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Fuzzy type-II De-Novo programming for resource allocation and target setting in network data envelopment analysis: A natural gas supply chain

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ABSTRACT

Developing effective approaches to design optimal resources of system based on the concepts of benchmark in DEA and optimal design in De-Novo programming is one of the important managerial decision making problems. In this paper, a decision support system is developed for allocation of resources and setting the targets across a set of entities in an equitable manner in presence of uncertainty. The proposed approach has two main modules. First, the most suitable system is designed using De-Novo programming. De-Novo programming. De-Novo programming is used to optimally determine the inputs (i.e., resources) and outputs (i.e., targets) of DMUs in network DEA rather than optimizing existing DMUs. Then, the optimal values of resources are allocated and optimal values of the targets are set in a complex network structure. Furthermore, in real-world problems budget of resources and targets are usually mixed with uncertainties, so in this paper, two concept of fuzzy and interval type-II fuzzy resources and target are developed for resource allocation and target setting. Finally numerical example based on real case of natural gas supply chain is also used to evaluate the applicability and efficacy of the proposed models.

1. Introduction

DEA plays an important role in performance evaluation of a set of decision-making units (DMUs) since the publication of Charnes, Cooper, and Rhodes (1978). The first use of DEA is to measure the relative efficiency of the decision-making units (DMUs) in both conventional DEA and Network Data Envelopment Analysis (NDEA). There are various research in this filed. (Lewis and Sexton, 2004; Cao and Yang, 2011; Chen and Zhu, 2004; Chen et al., 2010; Chen, Cook, Li, and Zhu, 2009a; Chen, Liang, and Zhu, 2009b; Chiu, Huang, and Ma, 2011; Cook, Zhu, Bi, and Yang, 2010; Golany, Hackman, and Passy, 2006; Kao, 2009; Kao and Hwang, 2008; Kao and Lin, 2011; Kao and Lin, 2012; Kao, 2014; Khalili-Damghani and Shahmir, 2015; Khalili-Damghani, Taghavifard, and Karbaschi, 2015; Khalili-Damghani, Taghavifard, Olfat, and Feizi, 2012b; Liang et al., 2008; Liang, Li, Cook, and Zhu, 2011; Liu, 2011; Liu and Wang, 2009; Seiford and Zhu, 1999).

1.1. Application of DEA and NDEA in resource allocation and target setting

In recent years, several applications of resource allocation and target setting have been devoted to literature of DEA. The use of DEA for resource allocation provides a situation to consider feasible production plans and trade-offs between the inputs/outputs based on the production possibility set (Amirteimoori & Emrouznejad, 2012; Korhonen & Syrjanen, 2004).

A resource allocation model was proposed to allocate fixed cost as an additional input based on two principles of efficiency invariance and Pareto optimality for the first time by Cook and Kress (1999) proposed. The method proposed a new resource (common cost) among all DMUs that maintained the performance of the DMUs before and after the change. In the first phase, the efficiency of the DMUs was determined through the CRS model. In the second phase new source was assigned in such a way that the performance of all DMUs before and after the assignment was the same. To deal with the problem of non-uniqueness in the proposed model by Beasely (2003) and Cook and Kress (1999) provided a model with assumption on maximizing the average efficiency of all DMUs after allocation. Because the Cook and Kerss (1999) approach were not directly used to determine the cost assigned to decision-making units, but only to examine the existing rules for fair allocation of costs, so Cook and Zhu (2005) developed the method for variable return to scale that only provided one feasible solution, which may not be optimal. The method by Cook and Zhu (2005) did not produce any feasible solutions in the presence of certain constraints. As a result, Lin (2011) developed that model to obtain a fair allocation of fixed costs or new resources by

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maintaining efficiency. Jahanshahloo, Hosseinzadeh Lotfi, Shoja, and Sanei (2004) and Jahanshahloo, Hosseinzadeh Lotfi, and Moradi (2005) presented a simple method for equitable allocation of shared costs and common revenue, respectively, based on invariance principle of Cook and Kress (1999) using a formula without solving any linear programming problem. As the Model proposed by Beasely (2003) is not always feasible so, Amirteimoori and Kordrostami (2005) have introduced a feasible model that provided a unique allocation of new resources (simultaneous input and output) with the aim of maintaining the efficiency of the DMUs. They considered simultaneous allocation of new inputs and new outputs. They developed allocation model by combining the efficiency invariance of Cook and Kress (1999) and unique allocation model proposed by Beasley (2003). Amirteimoori and Mohaghegh Tabar (2010) have also proposed a new resource allocation and target setting model based on minimizing total deviation of ideal solutions and minimizing the maximum deviation of ideal solution. The model proposed by Amirteimoori and Mohaghegh Tabar (2010) extended by Hosseinzadeh Lotfi, Hatami-Marbini, Agrell, Aghayi, and Gholami (2013) from single resource and target to multiple resources and targets considering common-weights concept.

There are some limitations in traditional resource allocation and target setting models. Most of them are based on classic DMUs, decentralized approach, and exact input / output. One of the limitations of traditional resource allocation and target setting DEA models is that the DMUs are treated as black box. On the other hand the internal relations of DMUs have never been considered. Hence, the resource allocation and target setting is not clear for sub-DMUs. Bi, Ding, Luo, and Liang (2011) proposed the resource allocation and target setting model for the organization consisting of production units, each of which had several parallel production lines. The proposed method maximized the performance of the worst production line within the production unit, while the efficiency of the entire unit maintained. Yu, Chen, and Hsiao (2015) proposed a resource allocation model for two-stage structure. The proposed model obtained the optimal fixed cost allocation among all DMUs by an iterative procedure. Azadi, Jafarian, Farzipoor Saen, and Mirhedayatian (2015) developed two DEA models to set targets for two-stage network structures. The objective of proposed approaches was to plan a feasible solution to ensure targets were within current operational capacity.

Another limitation of traditional models is that they analyze one DMU at a time independently. Centralized DEA approach for resource allocation was recommended to resolve this issue. Several studies have developed centralized resource allocation models considering output and output orientations and constant or variable return to scale assumptions. Lozano and Villa (2004) developed two input-oriented centralized DEA models to reduce the total quantity of consumed resources by all DMUs. Asmild, Paradi, and Pastor (2009) extended the proposed model by Lozano and Villa (2004) for variable return to scale conditions. Several output-oriented centralized models that maximized the total amount of the outputs of all DMUs simultaneously has been proposed (Fang & Hecheng, 2015; Fang & Li, 2015; Lozano, Villa, & Adenso-Diaz, 2004; Lozano, Villa, & Brännlund, 2009; Lozano, Villa, & Canca, 2011).

In conventional resource allocation and target setting models data are assumed to be precise. However, there are real situations where data are imprecise or uncertain. To cope with such situations, Hosseinzadeh Lotfi, Nematollahi, Behzadi, Mirbolouki, and Moghaddas (2012) presented the stochastic centralized resource allocation in order to allocate centralized resources where inputs and outputs were stochastic. They converted the stochastic model into a deterministic model. Hatami-Marbini, Ghelej Beigi, Fukuyama, and Gholami (2017) presented DEA models to allocate imprecise resources and setting imprecise targets to DMUs. They used the common set of weights approach to obtain the upper and lower efficiency of DMUs with interval inputs and outputs. Finally, they proposed two models to find an adequate assignment for the resource allocation and target setting such that the interval efficiency of all the DMUs improved or at least remained.

Another aspect of resource allocation and target setting is the reconfiguration of the inputs and outputs of DMUs instead of using existing inputs and outputs which is known as system design. System design concept that seeks a suitable configuration for levels of the resources considering resource price has become important managerial issue. For the first time Zeleny (1990) proposed a De Novo programing method to construct the optimal system design. Li, Yang, Liang, and Hua (2009) allocated fixed cost as a dependent input to determine a unique allocation. Pachkova (2009) proposed a model to reallocate the inputs using trade-off between the maximum allowed reallocated cost and the highest possible aggregation of the efficiency of DMUs.

1.2. Developing fuzzy set theory in DEA

Crisp inputs and outputs are fundamentally essential in classic DEA models. However, in real world problems data are often imprecise, so many researchers have proposed methods for dealing with the imprecise data in DEA. Fuzzy sets theory has been widely used to model uncertainty in DEA. Several researchers tried to deal with fuzzy inputs and outputs in DEA. Abtahi and Khalili-Damghani (2011) proposed a fuzzy DEA approach to measure the agility of supply chains. Khalili-Damghani et al. (2011) proposed a hybrid approach on the basis of fuzzy DEA and simulation to measure the efficiency of agility in dairy supply chains. Khalili-Damghani, Taghavifard, and Abtahi (2012a) developed a fuzzy two-stage DEA model for performance assessment of agility of supply chain. Khalili-Damghani and Abtahi (2012) proposed a fuzzy DEA model to measure the efficiency of just in time (JIT) production system. The applied the proposed model in a dairy industry supply chain. Khalili-Damghani and Taghavifard (2012) proposed a fuzzy three-stage DEA model to calculate interval efficiency scores of JIT practices, different levels of agility indices, and goals of supply chains. Khalili-Damghani and Hosseinzadeh-Lotfi (2012) proposed a fuzzy DEA based Malmquist productivity index in order to measure the productivity of traffic police centers. Khalili-Damghani and Tavana (2013) proposed fuzzy network DEA model for measuring the performance of agility in supply chains. Tavana and Khalili-Damghani (2014) developed two-stage processes with uncertain inputs and outputs using leader-follower game theory. Wang, Lu, and Liu (2014) applied fuzzy multiple objective programming approaches to calculate the efficiency of bank holding companies. Puri and Yadav (2014) developed a DEA model with undesirable fuzzy outputs for measuring efficiency of banking sector using α-cut approach. Liu and Chuang (2009) presented a fuzzy DEA model to calculate the fuzzy efficiency score while the input and output data were represented as convex fuzzy numbers. Khalili-Damghani et al. (2016) proposed a comprehensive fuzzy DEA model to measure the efficiency of emerging markets. Amirkhan, Didehkhani, Khalili-Damghani, and Hafezalkotob (2018) proposed a network DEA model in order to measure the relative efficiency of a process including three serial stages. Amirkhan et al. (2018) addressed mixed of uncertainty including fuzzy and robust paradigms in network DEA models.

From practical and financial perspective, the allocation of resources and targets across a set of DMUs in an equitable manner involves different concerns for decision makers especially in presence of uncertainty. So, the design and application of a decision support system or an expert system with decision making ability is a practical way to solve such problem. The purpose of this paper