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Minimizing adjusted simple terms in the consensus reaching process with hesitant linguistic assessments in group decision making

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A B S T R A C T

In some real-world decision processes, decision makers may prefer to provide their opinions using linguistic expressions instead of a single linguistic term. Particularly, they may hesitate between several linguistic terms. In this paper, we deal with the consensus issue in the hesitant linguistic group decision making (GDM) problem. Firstly, a novel distance-based consensus measure is proposed. Then, using this consensus measure we develop an optimization-based consensus model in the hesitant linguistic GDM, which minimizes the number of adjusted simple terms in the consensus building. Furthermore, a two-stage model is displayed to further optimize the solutions to the proposed consensus model, through which we obtain the unique optimal adjustment suggestion to support the consensus reaching process in the hesitant linguistic GDM. Finally, several desirable properties are proposed to justify the proposal, and two examples are used to demonstrate the validity of the models.

1. Introduction

In real-world decision-making activities, decision makers often provide their opinions linguistically. However, solving a linguistic decision problem is complex, and implies a need of linguistic computational models for computing with words (CWW) [13,22,30]. There are three different linguistic computational models in decision making: (1) the model based on type-1 fuzzy sets [7,44] (or interval type-2 fuzzy sets [25,26,39,40]), (2) the symbolic model based on ordinal scales [8,41–43] and (3) the model based on the 2-tuple representation [10,11,14,37].

However, the linguistic computational models mentioned above are based on single linguistic term sets. In some decision-making situations, it is more comfortable for decision makers to use linguistic expressions to provide their opinions instead of using a single linguistic term. In recent years, several studies based on linguistic expressions have been proposed [1,21,23,34,45]. Particularly, if decision makers are not confident of their opinions, they may hesitate between several different linguistic terms [2,20,31,32,38,48]. Rodríguez et al. [31] introduced the concept of a hesitant fuzzy linguistic term set (HFLTS) by using comparative terms to provide a linguistic and computational basis to enrich linguistic elicitation based on hesitant linguistic approach. Rodríguez et al. [32] extended the use of context-free grammars to develop a group decision

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making (GDM) model based on HFLTSs. Wei et al. [38] defined operations on HFLTSs, and gave possibility degree formulas for comparing HFLTSs and also presented two new linguistic aggregation operators for HFLTSs. Liu and Rodríguez [20] proposed a new representation of HFLTSs by means of a fuzzy envelope to carry out the CWW processes. Beg and Rashid [2] proposed a new method to aggregate the opinions of decision makers on different criteria, regarding a set of alternatives, where the opinions of decision makers are represented by HFLTSs. Zhu and Xu [48] introduced the concept of hesitant fuzzy linguistic preference relation and defined several consistency measures for hesitant fuzzy linguistic preference relations. Agell et al. [1] and Roselló et al. [34] introduced a complete description of the order-of-magnitude qualitative space, which is related to the HFLTS proposed in Rodríguez et al. [31]. Agell et al. [1] and Roselló et al. [34] considered a set of consecutive linguistic labels based on order-of-magnitude qualitative space to represent the uncertainty.

Generally, at the beginning of GDM problems, decision makers' opinions may differ substantially. As a result, consensus processes are proposed to help decision makers reach a consensus. In consensus processes, full and unanimous agreement for every decision maker is often not necessary, so "soft" consensus has been presented [5,17,18]. Afterward, a number of studies for modeling the consensus process based on "soft" consensus have been presented (e.g., [6,15,16,24,28,29,34]). Feedback mechanism is one of the key elements in the consensus process, and the most important issue in feedback mechanism is to provide the adjustment suggestions to help decision makers reach a higher consensus level. It is natural that decision makers often hope to minimize adjustments between the original and adjusted individual opinions. Dong et al. [9] proposed a consensus operator, which provided an alternative consensus model for GDM problems to minimize the deviation between original and adjusted individual opinions. Ben-Arieh and Easton [3] and Ben-Arieh et al. [4] considered that the cost of moving each decision maker's opinion 1 unit distance is different. Based on the concept of consensus cost, they proposed the minimum cost consensus model and the maximum expert consensus model. Subsequently, Zhang et al. [46,47] extended the minimum cost consensus models and proposed a novel framework to achieve minimum cost consensus under aggregation operators.

As mentioned above, consensus models with minimum adjustments have been proposed in numeric environments [3,4,46,47] (or linguistic environments with single linguistic term [9]). But none of these consensus studies relates to the hesitant linguistic assessments. Actually in some real-world decision processes, decision makers may hesitate about their opinions. Therefore, we focus on the theories of HFLTSs that allow for handling of imprecise and vague assessments, and hope to solve the open problem: reaching a consensus with minimum adjustments in the hesitant linguistic GDM context. In order to do this, we must tackle the following two challenges:

(1) How to measure the consensus level among decision makers in hesitant linguistic GDM problems.
(2) How to design a procedure to provide adjustment suggestions, which helps the decision makers reach a consensus in the hesitant linguistic GDM context. Particularly, we hope to minimize the adjustments between original and adjusted hesitant linguistic opinions in the consensus building.

Motivated by these challenges, in this paper we define a distance between two HFLTSs, which reflects the number of different simple terms between two HFLTSs. For example, let $S = \{s_0 = \textit{very poor}, s_1 = \textit{poor}, s_2 = \textit{average}, s_3 = \textit{good}, s_4 = \textit{very good}\}$ be a linguistic term set, and let $Q = \{s_1, s_2, s_3\}$ and $N = \{s_3, s_4\}$ be two HFLTSs of S. The distance between Q and N is defined as the number of different simple terms between Q and N, i.e., the number of simple terms in the set $(Q \cup N) - (Q \cap N) = \{s_1, s_2, s_4\}$. Based on this idea, a novel consensus measure is proposed for measuring the consensus level in hesitant linguistic GDM problems. Furthermore, we design an optimization-based two-stage procedure to provide optimal adjustment suggestions to help the decision makers reach a consensus in the hesitant linguistic GDM context.

The purpose of this paper is to provide tools to help the decision makers manage the consensus reaching process in hesitant linguistic GDM problems. The rest of this paper is organized as follows. Section 2 provides background regarding the HFLTSs developed by Rodríguez et al. [31] and proposes the hesitant linguistic GDM problem. A distance-based approach for measuring the consensus level in the hesitant linguistic GDM is provided in Section 3. Following this, Section 4 proposes an optimization-based two-stage model with minimum adjustments to obtain the optimal adjusted individual opinions. Subsequently, several desired properties are investigated in Section 5. Finally, two illustrative examples are provided in Section 6, and concluding remarks are included in Section 7.

2. Background and the proposed problem

In this section, we review the concept and related operation laws of HFLTS, and then propose the hesitant linguistic GDM problem.

2.1. Hesitant fuzzy linguistic term sets

The basic notations and operational laws of linguistic variables were introduced in [14]. Let $S = \{s_j | j = 0, \ldots, g\}$ be a linguistic term set with odd granularity $g + 1$, where the term s_j represents a possible value for a linguistic variable. The linguistic term set is usually required to satisfy the following additional characteristics: