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Fuzzy mathematical programming approach to heterogeneous multiattribute decision-making with interval-valued intuitionistic fuzzy truth degrees

Q1 Shu-Ping Wan [a,b], Deng-Feng Li [b,*]

[a] College of Information Technology, Jiangxi University of Finance and Economics, Nanchang 330013, China
[b] School of Economics and Management, Fuzhou University, Fuzhou, Fujian 350108, China

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A B S T R A C T

Considering the hesitancy degrees on pair-wise comparisons of alternatives as interval-valued intuitionistic fuzzy (IVIF) sets (IVIFSs), we develop a new fuzzy mathematical programming method for solving heterogeneous multiattribute decision-making problems based on the Linear Programming Technique for Multidimensional Analysis of Preference. In this method, IVIFSs, intuitionistic fuzzy sets (IFSs), trapezoidal fuzzy numbers, linguistic variables, intervals and real numbers are used to represent multiple types of attribute values and the attribute weights are not completely known. The preference relations between alternatives given by decision maker are expressed with IVIFSs of ordered pairs of alternatives. The consistency and inconsistency indices are defined as IVIFSs on the basis of comparisons of alternatives with IVIF truth degrees. The attribute weights and fuzzy ideal solution (FIS) are estimated through constructing a fuzzy mathematical programming model, which is solved by the technically developed method of IVIF mathematical programming. Hereby the distances of alternatives to the FIS are computed to rank the alternatives. Some generalization and discussion on the constructed IVIF mathematical programming model are also presented. A green supplier selection example is provided to illustrate the effectiveness of the proposed model and method. The comparison analyses verify the superiorities of the proposed method.

1. Introduction

With the drastic development of social economics and the significant progress of science and technology, environmental pollution is getting more and more attention. To protect the environment, many governments have enacted some laws and acts to restrict the use of harmful substances in native and import goods. This restriction causes a big change of enterprise's operating environment. To suit this change, green supply chain management appears in the last few years [22]. Selecting suitable green suppliers is one of the most critical activities in the success of green supplier purchase system. Some suppliers that meet some selection criteria (attributes) may fail in some other criteria. Therefore, green supplier selection problems may be ascribed to a kind of multiattribute decision-making (MADM) problem [13,25,26,29]. Since the green supplier selection problems involve multiple different attributes, which are qualitative and quantitative, the assessments of these attributes may be expressed with different formats, such as real numbers, intervals, linguistic variables [34], trapezoidal fuzzy numbers (TrFNs) [8], intuitionistic

Q2 * Corresponding author. Tel.: +86 0591 83768427; fax: +86 0591 83768427.
E-mail address: lidengfeng@fzu.edu.cn, lidengfeng65@hotmail.com (D.-F. Li).

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fuzzy (IF) sets (IFSs) [1], interval-valued intuitionistic fuzzy (IVIF) sets (IVIFSs) [3]. Such an MADM problem with multiple formats of information is simply called the heterogeneous MADM problem, which is very complicated and challengeable in real applications [9,10,18,21].

Linear Programming Technique for Multidimensional Analysis of Preference (LINMAP) developed by Srinivasan and Shocker [27] is a typical method for solving MADM problems. The LINMAP requires the decision maker (DM) to give pair-wise comparisons of alternatives and generates the best compromise alternative according to the distance to the ideal solution (IS). In the classic LINMAP [27], all decision data are known precisely or given as crisp values. However, in many practical situations, there usually exists incomplete and uncertain information, and the DM cannot easily express his/her judgment on the alternatives with crisp values. The fuzzy sets [33], linguistic variables, IFSs, and IVIFSs are usually more adequate or sufficient to model real-life decision problems than real numbers. Hence, various fuzzy extensions of the LINMAP [15,16,19,20,32,34] have been proposed in fuzzy or IF environments. Li and Sun [19] and Li and Yang [20] used linguistic variables to assess alternatives' attributes. These linguistic variables are transformed into positive triangular fuzzy numbers (TFNs). Xia et al. [32] transformed the linguistic variables into positive TrFNs. Hereby the fuzzy LINMAP was proposed for solving MADM problems. Li [15] and [16] respectively developed the linear programming methodologies for solving MADM and multiattribute group decision-making (MAGDM) problems in which the attribute values of alternatives are expressed with IFSs. Wang and Li [30] extended the LINMAP method to solve MAGDM problems in which the attribute values of alternatives are expressed with IVIFSs.

The above extensions of the LINMAP are effective and applicable to solve MADM and MAGDM problems. However, there are some limitations in the classic LINMAP [27] and fuzzy LINMAP [15,16,19,20,30,32]. On the one hand, the LINMAP and its extensions only considered the single type of attribute values and cannot deal with the heterogeneous MADM and MAGDM problems. On the other hand, the DM gives pair-wise comparisons of alternatives in the form of ordered pairs with crisp truth degrees 0 or 1 [15,16,19,20,27,30,32]. In reality, however, the DM is not sure enough in all comparisons and may give the pair-wise comparisons of alternatives with some hesitancy degrees due to time pressure, lack of knowledge (or data), and limited expertise about the problem domain. IFSs and IVIFSs seem to be suitable for describing this kind of fuzzy information with hesitancy degrees on the comparisons of alternatives. Therefore, extending the LINMAP to suit MADM and MAGDM problems considering comparisons of alternatives with hesitation degrees is a research topic, which should be paid attention to.

In a famous monograph [23], Pedrycz points out that it is not quite justifiable or technically sound to quantify grades of membership and non-membership in terms of a single numerical value. IVIFSs with interval-valued membership and non-membership functions have stronger ability and flexibility to express the hesitancy information than IFSs [5-7,23,35]. Thus, the IVIFSs are suitable to be used for capturing the hesitation degrees on comparisons of alternatives. In addition, with ever increasing complexity in real decision situations, there are some challenges for the DM to provide precise and complete weight preference information. Usually weights are totally unknown or partially known *a priori* [4,17,24,31,36]. For example, in a green supplier selection problem, technological ability and environmental protection consciousness of a green supplier can be assessed by IVIFSs and IFSs, respectively. Flexibility can be expressed by TrFNs. Social responsibility can be assessed by linguistic variables. The assessment for delivery time can be represented with intervals. The price can be measured by real numbers. Furthermore, it is not easy for the DM to precisely give the aforementioned attribute weights thanks to the influence of various subjective and objective factors. Therefore, the green supplier selection problem is a representative example of heterogeneous MADM problems with incomplete preference information.

The aim of this paper is to develop a new fuzzy mathematical programming method for solving heterogeneous MADM problems with IVIF truth degrees and incomplete weight information. In this method, the multiple types of attribute values include real numbers, intervals, linguistic variables, TrFNs, IFSs, and IVIFSs. The consistency and inconsistency indices are defined as IVIFSs because the hesitation degrees on comparisons of alternatives are represented as IVIFSs. A new IVIF mathematical programming model is constructed to estimate the attribute weights and the fuzzy IS (FIS). The ranking order of all alternatives can be generated according to the distance of each alternative to the FIS. The proposed fuzzy mathematical programming method can not only adequately consider the DM's hesitation about the comparisons of alternatives but also allow the DM to represent the assessment information with multiple different formats. The method proposed in this paper generalizes the classical LINMAP and its extensions.

The remainder of this paper is arranged as follows. Section 2 reviews some preliminaries regarding IVIFSs, IFSs, TrFNs, linguistic variables and interval objective programming. In Section 3, we describe the heterogeneous MADM problems and give the normalization methods. In Section 4, a new IVIF mathematical programming model is constructed to derive the attribute weights and FIS objectively. Then the corresponding method for heterogeneous MADM is proposed. Further discussions of the constructed IVIF mathematical programming model are presented in Section 5. In Section 6, a real example of the green supplier selection problem is analyzed to verify the effectiveness of the proposed method. We conclude this paper and give some remarks in Section 7.

2. Preliminaries

In this section, we first introduce some basic preliminaries on IFSs [1], IVIFSs [3], trapezoidal fuzzy numbers [8,15], linguistic variables [34], and interval objective programming [12].

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