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Interval-valued fuzzy multiple criteria decision-making methods based on dual optimistic/pessimistic estimations in averaging operations

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ABSTRACT

This study aimed to consider the effect of dispositional optimism and pessimism to provide simple and useful decision models and methods for multiple criteria decision analysis within an interval-valued fuzzy environment. Uncertain and imprecise assessment information is usually present in many practical decision-making situations. Interval-valued fuzzy sets are useful for modeling impressions and quantifying the ambiguous nature of subjective judgments in a convenient way. Based on measurement tool estimations defined on interval-valued fuzzy sets, dual optimistic and pessimistic point operators were utilized in this study, and this paper discusses several important properties of optimistic/pessimistic averaging operations. Two algorithmic procedures were developed to address the effects of optimism and pessimism, involving changes in overall judgments and in the separate evaluations of alternatives with respect to each criterion. Furthermore, this study explored the practical problem of medical decision making to demonstrate the feasibility and applicability of the proposed method and to make a comparison with other existing methods. Finally, computational experiments were designed using enormous amounts of simulation data, and a comparative analysis of rank orders yielded by dual optimistic and pessimistic averaging operations was conducted.

1. Introduction

The concept of interval-valued fuzzy sets (IVFSs) is defined by an interval-valued membership function [1,2], and an element's degree of membership in a set is characterized by the closed subinterval [0,1]. Because it may be difficult for decision makers to exactly quantify their opinions or subjective judgments as a number within the interval [0,1], it is appropriate to represent the degree of membership by an interval rather than a single number. IVFSs are the most widely used higher-order fuzzy sets because of their relative simplicity [3], and they are suitable for capturing imprecise or uncertain decision information in multiple criteria decision analysis (MCDA) problems. Many useful methods have been developed to enrich IVFS theory in MCDA [4–10]. Although MCDA methods with IVFSs have been and still are studied in a variety of ways [11,12], issues related to optimistic and pessimistic MCDA methods using IVFS data have not yet been thoroughly explored.

In general, optimistic decision makers are confident that a decision goal is attainable and anticipate desirable evaluation values; thus, they may overestimate the decision outcomes. Pessimistic decision makers, in contrast, are often doubtful about the level of attainment, making them more likely to underestimate the decision outcomes [13,14]. From this perspective, the effects of optimism and pessimism should be integrated into decision analysis processes, especially when they bear heavily on subjective judgments and decision outcomes. Chen [23] utilized several score functions based on interval-valued fuzzy point operators to quantify optimistic and pessimistic estimations and developed a model to reduce cognitive dissonance. Atanassov [15,16] introduced the concept of an intuitionistic fuzzy set, which is characterized by the degree of membership, the degree of non-membership, and the degree of non-determinacy [17]. In the framework of intuitionistic fuzzy sets, some studies have been performed on MCDA methods with optimism and pessimism, such as multi-measure

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approaches [18], bivariate models [14], optimization models with score functions [19] or net predispositions [20], QUALItative FLEXible (QUALIFLEX) multiple criteria methods [21], and empirical outcome-oriented methods [22].

However, Chen [22,14,23,18–20] and Chen and Tsui [21] neither consider the influences of averaging operations nor investigate optimistic and pessimistic estimations in averaging operations within the interval-valued fuzzy environment. The concept of averaging operations is a commonly known and very widely used approach to providing an aggregation procedure for MCDA or other comparative evaluations. For example, the weighted aggregation operators proposed by Liu [24], the weighted geometric aggregation operators proposed by Liu and Jin [25], and the intuitionistic linguistic power generalized aggregation operators proposed by Liu and Wang [26] provide useful and valuable aggregation procedures for handling MCDA problems. In MCDA, the averaging operation uses all criterion values of an alternative and employs arithmetic addition operations. MCDA can be solely utilized to compare the overall evaluations of alternatives. Furthermore, the averaging operation can serve as the core of sophisticated MCDA methods when it is incorporated into existing decision-making methodologies. The aforementioned studies [14,18–23] developed useful optimistic and pessimistic decision-making models and methods in the context of IVFSs or intuitionistic fuzzy sets. Nevertheless, they neither extended the basic averaging operations to handle optimistic and pessimistic estimations nor investigated optimistic/pessimistic averaging operations and their essential properties. Viewed in this light, this paper developed useful optimistic/pessimistic averaging operations to effectively capture the effects of optimism and pessimism on decision-making processes.

The purpose of this paper was to propose optimistic/pessimistic averaging operations by incorporating the effect of dispositional optimism and pessimism into interval-valued fuzzy MCDA and to conduct a comparative analysis of dual optimistic and pessimistic point operators in averaging operations via computational experiments and practical applications. Specifically, this paper developed an appropriate method for capturing the effects of optimism and pessimism on MCDA using optimistic/pessimistic averaging operations. The concepts of optimistic and pessimistic point operators were employed to effectively determine optimistic and pessimistic estimations. Based on the suitability function of optimistic/pessimistic averaging operations, this paper established two algorithms to solve interval-valued fuzzy MCDA problems. The feasibility and applicability of the proposed methods were illustrated by considering a practical medical decision-making problem concerning acute inflammatory demyelinating disease. In addition, a comparative analysis with other existing approaches was performed to validate the effectiveness of the proposed methodology. Finally, different computer simulation experiments were carried out to determine the relationship between dual optimistic and pessimistic estimations. The rank-based comparison results indicated that optimistic and pessimistic point operators behave differently in averaging operations.

The main advantages of the developed methods are a simple treatment procedure for aggregating IVFS decision information and methodological flexibility in dealing with the effects of optimism and pessimism in MCDA. Further advantages include the following. First, dual optimistic and pessimistic estimations were implemented based on IVFSs to determine the effects of optimism and pessimism on MCDA. Second, classical averaging operations were extended via dual optimistic and pessimistic estimations, and several important properties thereof were discussed in this study. The proposed optimistic/pessimistic averaging operations can be widely applied to solve MCDA problems for evaluation and selection. Third, compared with other optimistic/pessimistic MCDA methods in the IVFS context, it is easy to implement the computation procedure of the proposed method using the suitability function with optimistic/pessimistic averaging operations. Fourth, the optimistic/pessimistic averaging operations can not only be used to evaluate alternatives but can also be combined with other MCDA methods. Finally, the proposed method allows for the aggregation of decision information to utilize distinct optimistic/pessimistic point operators for each criterion. Employing different point operators according to the optimistic or pessimistic nature makes the proposed method very flexible.

This paper is organized as follows. Section 2 briefly reviews the concept of IVFSs. Section 3 establishes dual optimistic and pessimistic estimations using several point operators based on IVFSs. Several important and valuable properties of the optimistic/pessimistic averaging operations are also discussed. Section 4 proposes a suitability function based on optimistic/pessimistic averaging operations to develop two algorithms for handling interval-valued fuzzy MCDA problems. Section 5 demonstrates the feasibility and applicability of the proposed methodology by considering a medical decision-making problem and conducting a comparative analysis with existing methods. Section 6 discusses the experimental analysis of rank orders yielded by dual optimistic/pessimistic point operators and averaging operations. Section 7 presents the conclusions of this work.

2. Preliminaries

This section briefly reviews some of the most important definitions, relations, and operations of IVFSs. Additionally, Table 1 provides a list of mathematical notations for ease of reference throughout this paper.

Definition 2.1. Let Int([0,1]) stand for the set of all closed subintervals of [0,1]. Let X be an ordinary finite non-empty set. An IVFS A in X is expressed as follows:

$$A = \left\{ \left\langle x, M_A(x) \right\rangle \middle| x \in X \right\}, \tag{1}$$

where the function $M_A: X \to \text{Int}([0,1])$, such that $x \to M_A(x) = [M_A^-(x), M_A^+(x)]$, defines the degree of membership of an element x to A.

Definition 2.2. For each IVFS A in X, the value

$$W_A(x) = M_A^+(x) - M_A^-(x) \tag{2}$$

represents the width of the interval $M_A(x)$. $W_A(x)$ can be considered the degree of hesitancy associated with the membership of element $x \in X$ in IVFS A.

For convenience of notation, the class of IVFSs in the universe X is denoted by $IVFS(X)$. Let $\bar{a} = 1 - a\, \forall a \in [0, 1]$.

Definition 2.3. For every $A, B \in IVFS(X)$, the relations and operations of IVFSs are defined as follows ("iff" means "if and only if" throughout this paper):

$$A \subset B \text{ iff } M_A^-(x) \le M_B^-(x) \text{ and } M_A^+(x) \le M_B^+(x) \text{ for all } x \in X; \tag{3}$$