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Determination of Highway Database Construction Priority using the GIS Method and AHP

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ABSTRACT

The Korean Highway Agency manages the current status of roads and related facilities as a form of CAD drawings or databases (DBs) to achieve systematic road management. Although the current status of roads is modified from time to time, there is a limitation on rapid update on road information due to the limited budget. Therefore, it is necessary to assign financial resources by determining priority on target areas requiring a budget to perform the road DB update effectively within a given budget. To achieve this objective, this study calculated weights of evaluation criteria to determine priorities using an Analytic Hierarchy Process (AHP) and presented a methodology that can determine priority areas by employing the calculated weight factor with a GIS method. Through the study, it was found that an aspect of DB utilization by road manager was more important than the safety aspect of roads to develop a road DB

Keywords: *Highway database, MCDM (multi-criteria decision making), AHP, GIS*

1. INTRODUCTION

The highway agency should have road information as a form of drawings or database for effective road management. However, since roads are updated from time to time, it is difficult to update road information quickly.

To manage roads effectively, budget shall be allocated continuously to update road information quickly but this cannot be done properly due to the limited budget.

Therefore, it is important to assign financial resources effectively to update a road DB quickly within a limited budget. To this end, priority of areas where a budget is spent shall be determined in advance. Accordingly, this study aimed to provide a methodology that can determine priority areas where road DB update is required within a given budget condition using a Geographic Information System (GIS) and AHP (Analytic Hierarchy Process) for national highway maintained by the Ministry of Land, Infrastructure and Transport.

2. RELATED WORK

C Kara, N Doratli (2012) conducted a study on usability of multi-criteria evaluation (MCE) based on a GIS in Northern Cyprus. To determine the most suitable landfill site, they used an AHP, one of the MCE techniques, to define weights of landfill site criteria such as distance from roads, soil productivity, vegetation types, distance from settlements, and distance from cultural sites and conducted a study that can determine the most suitable site through spatial analysis.

Xion Ying et al. (2007) utilized a GIS and AHP to analyze ecological environmental quality in Hunan Province comprehensively. The authors extracted regional characteristics for ecological environmental quality analysis through the combination of a GIS and the AHP thereby constructing a synthetic evaluation index system that included not only natural environment but also disasters, environmental pollution and socio-economic factors.

Makram Anane et al. (2008) conducted a study to determine the priority for the most suitable site for soil aquifer (body of permeable rock that can contain or transmit groundwater) treatment in the Jerba Island (South Tunisia) region by integrating the AHP method with a GIS model.

Shin et al. (2011) calculated weights of population density, snowfall, and road length managed by Regional Offices in order to determine a site for deicing material storage facilities and determined priority of storage facilities per administrative district using a GIS.

3. METHODOLOGY

Determination of priority areas for road DB update project is regarded as Multi-criteria Decision Making (MCDM) problem to selects that selects the most suitable alternative that suits the predetermined criteria among a number of alternative candidates. The MCDM technique has an advantage of systematic decision making process that can maximize project benefit with a limited budget but it has a drawback of difficulty in dealing with spatial issues.

The present study aims to derive a reasonable and objective priority selection methodology that applies spatial analysis by integrating a GIS and MCDM method. Among the MCDM methods, an AHP decision making method was utilized to acquire preferred information of decision makers through pairwise comparison to derive importance (weight) on criteria (Vargas, 1990).

As a study method, this study determined criteria to achieve the objectives of decision making as shown in Figure 1 and created a hierarchy for each criterion. Data that was determined as evaluation criteria was developed as a form of spatial database to create a criterion map. To reflect relative importance of each evaluation criterion, importance (weight)

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of evaluation criteria was calculated using an AHP and weighted criterion maps were created by reflecting the importance in the criterion maps attributes. Finally, GIS spatial analytical functions were used to select priority areas of budget execution (Malczewski, 1999).

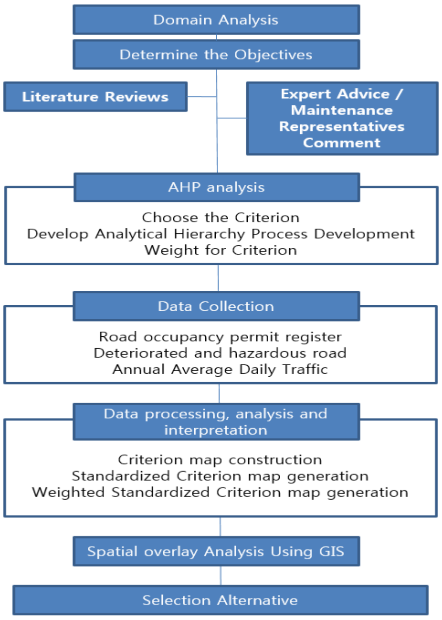

Figure 1: Research methodology

In this study, regions where road DB has been already updated in recent three years, regions where road construction is currently underway and completed thereby having the most up-to-date road information, and existing road DB update regions were removed from the selection candidates of priority areas requiring the road DB update projects as shown in Figure 2.

Figure 2: Road DB update target regions (Chungcheong and Gyeongsang Provinces)

4. APPLICATION OF AHP

4.1 Define the evaluation criteria

Evaluation criteria were set up to select areas that require the road DB update project in priority with the help of road agency officials and road traffic experts. To set up the evaluation criteria, the following three characteristics of region were considered: (1) a region in which the road DB update project is requested by practicing professionals in road management, (2) a region in which the road DB update project is requested for road safety, and (3) a region in which a traffic volume is large. Evaluation criteria based on these characteristics were the number of road occupancy permit, road deterioration and hazardous road sections, and Annual Average Daily Traffic (AADT).

4.2 Develop the hierarchy structure of the evaluation criteria of AHP

Once the evaluation criteria were set up, the evaluation criteria were placed in hierarchy to conduct an AHP. In the uppermost hierarchy, "Road DB Update Project Priority Area", which was an ultimate goal of decision making was laid, and then factors that affect the objective and goals of decision making were layered in the below (Figure 3).

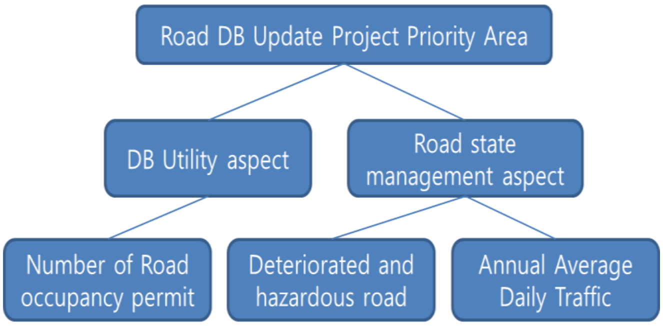

Figure 3. Hierarchical structure of evaluation criteria that affect budget allocation

4.3 Calculation of importance (priority) as per evaluation criterion

This study produced a pairwise comparison matrix by comparing importance of evaluation criteria determined through a survey study while final weights were calculated by assigning relative importance between evaluation criteria as shown in Table 1. Through the AHP analysis, weights of the number of road occupancy, road deterioration and hazardous road, and traffic volume were calculated and they were 0.515, 0.355, and 0.130. In this study, the number of road occupancy permit was found as the highest weight when selecting priority areas for the budget execution.

Table 1: Construct an overall priority rating

Criteria	priority	rating
Number of road occupancy permit	0.515	1
Road deterioration and hazardous road	0.355	2
Traffic volume	0.130	3

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5. GIS-BASED RATING OF ALTERNATIVES

5.1 Criterion map

Data of the evaluation criteria in this study was collected by a Traffic Monitoring System managed by the Korea Institute of Civil Engineering and Building Technology (KICT) and Road Agency. The collected data was constructed as a form of GIS data to conduct Intersect Overlay Analysis in space with respect to relationships between the evaluation criteria of the number of occupancy permits, road deterioration and hazardous road, and traffic volume thereby constructing criterion maps. The minimum construction unit used in the road DB is a 10 to 15km section divided by boundary of Road Agency, bridges, or branches. Accordingly, it is necessary to recalculate values of data with respect to the number of road occupancy permits, road deterioration and hazardous road section length, and traffic volume on the basis of 10 to 15km section.

5.2 Construction of road occupancy layer

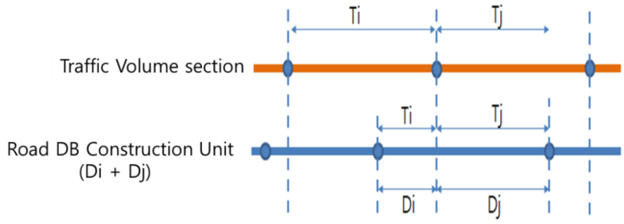
The road occupancy permit data was collected through Road Agencies and a road section layer was created by creating a link to make road centerlines of national highways to be consistent with a DB construction unit to calculate the number of road occupancy according to a DB construction unit. In addition, since road occupancy permit area had only a lot number (number-number format) without coordinate information, a road occupancy permit layer was created by extracting only occupied lot numbers using a land registration map.

To identify the number of created occupancy permits, the number of occupancy in a section was extracted by conducting Intersect Overlay Analysis after a buffer was created in the link of the road centerlines.

5.3 Construction of traffic volume layer

A large traffic volume area is likely to increase facility maintenance and civil complaints. Therefore, it would increase the utilization of the road information DB if the road information DB is constructed for such areas in terms of effective budget spending.

A regional AADT used in this study is based on the Traffic Statistics published every year in the Ministry of Land, Infrastructure and Transport in Korea to construct a regional AADT layer. Since the originally constructed AADT layer was data created according to sections defined by the traffic volume survey team, a section in the original AADT did not match with a minimum road DB section mentioned in Section 5.1. Therefore, it was needed to recalculate a traffic volume according to a minimum road DB construction unit. To this end, intersect overlay analysis was conducted with the original AADT layer and a minimum road DB construction section layer as shown in Figure 4 to recalculate a traffic volume per road section in which a mean weight was applied in consideration of the road section length.



$$T' = \{Di/(Di+Dj) \times Ti\} + \{Dj/(Di+Dj) \times Tj\}$$

T : Traffic Volume, D : Length of road section in road database

Figure 4: Recalculation of traffic volume with the road DB construction unit

5.4 Construction of road deterioration and hazardous road sections

A deteriorated and hazardous road section is a main target area in which a budget for road maintenance is required. Therefore, road deterioration and hazardous road is a main criterion of areas that need the road information DB construction along with hazardous road improvement projects. Accordingly, a road deterioration layer was constructed by distinguishing roads with a link by which an attribute of construction completion date was the same using road completion date obtained from the Road Agency while additional links were created for hazardous road sections.

A deterioration and hazardous road layer also did not match with a minimum road DB construction section layer as the same as in the traffic volume layer so that intersect overlay analysis, in which a mean weight was applied in consideration of road section length, was also conducted here using a method employed for recalculation of traffic volume in the above.

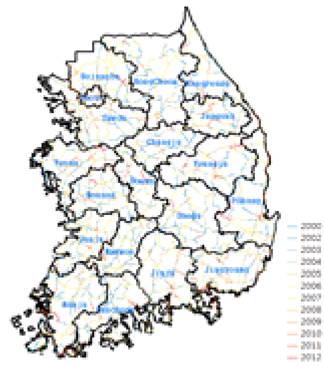


Figure 5: Maps of the number of road occupancy permits, deteriorated roads, and AADT

5.5 Normalization

Once weights between evaluation criteria were created through the AHP, attribution values of each criterion shall be normalized in order to perform intersect overlay analysis within the same scale.

That is, a unit of data representation for each criterion was different and maximum and minimum values per scale were different from each other. As a result, it was meaningless to compare them directly with each other. To compare such scales by standardized criteria, a rating was assigned to each evaluation criterion.

Cluster analysis was conducted with road occupancy in the evaluation criteria by calculating the number of road occupancy permit per section in the road DB construction. Cluster analysis is a method of clustering objects (entities or variables) with various and different characteristics into homogenous groups based on similarity of characteristics, which can be used usefully when classification criteria of objects did not exist or were not clearly known in advance. In this study, a K-means method that clusters observed values non-hierarchically rather than clustering them hierarchically was used. Tables 2 and 3 show the statistical values of the analysis result while Table 4 shows a calculated rating range of the number of road occupancy permits using a distance between clustering centers and the final clustering center.

Clustering analysis for AADT also used a K-means method as same as in the number of road occupancy permits. Tables 2 and 3 show the statistical values of the analysis result while Table 4 shows a calculated rating range of the number of road occupancy permits using a distance between clustering centers and the final clustering center.

Scores were not assigned to recently completed sections (after 2012) among deteriorated and hazardous road sections whereas a maximum rating was given to sections where hazardous road improvement projects were conducted regardless of deterioration level. In recent years, Road Agencies in Korea define design frequencies (year) according to the Road Design Standards and Maintenance Guidelines. As local floods have occurred frequently in recent years caused by extreme weather events due to global warming, a design frequency of drainage facilities has been revised from five years to two years. Accordingly, an increase trend of deteriorated roads was scaled with two-year interval scale to assign a rating of deteriorated roads according to road completion years.

6. THE COMBINATION OF AHP AND GIS

Figure 6. shows a diagram of the GIS-based AHP decision making process to determine regional priority of budget execution, in which each layer created standardized criterion maps through normalization. Each of standardized criterion maps created according to the above process was reflected to the weights calculated by the AHP method to generate weighted standardized criterion maps. The final maps were derived using the intersect overlay analysis as shown in Equation 1 in order to assign rankings to all alternatives. In addition, derived result values were represented by normalized ranks by dividing a sum of all values by each value.

$$Score = (Ocup \times W_o) + (Old\ Risk\ Road \times W_r) + (Traffic\ Volume \times W_t) \quad (1)$$

Where,

Ocup : Rating score of the number of road occupancy permit

Wo : Weight of the number of road occupancy permit

Old Risk Road : Rating score of deteriorated and hazardous road

Wr : Weight of the deteriorated and hazardous road

Traffic Volume : Rating score of AADT

Wt : Weight of AADT

In this study, regions with the high number of road occupancy permits, which were regarded as more important in terms of DB utilization of road managers than deteriorated or hazardous sections for the development of road information DB, acquired higher scores in general. Although weights with respect to a traffic volume were lower than those of other criteria, a traffic volume affected the priority due to unique regional characteristics in Korea where a traffic volume was extremely deviated between urban and local regions.

The study result showed that spatial decision making can be made scientifically and objectively by representing regional characteristics or spatial location requirements quantitatively utilizing the AHP that can structure and systematize subjective characteristics held by decision makers while accuracy and reliability of decision making will be enhanced by determining a rank numerically.

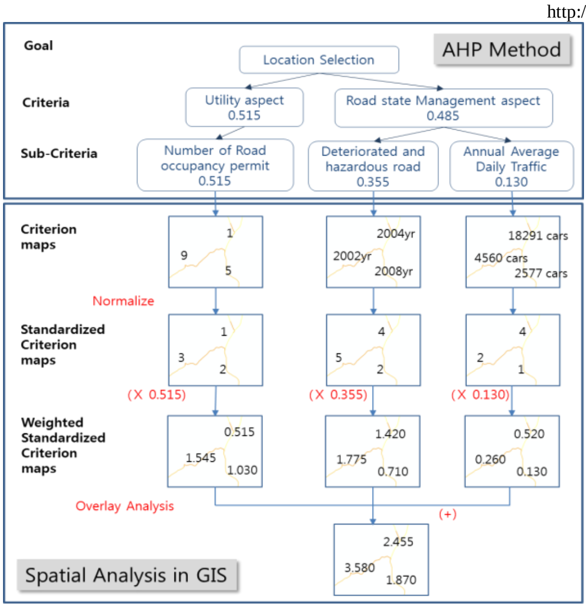


Figure 6: GIS-based AHP decision making process

Table 5 shows a list of priority for budget execution per road DB construction section as weights of the GIS intersect overlay analysis were applied to the importance of evaluation criteria calculated using the AHP while Figure 7 and Table 6 show the mean scores per regional office of Road Agency.

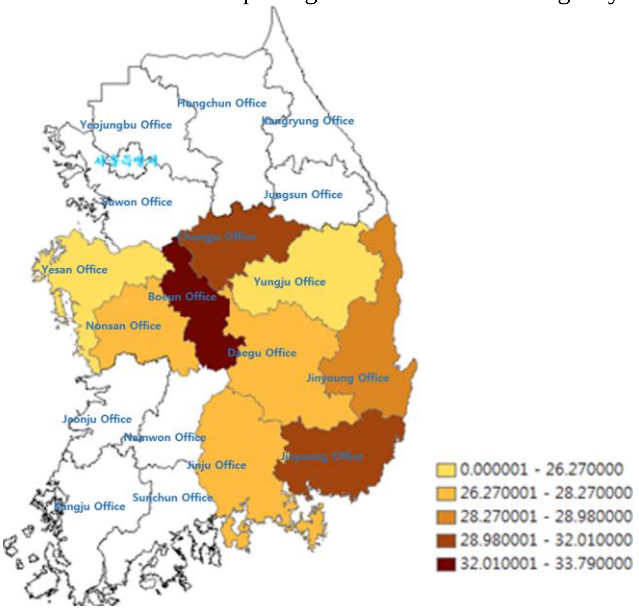


Figure 7. Regional priority map in the road agency

7. CONCLUSIONS AND FURTURE STUDY

This study aimed to search a scientific and flexible process and procedure to select priority regions for budget execution of road DB update per Road Agency by employing the GIS and AHP.

Previous results using simple intersect overlay analysis on GIS attribute values had a limitation that could not provide meaningful information to decision makers. To overcome such limitation, relative importance of evaluation criteria was reflected in the GIS intersect overlay analysis using the AHP thereby adjusting contradictory goals in relation to decision making and minimizing subjective intervention of policy makers due to arbitrary judgment.

Therefore, reasonable and balanced budget allocation can be optimized through this study, in which importance of road occupancy, road deterioration, and traffic volume was analyzed quantitatively in consideration of regional characteristics rather than arbitrary judgment of decision makers as conducted previously. In addition, as a decision making process for budget execution was systematized and regional characteristics extracted through the GIS spatial analysis technique were reflected in the budget execution priority, cost-effective budget execution of road DB update projects can contribute to road maintenance and safety in the future.

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