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An extended 2-tuple linguistic DEA for solving MAGDM problems considering the influence relationships among attributes

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ABSTRACT

The main purpose of this paper is to propose an extended data envelopment analysis (DEA) approach for solving multiple attribute group decision making (MAGDM) problems with unknown decision maker (DM) weights and attribute weights. The 2-tuple linguistic representation model is more suitable to deal with linguistic evaluations than the extension principle and the symbolic method. So we propose a 2-tuple linguistic DEA model and objective DM weights determination method in 2-tuple MAGDM problems. The DMs' objective weights are dynamic with respect to each attribute over different alternatives, which are determined according to the grey relational degree of the decision information DM given with the ideal decision information obtained by solving a weighted least square optimization model. The optimized attribute weights based on the DEA model only reflect the beneficial side to each alternative and ignore the objective side like influence relationships among attributes. Therefore, a 2-tuple linguistic DEMATEL technique is presented and applied to adjust the attribute weights obtained by DEA, and then the comprehensive attribute weights are derived. Finally, the evaluation values of alternatives are obtained based on the comprehensive attribute weights according to the efficiency evaluation method of DEA. A case study is put forward to validate the effectiveness of the proposed approach.

1. Introduction

Multiple attribute decision making problems widely occur in real-life decision-making situations, such as alternative selection (Yayla, Oztekin, Gumus, & Gunasekaran, 2015), supply chain management (Dursun & Karsak, 2013), technology evaluation (Liu, You, Lu, & Chen, 2015) and performance improvement (Tsui, Tzeng, & Wen, 2015). The increasing complexity of the socio-economic environment makes it less and less possible for a single expert or decision maker (DM) to consider all relevant aspects of a problem (Kim, Choi, & Kim, 1999). Therefore, multiple attribute group decision making (MAGDM) has been regarded as one critical subfield of modern decision theories, which has a complex process where several attributes must be satisfied to find the desirable alternative from a given alternative set by multiple DMs. It is quite common that in MAGDM problems both the DM weights and the attribute weights are partially known or completely unknown, but researches focusing on this issue are few. The purpose of this paper is to develop a new approach based on data envelopment analysis (DEA) for solving MAGDM problems with unknown DM weights and attribute weights.

Generally, the resolution of a MAGDM problem needs two phases: aggregation and exploration (Chiclana, Herrera, & Herrera-Viedma, 1998). The components of the aggregation phase are acquiring each DM's judgment information, determining DM weights and aggregating all DMs' judgment information into a collective decision matrix by a given method. The components of the exploration phase are calculating the comprehensive values of alternatives and obtaining the ranking of alternatives. The corresponding key issues this paper focusing on are determining DM weights and ranking the alternatives. In the aggregation phase, various aggregation operators are applied to aggregate all individual decision matrices into a collective one, in which the DMs' weights are considered due to their unique characteristics with regard to knowledge, skills, experiences and preferences. Different DM weights allocation may result in different collective decision matrices and then can significantly influence the final result. DM weights can be determined by using subjective methods such as Delphi and the analytical hierarchy process (AHP) or objective methods by judging the quality of each DM's judgment. The objective DM weights are preferred in group decision making process. However, every DM is often assumed to be good at evaluating all attributes, and his or her weight remains unchanged with respect to different attributes. In fact, it is more natural and reasonable to allocate different weights for each DM with respect to different

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attributes (Wan, Xu, Wang, & Dong, 2015). Moreover, in practical decision problems, every DM cannot be expected to have sufficient expertise to comment on all alternatives. Thus, we consider the potential for allocating dynamic weights to each DM with respect to different attributes over different alternatives, and determine the dynamic DM weights. The dynamic DM weights are derived according to the correlation degree of the DM's evaluation with the ideal evaluation information, which is obtained by constructing a goal programming model according to the principle of least squares method. The higher the correlation degree of attribute evaluation value given by a certain DM for an alternative is, the larger the dynamic weight of his or hers in this context is.

In the exploration phase, how to select multiple attribute decision making (MADM) methods such as AHP, analytic network process (ANP), technique for order preference by similarity to ideal solution (TOPSIS), grey relational analysis (GRA) and multi-criteria optimization and compromise solution (VIKOR), is a critical problem. However, most of these methods should pre-determine the attribute weights, which always involve vagueness and objectivity. DEA developed by Charnes, Cooper, and Rhodes (1978), is a commonly used method to measure and analyze the relative efficiencies of comparable decision-making units (DMUs) with multiple inputs and outputs. Bouyssou (1999) studied proposals to use DEA as a tool for solving MADM problems, and investigated that the concept of efficiency in DEA and convex efficiency in MADM are equivalent. Some researchers have applied DEA as a tool for solving MADM problems or vice versa (Liu, Huang, & Yen, 2000; Yougbare & Teghem, 2007; Yun, Nakayama, Tanino, & Arakawa, 2001). Keshavarz and Toloo (2014) have proved some theorems to clarify the relationships between DEA and multi-criteria assignment problem and then designed a new two-phase approach to find and classify a set of efficient assignment. DEA has a prominent merit that it does not require the decision maker to pre-define the attributes' weights but these are endogenously determined (Dotoli & Falagario, 2012). However, the traditional DEA model has some disadvantages that should be avoided, which can be summarized as the following three points: (1) The traditional DEA model assumes that both inputs and outputs are indicated as crisp number, and ignores the uncertainty and fuzziness of the assessment environment. (2) The optimized attribute weights can only reflect the beneficial side to each alternative and ignore the objective side like the influence relationships among attributes. (3) The traditional model has a lower discrimination power, which often results in several even all efficient DMUs are at the same level.

- Aiming at the first disadvantage, the majority of researchers have applied linguistic preferences to handle the uncertainty and vagueness in DEA models. They usually deal with the linguistic terms by using the extension principle or the symbolic method, in both of which an approximation process must be developed to express the result in the initial expression domain, and the computation results usually don't exactly match any of the initial linguistic terms. This produces the consequent loss of information and hence the lack of precision in the final results (Liu, Liu, & Wu, 2013). To address the above shortcomings, the 2-tuple linguistic representation model was put forward by Herrera and Martínez (2000), the main advantages of this representation can be summarized as the continuous treatment of the linguistic domain, the minimization of the loss of information and thus the lack of precision (Karsak & Dursun, 2015). MADM under 2-tuple fuzzy environment is an interesting and hot research topic. However, DEA model based on 2-tuple linguistic representation model has not been studied. In this paper, we develop a 2-tuple linguistic DEA model for solving fuzzy MAGDM problems. The difference between using 2-tuple representations for DEA models and those for MADM models is that 2-tuple linguistic representations are used for solving programming problems rather than carrying out general mathematical calculations.
- For the second point, the influence relationship among attributes is an indispensable factor in measuring the objective importance degree of attributes. The higher the impact degree of a certain attribute to other attributes is, the larger the objective importance degree of this attribute is. Therefore, the optimized attribute weights obtained by DEA model should be adjusted. In this paper, we study an extended 2-tuple DEA approach combined with the decision making trial and evaluation laboratory (DEMATEL) technique. DEMATEL is a comprehensive technique for constructing a structural model involving cause and effect interrelationships between factors, and has been widely used for analyzing the interrelationships or influence relationships among criteria in the literature (Uygun, Kaçamak, et al., 2015; Lin, Shih, Tzeng, & Yu, 2016). The 2-tuple linguistic DEMATEL is used to analyze the influence relationships among attributes and calculate the objective importance degrees of attributes for adjusting the attribute weights optimized by 2-tuple DEA.
- For the third point, there have been several studies to extend DEA models for improving discrimination power of classical DEA. They can be divided into two main groups: multiple criteria DEA (MCDEA) model (Karsak & Ahiska, 2005; Li & Reeves, 1999) and mixed integer linear programming (MILP) model (Amin & Toloo, 2007; Toloo, 2013, 2015). These models are complicated and appear to be completely different from classical DEA. In this paper, the usage of the comprehensive attribute weights in the consideration for the second point can enhance the discriminating power of DEA model indirectly through removing the constraint that the efficiency of evaluation object is not larger than 1. For the optimized attribute weights, several DMUs may have the equal efficiency value that is 1. After considering the objective attributes weights obtained by DEMATEL, these DMUs can be discriminated for that their comprehensive values are no longer equal and may be larger or less than 1. The comprehensive evaluation values of alternatives can be calculated based on the classical efficiency calculation method of DEA.

The specific properties of the proposed model are applying the 2-tuple linguistic representation model to DEA model using the dynamic DM weights and calculating the comprehensive values of alternatives using the efficiency formula by considering the optimized attribute weights and influential attribute weights. The model is new and unique in solving MAGDM problems with unknown DM weights and attribute weights under uncertain environment. The remaining part of this paper is organized as follows. Section 2 overviews the application of DEA, DEMATEL and related methods for determining DM weights in MAGDM process. In Section 3, the basic concepts of 2-tuple linguistic representation model are presented and the dynamic DM weights determination method in 2-tuple MAGDM problems is provided. Section 4 introduces the proposed extended 2-tuple linguistic DEA method combined with DEMATEL. In Section 5, a case study is presented to illustrate the proposed approach. The conclusions of this paper are given in the final section.

2. Related works

This section introduces the related works including (1) objective DM weights determination methods; (2) DEA and its extensions; and (3) DEMATEL technique and its applications.