Environmental Modelling & Software 36 (2012) 99–110

Contents lists available at SciVerse ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

A group agreement-based approach for decision making in environmental issues

Ivan Vrana[a,*], Jiří Vaníček[a], Pavel Kovář[b], Jiří Brožek[a], Shady Aly[a]

[a] Faculty of Economics and Management, Information Engineering, Czech University of Life Sciences in Prague, Kamycka 159, 16521 Prague 6, Czech Republic
[b] Faculty of Forestry and Wood Sciences, Czech University of Life Sciences in Prague, 16521 Prague, Czech Republic

ARTICLE INFO

Article history:
Received 10 February 2011
Received in revised form
29 September 2011
Accepted 13 December 2011
Available online 15 February 2012

Keywords:
Agreement
Averaging operator
Environmental decision making
Flood risk management
Fuzzy ambiguity
Multi-expert decisions

ABSTRACT

A decision-making process focusing on environmental issues is extremely complex because of the intricacy of the real-world systems. Such systems are subjected to many uncertain events, which make planning, modeling, and predicting performances and treatment inherently complicated. Typically, a decision-making process focusing on environmental problems is ill structured, uncertain, vague, and multidimensional and is often based on the opinions of experts with different viewpoints. A common problem is how to aggregate the opinions of experts, which might be diverse and sometimes even opposing. This paper presents a new method for aggregating experts' opinions and introduces a new aggregation operator *MaxAgM*, based on Shannon entropy, which maximizes the agreement of experts' opinions. Our method can be applied toward aggregating expert proposals that were expressed by crisp as well as fuzzy quantities to propose a binary solution or to estimate a numerical value of some parameter. A specialized software package MaxAgr was developed to optimize agreement drawn from experts' proposals. Application of the method and the software is illustrated in a case study on flood risk management.

1. Introduction

Sometimes "hard" theoretical models cannot adequately describe real events or processes. This may occur for one or both of the following reasons:

a) We cannot exactly identify the impact of individual factors on the real event or process, and therefore, the model does not describe the event or process adequately.
b) We have no detailed data for the model, or data collection might be too expensive.

Additionally, most environmental decision-making problems that include risk and impact assessments and action planning are unstructured or ill structured, multidimensional, complex, possibly multidisciplinary, vague and uncertain or stochastic. In such cases, it seems appropriate to rely on the intuition and judgments of multiple experts with either homogenous or heterogeneous knowledge that is based on personal experience and an intuitive understanding of the problem. Nonetheless, in spite of its appropriateness, significance, and efficiency, relatively few research attempts in environmental decision making have considered the application of expert consensus approaches in a fuzzy environment. However, the application of fuzzy set theory in environmental decision making to manipulate pure judgments and vagueness of expert opinions has been notably recorded during the last two decades (the reader may refer to Sadiq and Husain (2005), Nguyen et al. (2007), Shrestha and Rode (2008), Nasiri and Huang (2008), Barreto-Neto and Filho (2008), Paterson et al. (2008), Ferraro (2009), Liu and Yu (2009), Li et al. (2009), Fernandez et al. (2009), Chen et al. (2010)). Some of the past research studies that considered expert judgments and the resolution of conflict through consensus when facing vagueness and uncertainty include Sadiq and Husain (2005), Kangas and Leskinen (2005), Nguyen et al. (2007), Tastle and Wierman (2007a), Nasiri and Huang (2008), Paterson et al. (2008), Ferraro (2009), Zendehdel et al. (2009), Fish et al. (2009), Metcalf et al. (2010), Barreto-Neto and Filho (2008), and Ritzema et al. (2010). More relevantly, in water management, several research attempts have considered the ill-structuredness and fuzziness of the decision-making process and have utilized fuzzy expert opinions and the consensus approach. Nguyen et al. (2007) proposed a new approach for testing integrated water systems models and applied them to test the Rapid assessment Model for Coastal-zone Management (RaMCo) model. Expert

* Corresponding author. Tel.: +420 224384276; fax: +420 224382274.
E-mail address: vrana@pef.czu.cz (I. Vrana).

1364-8152/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.envsoft.2011.12.007

knowledge is elicited in the form of qualitative scenarios and translated into quantitative projections using fuzzy set theory. In 2007, Refsgaard et al. (2007) presented a framework and guidance for treating uncertainty in the environmental modeling process. They focused on the water management modeling process. Barreto-Neto and Filho (2008) introduced a fuzzy rule-based model to estimate runoff in a tropical watershed using the Soil Conservation Service Curve Number model. They stated that the evaluation of runoff derived from fuzzy and Boolean methods demonstrated that the former provided calculated runoff closer to the measured runoff in the watershed, confirming the suitability of the fuzzy theory in modeling natural phenomena. In 2008, Shrestha and Rode (2008) presented a multiobjective calibration and fuzzy preference selection approach for a distributed hydrological model. Li et al. (2009) developed a multistage fuzzy-stochastic programming (MFSP) model for tackling uncertainties presented as fuzzy sets and probability distributions. They applied their approach to water resource allocation and management. Relevant to flood management and catchment modeling, Kragt et al. (2011) stated that experts in the field still have limited experience in developing catchment models that consider environmental changes and economic values in a single framework. They described a model development process in which biophysical modeling is integrated with economic information on the nonmarket environmental costs and benefits of catchment management changes. Subsequently, they proposed an integrated assessment approach, and Bayesian network modeling techniques were used to integrate knowledge about hydrological, ecological and economic systems.

However, based on a survey of relevant literature, it was apparent that in flood risk decision making, resorting to multi-expert decision making and the group consensus approach under conditions of uncertainty or fuzziness was rare, in spite of the appropriateness of using these approaches in such ill-structured, completely vague and uncertain decision-making situations. These situations are critical and significant enough to seek reliability through reliance on the judgment of relevant multiple expertise. This issue constitutes the main focus of this research.

Experts must consider many factors, which are sometimes even conflicting, as seen in Bardossy et al. (1993), Donga et al. (2009), Tsabadze (2006), and Zhang and Chu (2009). It may not be enough to simply aggregate the opinions of experts in order to reach a reliable conclusion. Evaluating the level of mutual agreement is necessary. In order to tackle inherent conflicts of opinions amongst experts, the overall reliability of the conclusions should be improved through provisions for consensus evaluation and analysis. A number of aggregating operators for comparing and aggregating opinions exist, see e.g., Vaníček et al. (2009) and Grabisch et al. (2011) for a detailed overview of aggregating operators.

This paper presents a new aggregation operator based on maximum agreement in multi-expert decision making under fuzzy conditions. In order to measure and evaluate the level of agreement between experts, we developed a measure for the level of agreement and the value of τ-agreement based on the Shannon theory of entropy. The τ-agreement will be later defined by formulae (1) and (2). In contrast to the works of Tastle and Wierman (2007a, 2007b), the proposed approach is comprehensive and treats two possible basic decision-making situations, depending on the specific problem and the format of the input judgments. The first situation involves obtaining a binary YES/NO response from each individual expert, along with its associated uncertainty or membership degree. In the second situation, each expert assesses the value of an attribute for some entity or event as a real number or as a fuzzy interval or a fuzzy number. The presented generalization facilitates comparing and aggregating opinions, even though these opinions may have been expressed on different scales. Our recently developed open access MaxAgr software, which computes the value of τ-agreement and computes the generalized mean value *MaxAgM* maximizing agreement, will also be presented. The proposed general approach and software will be illustrated in a flood risk management case study.

In order to facilitate understanding of this paper for readers who are not familiar with fuzzy set theory, we have briefly outlined its basic concepts in Appendix A.

2. Fuzzy agreement approach

Expert estimation can be, in principle, used for two different purposes:

(1) To find a solution to specific YES/NO problems.
(2) To estimate the value of specific attributes or parameters.

In both cases, experts can formulate their opinion in the crisp or the fuzzy form. The expert may be asked to express the following four opinions:

(1a) For crisp advice to some YES/NO problem. In this case, a YES answer is interpreted as 1, and NO is interpreted as 0.
(1b) For advice to some YES/NO problem with additional information about the measure of his/her conviction on the validity of a given answer (for example, as some milestone on the Likert scale—*e.g., definitely NO, NO rather than YES, NEUTRAL, YES rather than NO, or definitely YES*—or in the form of the fuzzy truth value of the YES answer—a number from the closed interval [0, 1], where 0 = definitely NO, 1 = definitely YES).
(2a) For estimation of some attribute or parameter value in the crisp real number form.
(2b) For estimation of some attribute or parameter value in the form of a fuzzy interval or fuzzy number that expresses the measure of his/her conviction that the parameter can reach the respective value.

The Likert scale can be considered asone of methods of assigning a quantitative value to qualitative data, to make it comprehensible to statistical analysis. The Likert scale usually has five potential choices (e.g., strongly agree, agree, neutral, disagree and strongly disagree). For each choice, a numerical value, called a score, is assigned.

In all of the aforementioned situations, various averaging operators can be used to obtain a collective meaning. Let R be the set of all real numbers and m the number of experts. Then, the general averaging operator can be defined as a mapping of A from R^m into R, satisfying the following conditions:

1. A is a continuous mapping of R^m into R.
2. A is idempotent, that is: $A(p, p,\ldots, p) = p$ for all $p \in R$.
3. A is monotonic in each m coordinates, that is: if $p_j \in R$, $q_j \in R$, and $p_j \geq q_j$ for each $j = 1,\ldots, m$, then $A(p_1, p_2,\ldots, p_m) \geq A(q_1, q_2,\ldots, q_m)$.
4. A is symmetric with respect to the permutation of indexes, that is: if $a_j \in R$ and P is a permutation of $(1,\ldots, m)$, then $A(a_1, a_2, \ldots, a_m) \geq A(a_{P(1)}, a_{P(2)}, \ldots, a_{P(m)})$.
5. A is internal, that is: $\min(p_1, \ldots, p_m) \leq A(p_1, \ldots, p_m) \leq \max(p_1, \ldots, p_m)$.

Special types of averaging operators called quasiarithmetic means are most frequently used. Let $a_1, a_2,\ldots, a_m$ be real numbers representing some attribute or parameter values or the values of membership functions. Such an α-quasiarithmetic mean is defined