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A multicriteria sorting approach based on data envelopment analysis for R&D project selection problem ☆

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ABSTRACT

In this paper, multiple criteria sorting methods based on data envelopment analysis (DEA) are developed to evaluate research and development (R&D) projects. The weight intervals of the criteria are obtained from Interval Analytic Hierarchy Process and employed as the assurance region constraints of models. Based on data envelopment analysis, two threshold estimation models, and five assignment models are developed for sorting. In addition to sorting, these models also provide ranking of the projects. The developed approach and the well-known sorting method UTADIS are applied to a real case study to analyze the R&D projects proposed to a grant program executed by a government funding agency in 2009. A five level R&D project selection criteria hierarchy and an assisting point allocation guide are defined to measure and quantify the performance of the projects. In the case study, the developed methods are observed to be more stable than UTADIS.

1. Introduction

Multiple criteria sorting problem is assigning a set of alternatives (DMUs) into predefined, homogeneous and ordinal groups via a criteria aggregation model in the existence of multiple criteria. It has attracted the attention of many researchers in the last four decades. Multiple criteria sorting methods can be grouped into three classes according to the criteria aggregation model structure. In the first class of sorting methods, allocation of alternatives into groups is performed by some heuristic approaches based on outranking relations such as ELETRE-TRI method [1]. In the second class of sorting methods, the placements of the alternatives into classes are accomplished by considering their global utilities such as MAUT [2] and UTADIS [3]. In the third class of sorting methods, alternatives are assigned into groups using rough sets theory [4].

Data Envelopment Analysis (DEA) [5] is a data oriented mathematical model for measuring the performances of decision making units (DMUs), that are evaluated by multiple and common inputs and outputs. Recently, two-stage DEA models are formulated to evaluate the performances of DMUs considering their internal resource utilization performances [6]. DEA has been used to solve multiple criteria ranking problems ([7,8] and see [9] for a review) even though using DEA for ranking purpose is criticized for its deficiencies [10]. One of the deficiencies of DEA is the lack of discrimination power which causes many DMUs to be efficient. While cross-efficiency DEA [11] favors DMUs that are close to each other and penalizes the ones that are different from the majority, super-efficiency DEA [12] favors extreme DMUs that are different from the majority. The other deficiency of DEA is the inappropriate weight dispersion which results in solutions that are impossible to attain in real life or in contradiction with the judgments of DMs. As a remedy, it is recommended to add assurance regions on weights when the preferential information of DMs is available [13]. In [14] non-homogeneity of input and output weight dispersions is discussed and a multiple criteria DEA model where the second objective is to minimize the coefficient of variation of weights is developed. In [15] and [16], it is argued that evaluating DMUs by using common set of weights is more fair and provides more information about DMUs, especially for the efficient ones.

To our knowledge, there are very few studies that use DEA for sorting. Johnson and Zhu [17] group alternatives into four prioritized classes based on their benchmarking shares and context-dependent DEA scores. Ulucan and Atıcı [18] also separate alternatives into efficiency levels by using context-dependent DEA. Madlener et al. [19] compare the efficiency values obtained from DEA, and DMUs are placed into the groups using IRIS/ELECTRE-TRI approach. Sueyoshi [20,21] incorporates DEA into discriminant analysis to generate separation functions between classes/groups.

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In this paper, a sorting approach based on data envelopment analysis (DEA) is developed and used for sorting R&D projects. Nowadays, the private sector companies should conduct Research and Development (R&D) projects in order to survive in the highly competitive global world. Many countries encourage R&D activities of private sector to increase the number of successful firms and to improve the competitive power of the country by executing R&D project support programs providing grants or loans.

In Turkey, R&D projects are funded by a grant program of a state institution. In the grant program, the project proposals are initially subjected to pre-assessment by the technical staff of the institution. The proposals eliciting preliminary conditions are then submitted to independent referees from universities or research centers that are specialized in the project field. Finally, the technology group committee makes funding decision based on the referee reports. However, making funding decisions for R&D projects that involve high uncertainties and risks is quite difficult. R&D project selection criteria considered by the institution are also challenging, and making a decision requires to consider trade-offs between these criteria. In addition, the decisions are always made by a group of decision makers (DMs) with different backgrounds and viewpoints. The recent increases in the number of project applications and total grant funding provided by the organization also increase complexity in decision making. Therefore, a method supporting the selection of R&D projects should not only provide a fair evaluation by decreasing the subjectivity of decision making but also should reduce the time requirement for evaluation. Generally, R&D project selection is performed by ranking all projects [22–24]. Although ranking provides more information about the importance of the projects, classifying them into ordinal groups provides more robust results [19,25,26].

There are very few studies that use DEA for project selection and ranking problems. DEA is integrated into knapsack problem to select a portfolio of projects without exceeding limited capital resources [27]. Project selection problem is similar to technology selection problem where technology such as machine tools, industrial robots or flexible manufacturing systems is selected considering performance and cost criteria. There are some studies that use DEA to select the best technology [28], identify a set of efficient technologies [29] and to rank the technologies [30–33]. However, DEA is not used for sorting projects or technologies.

In this paper, two threshold estimation models are developed for determining the thresholds of the classes when solved for the projects of reference set and five assignment models are developed for calculating the efficiencies of the unevaluated projects. Sorting of the projects is accomplished by comparing project efficiencies with the estimated thresholds, while project efficiencies also provide the ranking. Due to the uncertainties and complexities of the problem, the pairwise comparison matrices and criterion weights are determined as interval values rather than crisp values. The weight intervals obtained from the interval analytic hierarchy process (AHP) model [34] are used as the assurance region constraints of the developed models. The models are applied to a real case study considering the proposals of the grant program from the year 2009. First, R&D project selection criteria are determined. The qualitative criteria are converted to quantitative measures with the assistance of the proposed point allocation guide. The results are also compared with a well-known multiple criteria sorting method UTADIS [3].

To our knowledge, using DEA for sorting purpose is accomplished for the first time in this study. Furthermore, integrating interval AHP method that determines interval priorities from interval comparison matrices and DEA to acquire the assurance region constraints of DEA is also the first attempt in the literature. By this way, the shortcoming of inappropriate weight assignment of DEA is prevented. Also the other shortcoming of DEA, lack of discrimination, is also hindered by the second threshold estimation model and its compatible assignment models by restricting the optimal weight dispersions As far as we know, the hierarchy developed for selecting industrial R&D projects is the most complicated structure evaluated by AHP and this hierarchy is also a contribution to the literature.

Organization of the paper is as follows. In the next section, the developed methods are explained. In Section 3, a list of R&D project selection criteria with the point allocation guide is determined and methods are applied to a real case study. Finally, the discussions and conclusions are provided.

2. A DEA based sorting approach

AHP [35] is a structured decision making method to evaluate discrete set of alternatives with respect to multiple and conflicting criteria. Since its development, AHP is used widely in many applications because of its simplicity and flexibility [36,37]. Pairwise comparison matrices are constructed by the crisp comparison values utilizing nine point scale of Saaty [35]. However; taking interval judgments from DM is more realistic when the complexity and uncertainty of the problem increase [38–40]. Moreover, interval judgments are more rational due to the subjectivity of the human judgments [41] and easier to be used in case of group decision making [42]. The weights generated from the methods dealing with interval matrices can be crisp or interval [43,44]. Additive [44] and multiplicative normalizations [34,39,45] are developed to obtain weights from interval judgments in AHP.

In literature, AHP and DEA are integrated for several reasons. The main purpose of this integration is to incorporate precise weights obtained from AHP into DEA models. Inputs and outputs of DEA are identified and number of DEA inputs and outputs are reduced by using AHP. Moreover, criteria weight vectors are generated from pairwise comparison matrices of AHP by utilizing DEA [46–50]. In the developed approach, AHP is applied to provide upper and lower bounds on the criteria/subcriteria weights. These interval priorities are incorporated into the DEA based sorting methods as assurance regions.

2.1. Interval AHP models

The risks and uncertainties of R&D projects, variety of the project technology areas, group decision making and subjectivity of the referee evaluations make the utilization of interval comparison matrices and priorities more realistic in AHP. Since it is impracticable to obtain fully consistent comparison matrices, mathematical modeling approaches are used to handle inconsistent comparison matrices. Goal programming method of Wang and Elhag [44] and method developed by Karasakal and Öztürk [34] are chosen to analyze the results of additively and multiplicatively normalized AHP methods. The pairwise comparison matrices are acquired from the questionnaire conducted to the DMs of the grant program. Interval comparison matrices are constructed using the highest and the lowest crisp judgments of DMs for each pairwise comparison.

2.1.1. Method of Wang and Elhag [44]

The interval comparison matrix provided by DMs can be represented as follows:

$$A = \begin{bmatrix} 1 & [l_{12}, u_{12}] & \cdots & [l_{1n}, u_{1n}] \\ [l_{21}, u_{21}] & 1 & \cdots & [l_{2n}, u_{2n}] \\ \vdots & \vdots & \vdots & \vdots \\ [l_{n1}, u_{n1}] & [l_{n2}, u_{n2}] & \cdots & 1 \end{bmatrix} \tag{1}$$

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