Computers & Industrial Engineering 101 (2016) 81–90

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Resource allocation based on context-dependent data envelopment analysis and a multi-objective linear programming approach

Jie Wu [a], Qingyuan Zhu [a], Qingxian An [b,c,*], Junfei Chu [a], Xiang Ji [a]

[a] School of Management, University of Science and Technology of China, Hefei, Anhui Province 230026, PR China
[b] School of Business, Central South University, Changsha, Hunan Province 410083, PR China
[c] Industrial Systems Optimization Laboratory, Charles Delaunay Institute and UMR CNRS 6281, University of Technology of Troyes, Troyes 10004, France

A R T I C L E I N F O

Article history:
Received 8 December 2014
Received in revised form 23 July 2016
Accepted 28 August 2016
Available online 29 August 2016

Keywords:
Resource allocation
Data envelopment analysis
Multi-objective linear programming
Most productive scale size

A B S T R A C T

This paper discusses a mechanism for the allocation of resources among a set of decision making units (DMUs) which are managed by a centralized control unit in an organization. Data envelopment analysis (DEA) and multi-objective linear programming (MOLP) are integrated to deal with this resource allocation problem. Also, context-dependent DEA is introduced to identify the changed production possibility set after resource allocation, which determines the production plans that are feasible with input increase or decrease in general. For the centralized unit, the MOLP approach is proposed to simultaneously maximize total output and effectiveness while minimizing the total allocated variable input consumption. Among these objectives, the effectiveness is determined by the output growth rate for all DMUs, which can reflect the effects obtained by allocating the input resources that are not used up, such as new equipment. In addition, we restrict the production of limited resources to the new most productive scale size (MPSS) region where the DMUs have the best economic characteristics. Finally, an example is employed to illustrate the approach.

1. Introduction

Resource allocation is a problem that commonly appears in organizations with a centralized decision-making environment in which a set of units are operating under a central unit with power to control some decision parameters like resources. Resource allocation is an important issue which can greatly affect the development of corporations (Amirteimoori & Shafiei, 2006; Wu, An, Ali, & Liang, 2013). Commonly, resource allocation is a crucial tool for improving performance (Golany, 1988; Golany and Tamir, 1995). For example, for some car and refrigerator factories, the central decision making unit (CDMU) may have purchased several items of new, large-scale equipment which need to be allocated to its branch factories. With the new equipment allocated, some other more flexible input resources like car/refrigerator parts need to be arranged to suit the new equipment. In many enterprises, the flexible input resources are more easily available than other kinds of resources. In contrast, some inflexible input resources may remain unchangeable, examples being housing, land, and workshops. The CDMU is assumed to be interested in obtaining the most beneficial results by allocating these available resources (large scale equipment, spare parts, and so on) to its individual branch factories. In real life, some allocated resources like large scale equipment are always a limited resource, so how to allocate them plays a significant role in the development of a company. However, how to allocate these different kinds of resources reasonably and effectively remains an open issue.

The problem of resource allocation has become one of the classical applications of management science and has great practical application value (Korhonen & Syrjänen, 2004). Data envelopment analysis (DEA) brought a new perspective on the resource allocation problem. Developed by Charnes, Cooper, and Rhodes (1978), DEA is a non-parametric mathematical approach which is used to evaluate the relative performance of a group of homogenous DMUs, especially with multiple inputs and multiple outputs (Wu, Xiong, An, Sun, & Wu, 2015; An, Yan, Wu, & Liang, 2016). It does not require the assumption of functional form in the production function for measuring the efficiency. For an introduction to DEA basic theory and applications, refer to Cooper, Seiford, and Tone (2007), or Cook and Seiford (2009). The existing DEA studies on the resource allocation problem can be divided into different categories. One is resource allocation and target setting (Bi, Ding, Luo, &

* Corresponding author at: School of Business, Central South University, Changsha, Hunan Province 410083, PR China.

E-mail addresses: jacky012@mail.ustc.edu.cn (J. Wu), zqyustc@mail.ustc.edu.cn (Q. Zhu), anqingxian@163.com (Q. An), cjf0731@mail.ustc.eudu.cn (J. Chu), signji@mail.ustx.edu.cn (X. Ji).

http://dx.doi.org/10.1016/j.cie.2016.08.025
0360-8352/© 2016 Published by Elsevier Ltd.

Liang, 2011). The second category is centralized resource allocation (Lozano & Villa, 2004). The third category encompasses other perspectives (Korhonen & Syrjänen, 2004; Du, Cook, Liang, & Zhu, 2014).

There has been much research on resource allocation and target setting during the past few years. In order to identify the trade-offs between overall output and equity from alternative allocations of service resources among different public service delivery sites, Mandell (1991) proposed two related bi-criteria mathematical programming models. To handle the problem of allocating central grants to Greek local authorities, Athanassopoulos (1995) integrated resource allocation and target setting in multilevel planning problems based on goal programming and data envelopment analysis. In order to jointly determine input resources for each DMU, Golany, Phillips, and Rousseau (1993) proposed a DEA-based linear model to allocate the available resources. Bi et al. (2011) proposed a DEA-based methodology for resource allocation and target setting considering a parallel production system. Hosseinzadeh Lotfi et al. (2013) introduced an allocation mechanism that is based on a common dual weights approach.

Some other researches focus on centralized resource allocation. Lozano and Villa (2004) made the first attempt and presented two new BCC-DEA models for centralized resource allocation (CRA-BCC). One type of model seeks radial reductions of the total consumption of every input while the other type seeks separate reductions for each input according to a preference structure (Cecilio & Diego, 2006; Lozano, Villa, & Canca, 2011). Asmild, Paradi, and Pastor (2009) suggested modifying one of the centralized models to only consider adjustment of previously inefficient units. Fang (2013) introduced a new, generalized, centralized resource allocation model which extends Lozano and Villa's (2004) and Asmild et al.'s models (2009) to a more general case. Fang and Li (2015) proposed a centralized approach for reallocating resources based on an extended revenue efficiency model. Hatami-Marbini, Tavana, Agrell, Lotfi, and Beigi (2015) proposed an alternative common-weights DEA model to determine the amount of input and output reduction needed for each DMU to increase score of all the DMUs. An, Wen, Xiong, Min, and Chen (2016b) built a DEA model for allocating the carbon dioxide emission permits so as to control the amount of carbon dioxide emission.

In addition, there are some other perspectives on the resource allocation problem. Beasley (2003) established a non-linear alternative DEA-based resource allocation model aiming to maximize the average unit efficiency. His model is set up on the basis of non-linear formulation, which may lead to local optima instead of a global one. Korhonen and Syrjänen (2004) developed an interactive formal approach based on DEA and multiple-objective linear programming (MOLP) to find the most preferred allocation plan that maximizes the values of multiple output variables simultaneously. Their approach is based on the assumption that units are able to modify their production in the current production possibility set formed by some efficient DMUs. They also assume that the units can modify their production plans using constant return to scale, and that the efficiency remains unchanged. Recently, Wu et al. (2013) extended the previous studies by considering both the economic and environmental factors for the resource allocation problem. Du et al. (2014) used the cross-efficiency concept in DEA to approach resource allocation problems.

From the published literature, we know that the existing DEA models for resource allocation are mostly based on one of two assumptions. One is that the efficiency for each DMU may be different after resource allocation. The other is that the efficiency for each DMU is constant regardless of resource allocation. The main limitations of these two assumptions about resource allocation are that: (I) Some models based on the assumption of constant efficiency have changed the production possibility set (PPS) formed by all the DMUs. Although there are DEA-based models that do not change the PPS based on the assumption of constant efficiency, such models may be unreasonable, since for most production systems the efficiency always changes with a changed production scale. Therefore, considering efficiency changes after resource allocation is necessary. (II) Most of the research based on the assumption of changeable efficiency after resource allocation assumes that each unit can have its production on the efficient frontier formed by some efficient DMUs. They do not consider the units' actual production ability, and they give output targets that may not be achieved easily for some units.

In addition, few studies have considered the characteristics of input resources. In real life, there are different kinds of input resources. For example, some resources may be inflexible and have fixed characteristics, while some other resources may be flexible and have variable characteristics. Some resources may be scarce and some may be relatively abundant. Besides this, there may be some new additional resources which need to be allocated when some resources are used but are superfluous for other resources. In the above example of the car and refrigerator factories, the large scale equipment and spare parts belong to the category of additional allocated resource, and the housing, land, and workshops can be seen as input resources whose allocation cannot change. The large-scale equipment, housing, land, and workshops may be classified as having invariable characteristics and the spare parts may have variable characteristics. This shows that classifying the input resources is very important.

The focus of this paper is to design a reasonable and effective resource allocation mechanism, which can bring the greatest benefits for the central organization. We apply and extend DEA in order to design the resource allocation mechanism. In addition, the multi-objective linear programming (MOLP) approach is proposed to comprehensively optimize the CDMU's multiple objectives.

In our resource allocation problem, the central unit has additional resources and needs to allocate these resources to the DMUs based on their inputs and outputs in the current period. Compared with many other methods for doing so, our technique has the following advantages.

(I) We first classify the input resources into three groups. One group is the non-allocated constant inputs, another is allocated constant inputs, and the last group is allocated variable inputs. The characteristics of each kind of input resource are as follows. The non-allocated constant inputs are those that are unchangeable for each DMU, so they are neither used up nor allocated; they remain the same in the next production period. Land is an example. An allocated constant input for a DMU is one that is not used up by production so it never decreases, but it may increase in the next production period if the central control unit allocates more to the DMU from a fixed available amount (e.g. recently obtained and not yet assigned to a production unit). Large-scale equipment is an example of an allocated constant input. The third group, allocated variable inputs, consists of inputs that are used up in production in the current period but for which there is a ready supply, such as the car and refrigerator parts in the above example. For each DMU, the amount of allocated variable inputs can always be increased or decreased. Put simply, non-allocated inputs never change, allocated constant inputs never decrease but may increase, and allocated variable inputs may increase or decrease. This classification conforms to the situation in many enterprises.

(II) A second advantage of our method concerns the objectives for resource allocation. The CDMU may want to consider not only the total output and input consumption in next