$ (eq. 1)

Where

K: Maximum value of MCI



(a) MCI map (b) Modified MCI map

Fig. 5. Evaluation Criterion Map 2 (Pavement Condition)

c) Density of Cut-slope

The number of cut-slopes along a roadway may increase the risk of landslide causing huge traffic congestion and sometimes road block or even human damage. Therefore, the density of cut-slope, i.e., the number of cut-slopes divided by the total road length is selected as the next evaluation criterion. Fig. 6 represents (a) the distribution of cut-slopes and (b) its density.

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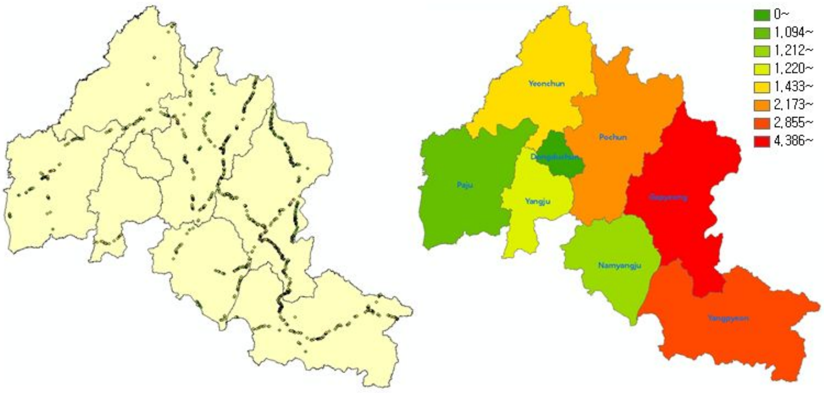
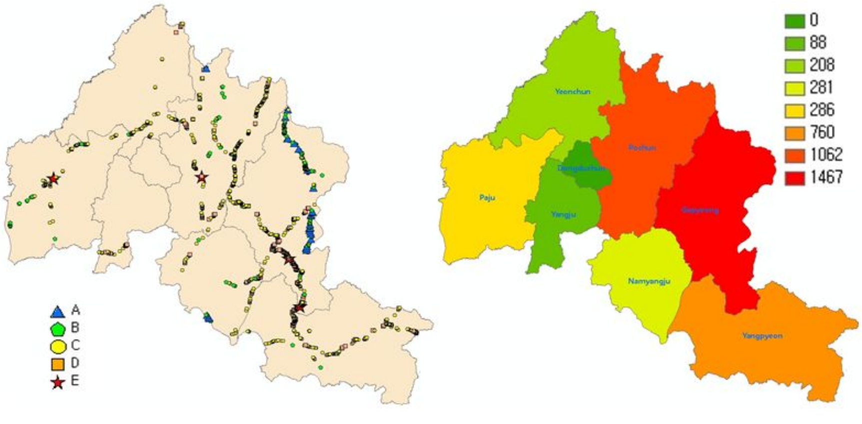


(a) Distribution of Cut-Slope (b) Density Map of Cut-Slope

Fig. 6. Evaluation Criterion Map 3 (Density of Cut-slopes)

d) Safety Index of Cut-Slope
In addition to the number of cut-slopes the safety index is also a significant factor to determine the need of road repair. Even if there is only one or two cut-slopes in a roadway (= low density) one unsafe cut-slope can be a great threat to the drivers. The cut-slopes were categorized into five groups (A, B, C, D, E) in terms of damages, weathering grades and geological features. Each group is assigned a value (A=1, B=2, C=3, D=4, E=5) with A(=1) of the best condition, and the sum of the assigned value for all cut-slopes in each city becomes the representative safety index of cut-slope for the city which is shown in the Fig. 7-(b).



(a) Safety Grade Map of Cut-Slope (b) Safety Index Map of Cut-Slope

Fig. 7. Evaluation Criterion Map 4 (Safety Index of Cut-Slope)

Weighted Normalized Criterion Maps and GIS Overlay Analysis
Once each evaluation criterion map was developed, the values must be normalized for the GIS overlay analysis. The dimension and units of criteria are different from each other and thus comparison is meaningless without normalization. Linear scale transformation is employed to normalize the criteria with the equation (2).

(eq. 2)

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Where

: Normalized value of criterion i
: Assigned value of criterion i
: Maximum of criterion i

In the next step the normalized values of criteria were multiplied by the AHP weights to calculate the weighted normalized criterion maps. Then the GIS overlay analysis was performed using ArcGIS to construct the final rating score map based on which the rank of alternatives are determined. Fig. 8 shows the process of calculating the cities' priorities for budget execution for a sample area of Pochun, Gapyeong and Namyangju.

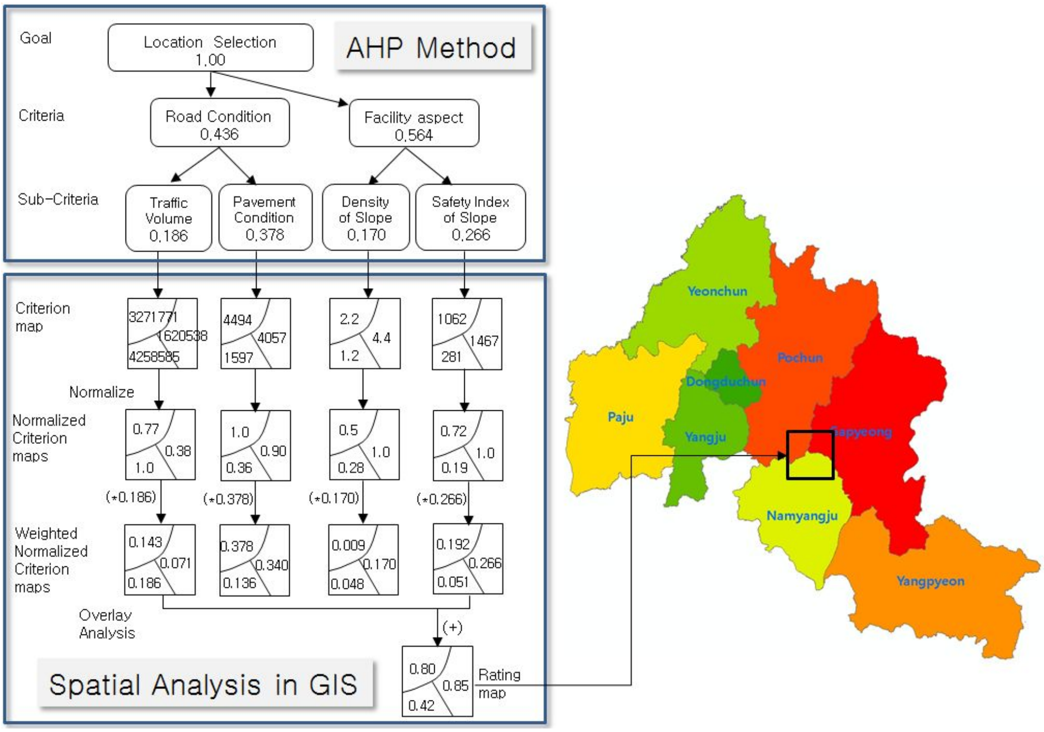

Fig. 8. Example of combined GIS and AHP Method

RESULTS AND DISCUSSION

The proposed methodology was applied to the study site. Table 3 represents the weighted normalized rating scores for seven cities, and Table 4 shows the final priorities for budget execution. The city of Dongduchun was excluded in the analysis since it is not administered by the Uijeongbu RCMA.

Namyangju has the highest traffic volume followed by Pochun and Paju. It's because Namyangju is closest to Seoul where population density is very high and so is travel demand. Pochun ranked high both in traffic volume and pavement condition and Yangju did low for both, from which it seems that traffic volume and pavement condition are correlated. It is, however, interesting that Namyangju with the highest traffic volume has well-managed pavement condition ranked sixth, which demonstrates that traffic volume and pavement condition should be considered separately and dealt with indifferently.

It also turns out that Gapyeong has the most of cut-slopes because most of its region consists of mountainous terrain. Gapyeong is also at the top in terms of the safety index of cut-slope since many unsafe cut-slopes exist. It should be noted that Paju ranked fourth in terms of safety index even with the fewest cut-slopes, which means the cut-slope management is not a major concern in the city even though the status of cut-slope is not actually

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good. So our approach may be useful for them to realize that the number of cut-slopes along the roadway does not necessarily determine the priority of budget execution for road maintenance.

As shown in Table 4 the city of Gapyeong is the top priority for budget execution since it has high densities of cut-slopes with many unsafe cut-slopes and its pavement condition is in the second place. Pochun is the worst city in terms of pavement condition which has the highest weight in AHP analysis, but Gapyeong is ranked high in most of criteria, leading to the city of the top priority.

Table 3. Weighted Normalized Rating Score

City Name	Traffic Volume (Weight = 0.186)		Pavement Condition (Weight = 0.378)		Cut-Slope Density (Weight = 0.170)		Safety Index (Weight = 0.256)	
Gapyeong	0.071	5	0.340	2	0.170	1	0.266	1
Pochun	0.143	2	0.378	1	0.085	3	0.192	2
Yangpyeon	0.079	4	0.231	3	0.110	2	0.138	3
Paju	0.113	3	0.219	4	0.043	7	0.051	4
Namyangju	0.186	1	0.136	6	0.048	5	0.051	4
Yangju	0.068	6	0.045	7	0.048	5	0.016	7
Yeonchun	0.036	7	0.140	5	0.056	4	0.037	6

Table 4 Priorities for Budget Execution

City Name	Weights	Priority
Gapyeong	0.847	1
Pochun	0.798	2
Yangpyeong	0.558	3
Paju	0.426	4
Namyangju	0.421	5
Yeonchun	0.269	6
Yangju	0.177	7

CONCLUSION

In this study we presented a combined AHP and GIS method to propose a well-designed process to construct the budget execution priority in road maintenance from the disaster management perspective. The GIS based overlaid values alone cannot provide meaningful information to road managers. So as to tackle this limitation, the well-known professional survey based AHP method was added to calculate the relative significance of each

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criterion. The proposed scheme is able to minimize the possibility of mixed personal decision in decision-making process and help the road managers make the most effective BEP based on the scientific and reliable method. In addition, the basic information such as the number of facilities and the road length was the only criterion for BEP before, but the quantified values of traffic volume, pavement conditions, cut-slope densities, safety index of cut-slope can now be used to make the BEP more reliable.

The outcomes from a case study for select regions showed that the pavement condition and the safety index of cut-slope are critical elements of the decision making from the point of view on disaster management. It was also shown that traffic volume and pavement condition should be considered separately and dealt with indifferently in road maintenance, and demonstrated that the proposed approach may be useful for road managers to realize that the number of cut-slopes along the roadway does not necessarily determine the priority of budget execution for road maintenance.
Future work might include the consideration of more criteria such as road linearity, width, and other facilities.

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