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A new fuzzy linear assignment method for multi-attribute decision making with an application to spare parts inventory classification

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ABSTRACT

In this paper, a novel fuzzy linear assignment method is developed for multi-attribute group decision making problems. Since uncertain nature of many decision problems, the proposed method incorporates various concepts from fuzzy set theory such as fuzzy arithmetic and aggregation, fuzzy ranking and fuzzy mathematical programming into a fuzzy concordance based group decision making process. Fuzziness in the group hierarchy and quantitative type criteria are also taken into account. In order to present the validity and practicality of the proposed method, it is applied to a real life multi-criteria spare part inventory classification problem. The case study has demonstrated that the proposed method is easy to apply and able to provide effective spare parts inventory classes under uncertain environments. In addition to the practical verification by the company experts, the proposed method is also compared with some of the commonly used fuzzy multi-attribute decision making methods from the literature. According to the comparison of the results, there is an association between classes of spare parts obtained by the proposed method and the benchmarked methods.

1. Introduction

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Linear Assignment Method (LAM) is one of the less known members of Multi-Attribute Decision Making (MADM) approaches in the literature. LAM is mainly depends upon concordance concept and linear programming technique to determine the ranking order of alternatives. The crisp version of LAM was first introduced by Bernardo and Blin [1] for consumer choice among multi-attributed brands by using a set of attribute-wise rankings and a set of attribute weights. In LAM, a preference ranking order which best satisfies a given concordance measure can be generated. LAM also features a linear compensatory process for attribute interaction and combination. Furthermore, it utilizes only ordinal data rather than cardinal data as inputs in the decision making process [2,3]. Thus, it is not required to scale the qualitative attributes. For this reason, performance rankings needed by LAM are easier to obtain than the performance ratings required by the other MADM methods available in the literature [4]. In spite of being practical and easy to apply in various problems, LAM was implemented by relatively few researchers in the literature so far. In this research the focus is on the fuzzy version of LAM. A brief literature review on LAM for MADM problems can be presented as follows. A crisp LAM was employed by Jahan et al. [5] in a material selection process to rank and choose the best materials for a given engineering component. The comparison of that method was also carried out with the other MADM methods such as ELECTRE, VIKOR, graph theory-matrix approach and gray-relational analysis. Additionally, developing a group decision making approach based on the linear assignment concept was scheduled as a future work by the authors. In order to deal with the imprecise information in the decision making process, Liu and Liu [6] presented a fuzzy LAM by utilizing trapezoidal fuzzy numbers. However, that method involves uncertain evaluations only into the decision matrix and assigned crisp weights for each rank of the individual alternatives. In detail, after obtaining attribute-wise ranking matrix, all of the linguistic evaluations was transformed into the crisp equivalents which lead to deterministic weighted and concordance matrices. Therefore, the resulted assignment model will also be a deterministic linear program which may result in information losses into the decision making process.

A fuzzy interactive LAM with a group decision making procedure was proposed by Bashiri and Badri [7] in order to allow decision makers to modify their preference information within the decision making process. In the first phase of that procedure, an initial order of alternatives was determined based on fuzzy decision and weighted matrices by solving the crisp equivalent form of a fuzzy LAM. However, the weighted matrix and importance weights of the criteria were defuzzified and a final linear programming model was obtained with crisp binding constraints. According

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to decision makers' preference information, ranking order of the alternatives were revised and improved during the interactive process. Unfortunately, the relative importance of the decision makers and the hierarchy between the group members were not taken into account.

This method was also implemented by [8] for selecting the optimum maintenance strategy. The maintenance experts interacted with the immediate solutions to revise these solutions progressively within the interaction process until the final ranking satisfies them and remains unchanged. That method also assumed that the decision makers have equal importance weights and the same defuzzification procedure was applied for the weighted attribute-wise matrix. An interval type-2 fuzzy LAM was proposed by Chen [9] to capture the imprecise or uncertain decision information into the MADM problems. In order to generate criterion-wise ranking matrix, signed-distance method which is one of the defuzzification based ranking technique was used to rank the alternatives in terms of each criterion. After obtaining the weighted rank frequency matrix which consists of fuzzy weights, the signed distance method was used again so as to produce the crisp permutation (concordance) matrix. Therefore, a crisp LAM was provided at the final step of that method.

An extended LAM with interval-valued intuitionistic fuzzy sets was developed by Chen [10] for better reflection of the ambiguous nature of the subjective judgments and assessments. Thus, the imprecision in the degrees of membership could be handled. In fact, that method incorporated score and accuracy functions, membership and hesitation uncertainty indices so as to obtain attribute-wise preference of the alternatives. In order to determine the best preference ranking, a modified weighted-rank frequency matrix was employed to construct the linear programming model. However, since the usage of score and accuracy functions in certain cases, that method also produces crisp concordance matrix and a LAM with crisp objective function coefficients. Additionally, these methods [9,10] were not able to produce results for MADM problems under group decision making environments.

Based on these observations, the present paper presents a new fuzzy LAM which combines various fuzzy logic concepts for multi-attribute group decision making problems. The proposed method is able to model uncertain evaluations of alternatives with mixed qualitative and quantitative criteria. To this end, the fuzziness embedded in performance ratings of the alternatives, importance weights of the criteria and hierarchy between the group members is taken into account. In order to show the validity and practicality of the proposed method, it is applied to a real-life multi-criteria ABC analysis for spare parts inventory classification considering multiple decision makers. Additionally, an extensive comparison is also carried out with some of the popular fuzzy MADM methods from the literature to support the practical verification by company experts.

In the present paper, the following contributions are made: (i) apart from the existing literature, the proposed method utilizes different concepts of fuzzy set theory along the whole solution procedure. In detail, the fuzziness is also preserved in the weight and concordance matrices and reflected to the mathematical formulation of the LAM in order to overcome the deficiencies which may be resulted from possible information losses. In other words, the proposed method does not use any defuzzification procedure while generating the weight and concordance matrices. The uncertainty of the examined problem is reflected to the LAM whose objective function coefficients are also stated as fuzzy numbers, (ii) a group decision making process considering uncertainty related to hierarchy between the group members and their relative importance is presented based on the fuzzy linear assignment concept. In the literature, most of the papers assign fuzzy weights to reflect the relative importance of the decision makers without any well-reasoned explanation. However, since the uncertain hierarchy between the group members, the decision makers may also have uncertain importance/weights in the decision making process. For this purpose, these fuzzy weights are derived from the uncertain hierarchy between the group members by using a subjective preference based weighting method, (iii) since the LAM for MADM problems primarily uses the attribute-wise rankings of the alternatives to construct the weight and concordance matrices, selection of an appropriate ranking procedure is so crucial in terms of the accuracy of the results. The available fuzzy LAMs in the literature employ defuzzification based ranking procedures to construct the attribute-wise ranking matrix. Although defuzzification based ranking procedures are computational efficient, they have many deficiencies in relation to "fuzzy preference representation", "the rationality of preference ordering", "robustness" and "accuracy". In the present paper a fuzzy preference based ranking procedure is employed and incorporated into the proposed fuzzy LAM in order to eliminate these deficiencies.

Due to all of these capabilities, the proposed method can be considered as a useful tool for a better reflection of the real-life multi-attribute group decision making problems under uncertain environments. The remaining part of this paper is organized as follows: a detailed algorithmic procedure of the proposed method is described in Section 2. Section 3 illustrates the computational procedure of the proposed method along with an application to a real life multi-criteria ABC analysis for spare parts inventory classification. The comparison of the proposed method with some of the recently developed fuzzy MADM methods is also presented in the same section. Finally, conclusions and future research directions are given in Section 4.

2. The proposed fuzzy LAM for MADM problems

In this section, the fundamentals of the proposed fuzzy LAM are presented which consists of thirteen steps. The proposed method incorporates the following concepts from the fuzzy set theory which are depicted in Fig. 1. The main steps of the proposed method are described in the following sections.

2.1. Construction of the fuzzy decision matrix

At first the fuzzy decision matrices are constructed for each decision maker. In fact, the decision makers need to assign the appropriate fuzzy numbers or linguistic values to each criterion regarding to all alternatives based on their own judgments. For the evaluation of the qualitative type criterion, the linguistic expressions can be defined as a variable whose values are words or phrase in natural or artificial language [11]. In Table 1, the linguistic variables and fuzzy ratings for both criteria and alternatives are presented. In addition, the membership functions of these linguistic terms which are related to the importance of different criteria are also demonstrated in Fig. 2. In this figure, μ_L represents the membership functions of each linguistic value, where $\mu_L \in [0, 1]$.

Finally, the fuzzy decision matrix ($\tilde{D}_k$) with fuzzy evaluations of decision maker k for the alternatives with regard to the predefined criteria can be constructed as follows:

$$\tilde{D}_k = \begin{array}{c} \\ A1 \\ A2 \\ \cdots \\ AM \end{array} \begin{array}{c} \begin{array}{cccc} C1 & C2 & \ldots\ldots & CN \end{array} \\ \begin{bmatrix} \tilde{x}_{11k} & \tilde{x}_{12k} \cdots & \tilde{x}_{1nk} \\ \tilde{x}_{21k} & \tilde{x}_{22k} \cdots & \tilde{x}_{2nk} \\ \cdots & \cdots\;\cdots & \cdots \\ \tilde{x}_{m1k} & \tilde{x}_{m2k} \cdots & \tilde{x}_{mnk} \end{bmatrix} \end{array} \quad (1)$$

Fuzzy ratings of the kth decision maker are presented by $\tilde{x}_{ijk} = (a_{ijk}, b_{ijk}, c_{ijk})$ where i = 1,2,. . ., M for alternatives; j = 1,2,. . .,N for criteria and k = 1,2,. . .,K for decision makers.