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A novel multiple attribute material selection approach with uncertain membership linguistic information

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ABSTRACT

In engineering design, the decision to select an optimal material has become a challenging task for the designers, and the evaluation of alternative materials may be based on some multiple attribute decision making (MADM) methods. However, the current methods for material selection may induce the information losing and cannot represent the real preference of decision maker precisely. Therefore, in this paper, inspired by the idea of the intuitionistic linguistic variables, we define a new fuzzy variable called uncertain membership linguistic variable (UMLV) which composes two linguistic variables and membership degrees of elements to the linguistic variables. Meanwhile, the operational laws, score function, accuracy function and comparison rules of the UMLV are defined. Then, some aggregation operators are developed for aggregating the uncertain membership linguistic information such as the uncertain membership linguistic weighted average (UMLWA) operator, the uncertain membership linguistic weighted geometric (UMLWG) operator, the uncertain membership linguistic ordered weighted average (UMLOWA) operator and the uncertain membership linguistic ordered weighted geometric (UMLOWG) operator, and some desirable properties of these operators are discussed. Based on the proposed operators, an approach is proposed for material selection problems under uncertain membership linguistic environment. Finally, two numerical examples for material selection are given to illustrate the application of the proposed approach.

1. Introduction

Material selection is one of the most prominent activities in the process of design and development of products, which is a task normally carried out by design and materials engineers and also critical for the success and competitiveness of the producers [1,2]. Without loss of generality, in engineering design, an appropriate selection of materials will give an enterprise the maximum performance and the minimum cost, while an improper selection of materials may result in damage or failure of an assembly and significantly decreases the performance of products [3], and the most suitable material is to be selected based on the requirements of the product. However, due to the increasing choice of materials and variety of manufacturing processes available to the designers [4], the selection of an optimal material becomes more complex and more challenging than before which has become a hot topic in recent several years. For example, when manufacturing bottles used for storing the milk, four kinds of materials are considered commonly including plastic, glass, argil and steel. Selecting different materials will cause different results. Choosing the plastic and argil as the material may result in the damage and pollution of the environment, while selecting the glass and steel as the material will produce high cost. Obviously, none of the results are the expectation of an enterprise. Therefore, it is necessary to take into account multiple attributes comprehensively when making a decision of material selection, such as performance, appearance, price, reliability, safety, availability, fashion, market trends, cultural aspects, aesthetics, recycling, environment and maintainability.

In order to guide the designers in selecting the best alternative for a specific engineering product and to increase the efficiency in design process, a variety of systematic and structured mathematical approaches have been proposed. For example, Rao [5,6] presented a methodology for a given engineering component using graph theory and matrix approach, and a logical procedure for a given engineering application based on an improved compromise ranking method, respectively, considering the material selection attributes and their relative importance. Shanian et al. [7] used a revised Simos' method with the ELECTRE III (Elimination et Choice Translating Reality) optimization model for group material selection under weighting uncertainty. Prasad and Chakraborty [8] proposed a quality function deployment (QFD)-based approach

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to solve the material selection problems which can integrate the voice of the customers for a product with its technical requirements. Karande et al. [9] proposed utility concept and desirability function approaches to solve four material selection problems which were based on the quality characteristic values of the considered material alternatives for arriving at the satisfactory results. Milani et al. [10] used the Analytic Network Process (ANP) method for multicriteria material selection by means of allowing feedback and interactions within and between sets of design criteria and alternatives. Zhou et al. [11] proposed an integration of artificial neural networks (ANN) with genetic algorithms (GAs) to optimize the multi-objectives of material selection. Chan and Tong [12] used the Grey relational analysis ranking the materials with respect to several criteria. Liu et al. [13] proposed a novel hybrid multiple criteria decision making (MCDM) model combining DEMATEL-based ANP (DANP) and modified VIKOR is used to solve the material selection problems of multiple dimensions and criteria that are interdependent.

The methods mentioned above have already been proven effective and feasible for dealing with the material selection problems, However, due to the inherent vagueness of human preferences as well as the objects being fuzzy and uncertain or data about the decision making problems domain, the attributes involved in the decision problems are not always expressed as crisp numbers, and some of them are more suitable to be denoted by fuzzy numbers [14–17]. The fuzzy set theory originally proposed by Zadeh [18] is a very useful tool to describe uncertain information. On the basis of the fuzzy set theory, Atanassov [19,20] proposed the intuitionistic fuzzy set characterized by a membership function and a non-membership function, and it has received more and more attention since its appearance [21–26].

However, in the real world, decision makers usually cannot completely express their opinions by quantitative numbers, and some of them are more appropriately described by qualitative linguistic terms. Since linguistic variables [27] have been proposed, so far, a number of linguistic approaches have been defined such as 2-tuple linguistic variable [28], interval-valued 2-tuple linguistic variable [4,29], uncertain linguistic variable [30], trapezoid fuzzy linguistic variable [31], and trapezoid fuzzy 2-tuple linguistic variable [32]. In order to express the uncertainty and ambiguity as accurate as possible, Wang and Li [33] proposed the concept of intuitionistic linguistic variables based on linguistic variables and intuitionistic fuzzy numbers. Furthermore, Liu and Jin [34] and Liu [35] proposed the intuitionistic uncertain linguistic variables and the interval-valued intuitionistic uncertain linguistic variables. Ju et al. [36,37] defined the intuitionistic trapezoid fuzzy linguistic variable and proposed several MADM approaches.

In real decision making process, when using the intuitionistic linguistic variables to express the attribute preference information, such as "$\langle s_3, (0.6, 0.3)\rangle$", which means that the membership degree and the non-membership degree to the linguistic variable "s_3" is "0.6" and "0.3", respectively. In real life situations, can the non-membership degree "0.3" be seen as the membership degree to another linguistic variable? Therefore, in order to express the uncertain information precisely, and motivated by the idea of intuitionistic linguistic variable, we define a new variable called the uncertain membership linguistic variable (UMLV). For example, when a decision maker gives his/her assessment on an alternative with respect to an attribute, the attribute value can be expressed by $\{(s_3, 0.6), (s_4, 0.3)\}$, which means that the membership degree to the linguistic variable "s_3" is "0.6" and the membership degree to the linguistic variable "s_4" is "0.3", i.e., the decision maker prefers s_3 to s_4. The main advantage of the UMLV is that it gives not only the possible linguistic variables but also the membership degrees to linguistic variables which can express the preference of decision maker more precisely and completely, and is more practical than the intuitionistic linguistic variables. Simultaneously, it also overcomes the preference information losing of the uncertain linguistic variables. This is the motivation of our study. It is easily seen that when the membership degree to a linguistic variable is "1", then the UMLV will reduce to the linguistic variable [27]; when both the membership degrees of the two linguistic variables are equal, the UMLV will reduce to the uncertain linguistic variable [30].

The remainder of this paper is organized as follows: some basic definitions of linguistic term set and intuitionistic linguistic variable are briefly reviewed in Section 2. In Section 3, the concept, operational laws, score function, accuracy function and comparison rules of the uncertain membership linguistic variable are defined. In Section 4, some uncertain membership linguistic aggregation operators are proposed, and then some desirable properties of the proposed operators are investigated. In Section 5, an approach for material selection with uncertain membership linguistic information based on the proposed operators is proposed. In Section 6, two numerical examples are given to illustrate the application of the proposed approach. The paper is concluded in Section 7.

2. Preliminaries

In the following, we briefly describe some basic concepts of linguistic term set and intuitionistic linguistic term set, the operational laws, calculation rules, as well as score function of the intuitionistic linguistic variables.

2.1. Linguistic term set

Suppose that $S = \{s_0, s_1, \ldots, s_g\}$ is a finite and fully ordered discrete linguistic term set with odd cardinality, where s_i represents the possible value for a linguistic term and $g + 1$ is the cardinality of S. In real situations, g would be equal to 2, 4, 6, 8, etc. For example, when $g = 6$, a set of seven linguistic terms S can be given as follows:

$S = \{s_0$ = extremely low, s_1 = very low, s_2 = low, s_3 = medium, s_4 = high, s_5 = very high, s_6 = extremely high$\}$.

For any linguistic term set S, it is required that s_i and s_j satisfy the following properties [38,39]:

(1) The set is ordered: $s_i \succ s_j$, if and only if $i > j$;
(2) There is the negation operator: Neg $(s_i) = s_j$, such that $j = g - i$;
(3) Maximum operator: $\max\{s_i, s_j\} = s_i$, if $i \geqslant j$;
(4) Minimum operator: $\min\{s_i, s_j\} = s_j$, if $i \geqslant j$.

To preserve all the given information, the discrete linguistic term set S can be extended to a continuous linguistic term set $\bar{S} = \{s_\alpha | \alpha \in [0, g]\}$, which satisfies the above properties [40]. If $s_\alpha \in S$, then s_α is called an original linguistic term; Otherwise, s_α is called a virtual linguistic term. In general, decision makers are used to utilizing original linguistic terms to evaluate the alternatives, and the virtual linguistic terms only appear in the operation process [40].

For any two linguistic variables $s_i, s_j \in \bar{S}$, the operational laws are defined as follows [40,41]:

(1) $\beta s = s_{\beta \times i}, \beta > 0;$ (1)

(2) $s_i + s_j = s_{i+j};$ (2)

(3) $s_i / s_j = s_{i/j}, j \neq 0$ (3)

(4) $(s_i)^\beta = s_{i^\beta}, \beta > 0.$ (4)