홍수터 관리 최적대안 결정을 위한 공간퍼지접근
The Spatial Fuzzy Approach to Multi-Criteria Decision Analysis for Flood Management

임광섭*, 최시중**
Kwang-Suop Lim, Si-Jung Choi

Abstract

The uncertainty or imprecision associated with vague parameters and weighting sets, reduces the ability to decide what alternative is better for a particular location. To efficiently reduce the effect of imprecision frequently arising in available information, fuzzy theory has been used to improve consideration of imprecision in a Multi-Criteria Decision Analysis (MCDA) problem. Fuzzy logic offers a way to represent and handle imprecision present in continuous real world applications. A GIS implementing fuzzy set theory, (referred to in this paper as the "Spatial Fuzzy Approach") enables decision makers to express imprecise concepts associated with geographic data and provides decision makers the ability to have even more definition and discrimination in terms of the best alternatives for a particular spatial location.

This study is focused on addressing questions pertaining to the methodology of floodplain analysis using GIS and Spatial Fuzzy MCDA to evaluate flood damage reduction alternatives. The issues will be examined in a case study of the Suyoung River Basin in Pusan, Korea.

Key words: Uncertainty, Spatial Fuzzy MCDA, Fuzzy, GIS

1. Introduction

In an MCDA incorporating multiple decision maker's problems, the evaluation criteria may not be precisely defined. In addition, when the decision makers evaluate the weighting of criteria and the appropriateness of alternatives versus criteria, they usually depend on their wisdom, experience, professional knowledge and information that are difficult to define and/or describe exactly (Liang and Ding 2005). The conventional MCDA method such as Compromise Programming(CP) and Spatial Compromise Programming(SCP), however, is unable to address the effect of imprecision on the answers in model parameters, criteria values, equipment accuracy, or lack of knowledge that also contribute to complexity in the decision-making process. Since these inputs to the MCDA are imprecise in nature, new methods are needed such that this imprecision can be represented and managed appropriately (Vanegas and Labib 2001). Several approaches for imprecision characterization by vagueness, inexactness, and ill definition have been proposed in the literature. Alternative ways of decreasing imprecision

---

* 정회원 · 한국건설기술연구원 수자원연구실 박사후연구원 · E-mail : oklim@kict.re.kr
** 정회원 · 한국건설기술연구원 수자원연구실 연구원 · E-mail : sjchoi@kict.re.kr

such as probability theory, neural networks and fuzzy set theory are needed (Lee and Park 1997). Among them, fuzzy set theory has emerged as a powerful way of quantitatively representing and manipulating the imprecision in decision-making problems in a great variety of applications.

2. Methodology

2.1. Fuzzy theory

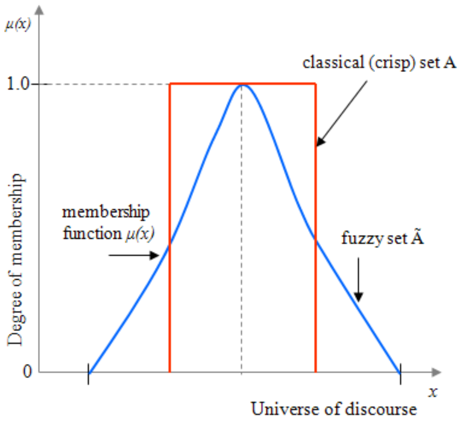

Fig 1. Fuzzy set and crisp set

Fuzzy set theory can appropriately represent imprecise parameters, and can be manipulated through different operations on fuzzy numbers. According to Bender and Simonovic (2000) many criteria in floodplain management problems are subjective in nature, so using fuzzy set theory seems appropriate. Because both importance levels of criteria as well as performance of alternative candidate data per criterion are usually vague, fuzzy numbers are able to handle subjective imprecision rather well. These, in some cases, may be associated with numeric terms; for example, preferences of a decision maker can be described by numeric terms, such as the crisp value 0.5 can be converted to a range of 0.25 to 0.75 while keeping its own value 0.5. This is a fairly convenient way of fuzzifying any number (Nirupama and Simonovic 2002; Vanegas and Labib 2001). Figure 1 shows a comparison between the normal case of set theory and fuzzy set theory.

The Spatial Fuzzy Weighted Average Method (SFWAM) is an MCDA technique designed to incorporate various sources of imprecision. This approach was developed by Bender and Simonovic (2000). The transformation of a distance metric to a fuzzy set can be accomplished by changing all inputs from crisp to fuzzy and applying the fuzzy extension principle. Expressing possibility values with fuzzy inputs allows experience to play a significant role in the expression of input information. The shape of a fuzzy membership function expresses the experience or the interpretation of a decision maker. A S-shaped membership function is applied in this paper. The best alternative for each location is determined by comparing the values in the distance metric images for each individual grid cell between the alternatives.

$$\tilde{L}_{j,x,y} = \left[\sum_{i=1}^{n} \tilde{w}_i^{\tilde{p}} \left| \frac{\tilde{f}^{*}_{i,x,y} - \tilde{f}_{i,j,x,y}}{\tilde{f}^{*}_{i,x,y} - \tilde{f}^{**}_{i,x,y}} \right|^{\tilde{p}} \right]^{1/\tilde{p}} \tag{1}$$

where $\tilde{L}_{j,x,y}$ is the fuzzy distance metric, $\tilde{w}$ is fuzzified weight of i^{th} criteria. Weights can be fuzzified to account for indecisiveness of their boundary values, for an instance, a value of 0.5 could be defined as approximately 0.5 (0.25 ~ 0.75). This means that fuzzy boundaries of weight values will take care of the imprecision associated with crispness. $\tilde{f}_{i,j,x,y}$ is the fuzzy value of the i^{th} criteria for alternative j, $\tilde{f}^{*}_{i,x,y}$ is the fuzzy most optimal value of the i^{th} criteria, $\tilde{f}^{**}_{i,x,y}$ is the fuzzy least optimal value of i^{th} criteria, $\tilde{p}$ is a fuzzified power parameter $(1 \leq p \leq \infty)$, $i=1,\ldots,n$ criteria, $j=1,\ldots,m$ alternatives, $x=1,\ldots,a$ rows in the image, $y=1,\ldots,b$ columns in the image, a is the number of rows in the image, and b is the number of columns in the image.

3. Case Study

3.1. Basin and Hydraulic and hydrologic data development

The target region for a demonstration application of the methodology was the Suyoung basin in Pusan Province. For the application of the developed methodology for evaluating flood damage reduction alternatives, the 1991 flood event and five different return periods were selected.

First, computed flood frequency estimates are based on more than 25-years of annual peak-flow records (1978~2005) from the Pusan weather station peak-flow data. After the interval of occurrence data was obtained, it was utilized as input data for the hydrologic model. And then the HEC-HMS hydrologic model was developed. Second, the resulting peak flows from hydrographs were used as input to a HEC-RAS model created for a specific portion of the Suyoung River Basin. The hydraulic model was created in conjunction with the HEC-GeoRAS extension, using 5m resolution DEM. HEC-GeoRAS was used to convert the resulting water surface elevations into specific digital floodplains. Finally, these digital floodplains were combined with additional GIS data to evaluate flood damage reduction alternatives (Bedient and Huber 2002, Lim 2008)

3.2. The spatial fuzzy approach to MCDA

To alleviate the flood damage produced by flooding in the Suyoung River Basin, a number of flood damage reduction alternative implementations are considered. These alternatives are: no action in which it is to leave the floodplain area as it is with no additional action, build a levee around the community that needs to be protected, channelization, pumping, and a combination of channelization and pumping.

Five criteria that exhibit a spatial variability are then selected for evaluating the flood damage reduction alternatives: flood water depth, flood damage, land use disruption, risk of flooding under different return periods, and drainage capacity. The computational procedures are necessary to produce the grid criteria images for the spatial fuzzy approach in an MCDA context.

The preferences of decision makers are typically expressed in terms of the weights of relative importance assigned to the evaluation criteria under consideration. In this paper the criteria are equally weighted.

3.1.1. SFWAM method analysis

The SFWAM method was applied to evaluate various flood damage reduction alternatives. The criteria maps were combined by fuzzy logical operators such as intersection and union in the SFWAM using the S-shaped membership function. As a result, there were a total of 30 georeferenced distance metric maps for evaluating the alternatives. Figure 2 is the one of the distance metric maps from the list of candidate alternatives and weight sets.

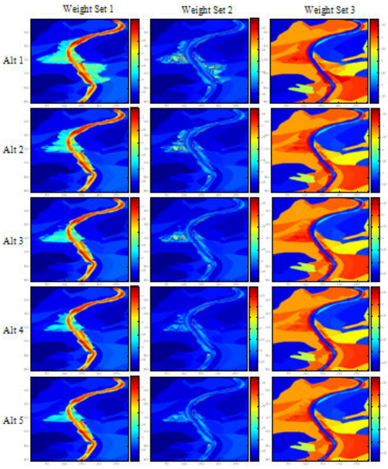

Fig 2. Distance metric maps

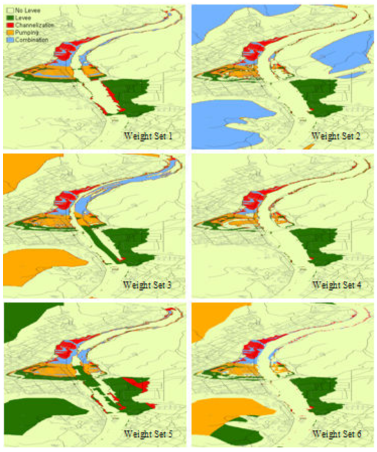

Fig 3. Preferred alternatives(Ranking maps)

Since the main criteria have been developed to reflect the objectives of the flood damage reduction plan, the resulting rankings (Fig. 3) indicate which alternatives best fulfill these objectives. Figure 3 contains a map showing the ranking of alternatives for each criterion that could be implemented to meet flood planning objectives. the ranking maps show the advantage of the spatial fuzzy approach as it provides the ability to have more detail about the gradual transition of the suitability of the each alternative and more definition and discrimination in terms of the alternatives that might be best for particular spatial locations. The range of the ranking value has a lot of detail and fluctuation in this figure. Moreover, this figure shows that it is possible to describe in more detail the floodplain meaning that it is easy to choose one of the most suitable alternatives or to plan flood-control measures in an area of interest.

Figure 4 shows the average overall rankings of the conventional method (SCP) and SFWAM method for each alternative. Figure 4 shows relatively large differences between the two methods are found in the results for Alternatives 3, 4, and 5. The SFWAM method was able to divide the alternatives with greater precision that the SCP method. The SFWAM method provided the ability to have even more definition and discrimination in terms of the alternatives that might be best for entire area. For example, the preference order for alternative

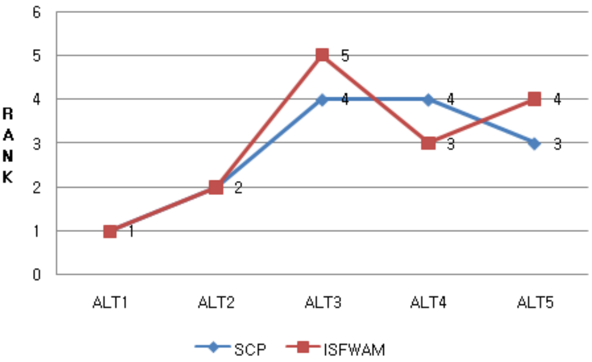

Fig 4. Average overall rankings of the SCP and SFWAM methods

ranking in the SCP method was:

Alternative 1 > Alternative 2 > Alternative 5 > Alternative 3 = Alternative 4.

In this case, both Alternatives 3 and 4 are equally ranked. However, the SFWAM method produced the following ranking:

Alternative 1 >Alternative 2 > Alternative 4 > Alternative 5 > Alternative 3.

Here Alternatives 3 and 4 are clearly separated. This gives the decision maker clearer and more detailed information, for when the decision maker finds the choice of alternative ambiguous. The ranks of the SFWAM method enlarge the range of one's choice and clearance.

4. Result

The results found in this paper reveal that the spatial fuzzy approach implemented in this paper is better not only because it produces less ambiguity, but also because it provides more detail about the gradual transition of the suitability of each alternative. For the case study in the Suyoung River Basin, the answers more diverse and showed more differences in the scores of the alternatives which allowed additional discrimination. Thus, the concept of fuzzy theory is a powerful tool for evaluating the discriminating alternatives with a deterministic MCDA method, since using fuzzy theory improves the consideration of the imprecision in the analysis.

참고문헌

1. Bender, M. J., and Simonovic, S. P. (2000). "Fuzzy compromise approach to water resource systems planning under uncertainty." Fuzzy Sets and Systems, 115(1), 35-44.
2. Lee, D. H., and Park, D. (1997). "Efficient algorithm for fuzzy weighted average." Fuzzy Sets and Systems, 87(1), 39-45.
3. Liang, G.-S., and Ding, J.-F. (2005). "Fuzzy MCDM based on the concept of alpha-cut." Journal of Multi-Criteria Decision Analysis, 12(6), 299-310.
4. Nirupama, and Simonovic, S. S. (2002). "A spatial fuzzy compromise approach for flood disaster management." The Institute of Catastrophic Loss Reduction, London, Ontario.
5. Vanegas, L. V., and Labib, A. W. (2001). "Application of new fuzzy-weighted average (NFWA) method to engineering design evaluation." International Journal of Production Research, 39(6), 1147-1162.