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Group decision making with linguistic preference relations with application to supplier selection

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A B S T R A C T

Linguistic preference relation is a useful tool for expressing preferences of decision makers in group decision making according to linguistic scales. But in the real decision problems, there usually exist interactive phenomena among the preference of decision makers, which makes it difficult to aggregate preference information by conventional additive aggregation operators. Thus, to approximate the human subjective preference evaluation process, it would be more suitable to apply non-additive measures tool without assuming additivity and independence. In this paper, based on λ-fuzzy measure, we consider dependence among subjective preference of decision makers to develop some new linguistic aggregation operators such as linguistic ordered geometric averaging operator and extended linguistic Choquet integral operator to aggregate the multiplicative linguistic preference relations and additive linguistic preference relations, respectively. Further, the procedure and algorithm of group decision making based on these new linguistic aggregation operators and linguistic preference relations are given. Finally, a supplier selection example is provided to illustrate the developed approaches.

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1. Introduction

Group decision-making problems generally involve the following two phases: (1) Aggregation phase: It combines individual preferences to obtain a collective preference value for each alternative; (2) Exploitation phase: It orders collective preference values to obtain the best alternative(s). But in some real-life situations, decision makers (DMs) may not possess a precise or sufficient level of knowledge of the problem, or is unable to discriminate explicitly the degree to which one alternative are better than others. In such cases, it is very suitable to express DM's preference values with the use of linguistic variable rather than exact numerical values (Bordogna, Fedrizzi, & Pasi, 1997; Kacprzyk, 1986; Zadeh, 1975). In other words, human beings are constantly making decisions under linguistic environment. For example, when evaluating the "comfort" or "design" of a car, linguistic terms like "good", "fair", "poor" are usually be used. Recently group decision making based on linguistic preference relations, which are usually used by decision makers (DMs) to express their linguistic preference information based on pairwise comparisons of alternatives with respect to a single criterion, has received a great deal of attention (Dickson, 1966; Figueira, Greco, & Ehrgott, 2005; Grabisch, 1995a, 1995b, 1996; Grabisch, Labreuche, & Vansnick, 2003; Grabisch, Murofushi, & Sugeno, 2000; Grabisch & Nicolas, 1994; Herrera & Herrera-Viedma, 2000, 2003). At present, many aggregation operators have been developed to aggregate linguistic preference information in aggregation phase, such as the linguistic ordered weighted averaging (LOWA) operators (Bordogna et al., 1997; Herrera & Herrera-Viedma, 2000), linguistic weighted geometric averaging (LWGA) operator (Xu, 2004a), linguistic ordered weighted geometric averaging (LOWGA) operator (Wu, 2009; Xu, 2004a, 2004b), and linguistic hybrid geometric averaging (LHGA) operator (Xu, 2004a).

Although there has been progress in group decision making with linguistic preference information, most of the work has assumed preferences of decision makers are independent. And these aggregation operators are linear operators based on additive measures, which is characterized by an independence axiom (Keeney & Raiffa, 1976; Wakker, 1999), that is, the operator is based on the implicit assumption that preference of DMs are independent of one another; their effects are viewed as additive. This property is too strong to match group decision behaviors in the real world. DM's subjective preference evaluation often shows non-linearity. There usually exists interaction among preference of DMs. The independence axiom generally can not be satisfied. Thus, it is more reasonable and appropriate to use a non-additive measure instead of traditional additive aggregation operators to approximate DM's subjective preference evaluation processes for group decision making problems. In 1974, Sugeno (1974) introduced the concept of

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fuzzy measure (non-additive measure), which only make a monotonicity instead of additivity property. For decision making problems, it does not need assumption that criteria or preferences are independent of one another, which make it an effective tool for modeling interaction phenomena (Grabisch, 1996; Ishii & Sugeno, 1985; Kojadinovic, 2002). As an extension of the additive aggregation operators, such as the weighted average and Ordered Weighted Averaging (OWA)(Yager, 1988) operator, the Choquet integral (Choquet, 1954) with respect to fuzzy measure can be used to mimic human being decision process, and deal with decision making problems (Figueira et al., 2005; Grabisch, 1995a; Grabisch et al., 2000; Marichal, 2000). In this paper, based on λ-fuzzy measure (Sugeno, 1974), we develop a practical method for group decision making with linguistic preference relations.

In order to do this, the paper is organized as follows. In Section 2, we review fuzzy measure. Based on λ-fuzzy measure, some new aggregation operator are proposed. In Section 3, we introduce the multiplicative linguistic preference relations and additive linguistic preference relations according to corresponding linguistic scales. In order to aggregate these linguistic preferences information, we developed some new linguistic aggregation operators such as linguistic ordered geometric averaging based on fuzzy measure (F-LOGA) operator and extended linguistic Choquet integral (ELC) operator, respectively. Some properties of these linguistic aggregation operators are shown. Further, the procedure and algorithm of group decision making based on these new linguistic aggregation operators and linguistic preference relations are given. In Section 4, a supplier selection example is given to illustrate the concrete application of the method and to demonstrate its feasibility and practicality. Conclusions are made in Section 5.

2. Some new aggregation operators based on fuzzy measure

In 1974, Sugeno (1974) introduced the concept of fuzzy measure (non-additive measure) as follows.

Definition 1. Let $X = \{x_1, x_2, \ldots, x_n\}$ be a universe of discourse, $P(X)$ be the power set of X. A fuzzy measure on X is a set function $m : P(X) \to [0, 1]$, satisfying the following conditions:

(1) $m(\phi) = 0$, $m(X) = 1$ (boundary conditions)
(2) If $A, B \in P(X)$ and $A \subseteq B$ then $m(A) \leqslant m(B)$ (monotonicity)

If the universal set X is infinite, it is necessary to add an extra axiom of continuity (Wang & Klir, 1992). However, in actual practice, it is enough to consider the finite universal set. In real decision problems, for weighted average or OWA operator, each alternative $i \in X$ (X denotes a alternative set) is given a weight $w_i \in [0,1]$ representing the importance of this alternative during the decision process, and the sun of all w_i $(i = 1,2,\ldots,n)$ amount to one. However, $m(S)$ can be viewed as the grade of subjective importance of alternatives S. Thus, in addition to the usual weights on alternative taken separately, weights on any combination of criteria are also defined by means of fuzzy measure. Since there existing often inter-dependent or interactive phenomena among alternative, the overall importance of a alternative $i \in X$ is not solely determined by itself i, but also by all other alternative T, $i \in T$. Suppose that $w(i)$ denotes the importance degree of i, we may have $w(i) = 0$, suggesting that element is unimportant, but it may happen that for many subsets $T \subseteq N$, $w(T \cup i)$ is much greater than $w(T)$, suggesting that i is actually an important element in the decision. According to Definition 1, the sun of every w_i (i = 1,2,…,n) does not equal to one.

In order to determine such fuzzy measures, we generally need to find $2^n - 2$ values for n criteria, only values $m(\phi)$ and $m(X)$ are always equal to 0 and 1, respectively. There are several methods for the determination of the fuzzy measure. For instance, linear methods (Marichal & Roubens, 1998), quadratic methods (Grabisch & Nicolas, 1994), heuristic-based methods (Grabisch, 1995b) and genetic algorithms (Wang, Wang, & Klir, 1998) are available in the literature. To avoid the problems with computational complexity, λ-fuzzy measure g, a special kind of fuzzy measure defined on $P(X)$ and satisfied the finite λ-rule (Sugeno, 1974), was proposed by Sugeno, which satisfies the following additional property:

$$g(A \cup B) = g(A) + g(B) + \lambda g(A)g(B), \tag{1}$$

where $-1 < \lambda < \infty$ for all $A, B \in P(X)$ and $A \cap B = \phi$.

In Eq. (1), $\lambda = 0$ indicates that the λ-fuzzy measure g is additive and there is no interaction between A and B. $\lambda \neq 0$ indicates that the λ-fuzzy measure g is non-additive and there is interaction between A and B. If $\lambda > 0$, then $g(A \cup B) > g(A) + g(B)$, which implies that the set $\{A,B\}$ has multiplicative effect. If $\lambda < 0$, then $g(A \cup B) < g(A) + g(B)$, which implies that the set $\{A,B\}$ has substitutive effect. By parameter λ the interaction between criteria can be represented.

If X is a finite set, then $\cup_{i=1}^{n} x_i = X$. The λ-fuzzy measure g satisfies following Eq. (2).

$$g(X) = g\left(\cup_{i=1}^{n} x_i\right) = \begin{cases} \frac{1}{\lambda}\left(\prod_{i=1}^{n}[1 + \lambda g(x_i)] - 1\right) & \text{if } \lambda \neq 0, \\ \sum_{i=1}^{n} g(x_i) & \text{if } \lambda = 0, \end{cases} \tag{2}$$

where $x_i \cap x_j = \phi$ for all $i, j = 1,2,\ldots,n$ and $i \neq j$. It can be noted that $g(x_i)$ for a subset with a single element x_i is called a fuzzy density, and can be denoted as $g_i = g(x_i)$.

Especially for every subset $A \in P(X)$, we have

$$g(A) = \begin{cases} \frac{1}{\lambda}\left(\prod_{i \in A}^{[1+\lambda g(i)]-1}\right) & \text{if } \lambda \neq 0, \\ \sum_{i \in A} g(i) & \text{if } \lambda = 0. \end{cases} \tag{3}$$

Based on Eq. (2), the value λ of can be uniquely determined from $g(X) = 1$, which is equivalent to solving the following Eq. (4).

$$\lambda + 1 = \prod_{i=1}^{n}(1 + \lambda g_i). \tag{4}$$

As generalization of the linear Lebesgue integral (e.g. weighted average method), Choquet integral is defined as follows (Wang & Klir, 1992).

Definition 2. Let f be a positive real-valued function on X, and g be a λ-fuzzy measure on X. The (discrete) Choquet integral of f with respective to μ is defined by

$$C_g(f) = \sum_{i=1}^{n} f_{(i)}[g(A_{(i)}) - g(A_{(i+1)})], \tag{5}$$

where $(\cdot)$ indicates a permutation on X such that $f_{(1)} \leqslant f_{(2)} \leqslant \cdots \leqslant f_{(n)}$. Also $A_{(i)} = \{(i),\ldots,(n)\}$, $A_{(n+1)} = \phi$.

The main advantage of the Choquet integral is that it coincides with the Lebesgue integral when the measure is additive. An additive measure may be directly tied to the notions of additive expected utility and mutual preferential independence. The Choquet integral is able to perform aggregation of alternative even when mutual preferential independence is violated.

Proposition 1. *Let f be a positive real-valued function on X, and g be a λ-fuzzy measure on X. If $\lambda \neq 0$, then*

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