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A fuzzy DEA/AR approach to the selection of flexible manufacturing systems

Shiang-Tai Liu *

Graduate School of Business and Management, Vanung University, Chung-Li, Taiwan 320, People's Republic of China

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Abstract

Flexible Manufacturing System (FMS) offers opportunities for manufacturers to improve their technology, competitiveness, and profitability through a highly efficient and focused approach to manufacturing effectiveness. Data envelopment analysis (DEA) has been utilized as a multiple criteria tool for evaluation of FMSs. The concept of the assurance region (AR) is restricting the ratio of any two weights to some range to avoid the evaluated alternatives from ignoring or relying too much on any criterion in evaluation. In this paper, we develop a fuzzy DEA/AR method that is able to evaluate the performance of FMS alternatives when the input and output data are represented as crisp and fuzzy data. Based on Zadeh's extension principle, a pair of two-level mathematical programs is formulated to calculate the lower and upper bounds of the fuzzy efficiency score of the alternatives. We transform this pair of two-level mathematical programs into a pair of conventional one-level DEA/AR method to evaluate the FMS performance. An example illustrates the application of the proposed methodology.

Keywords: Flexible manufacturing system; Data envelopment analysis; Assurance region; Fuzzy sets

1. Introduction

Changing economic conditions have challenged many companies to improve cost, quality, and responsiveness to meet fierce competition. A flexible manufacturing system (FMS) is designed to combine the efficiency of a mass-production line and the flexibility of a job shop to produce a variety of workpieces on a group of machines (Chan, Kazerooni, & Abhary, 1997). FMS brings opportunities for manufacturers to improve their technology, competitiveness, and profitability through a highly efficient and focused approach to manufacturing effectiveness. The primary reason for implementing FMS lies in its versatility. Generally, increased flexibility enables a company to adjust more easily to changes in market place and in customer requirements, while maintaining high quality standards for its products and keeping good performance of manufacturing system (Shang & Sueyoshi, 1995; Priore, Fuente, Puente, & Parreño, 2006).

* Tel.: +886 3 4529 320; Fax: +886 3 452 9326.
E-mail address: stliu@vnu.edu.tw

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The research work in the design, evaluation, justification and implementation of FMS has long been a concern of researchers. In the past years, a number of studies have included cases studies, empirical research, analytical and simulation modeling, to help understand and address the issues of the FMS justification by organizations. The contexts of the research have covered the spectrum of managerial issues from focus on cost management system to the application of advanced mathematical models to understand the FMS and its characteristics. When flexibility, risk and non-monetary benefits are expected, as with FMSs, analytical procedures are required. Value analysis, scoring models, mathematical programming, and risk analysis can be considered among the analytical procedures.

Mathematical models have been developed to quantify performance measures such as quality and flexibility for justifying investment in advanced manufacturing systems. Nelson (1986) presented a scoring model for FMS project selection, which supplements traditional capital budgeting procedures with the treatment of non-economic criteria and project interdependence. Stam and Kuula (1991) developed a two-phase decision procedure that used the AHP and multi-objective mathematical programming to select an FMS. Karsak and Tolga (2001) considered both economic evaluation criterion and strategic criteria and proposed a fuzzy decision algorithm to select the most suitable advanced manufacturing systems. Karsak and Kuzgunkaya (2002) presented a fuzzy multiple objective programming approach to facilitate decision making in the selection of a FMS. Kahraman, Çevic, Ates, and Gülbay (2007) developed a fuzzy hierarchical TOPSIS model for the multi-criteria evaluation of the industrial robotic systems.

Recently, the use of data envelopment analysis (DEA) has been recommended as a discrete alternative multiple criteria tool for evaluation of manufacturing technologies and FMSs. Shang and Sueyoshi (1995) proposed a framework utilizing DEA and AHP for selecting an FMS. In their method, assurance regions were employed to restrict the weight of inputs and outputs. Khouja (1995) introduced a two-phase approach in the selection of an advanced manufacturing technology from a set of feasible technology alternatives. Karsak (1998) proposed a two-phase robot selection procedure that integrated DEA with a fuzzy robot selection algorithm, which could rank robot alternatives by taking into account both subjective and objective criteria. Karsak and Ahiska (2005) proposed a novel practical common weight multi-criteria decision-making (MCDM) DEA approach for technology selection. In measuring the relative efficiency of DMUs, they considered the situation of multiple outputs and a single exact input.

One of the main challenges associated with the application of DEA is the difficulty in quantifying some of these input and output factors. In other words, a key to the success of the DEA approach is the accurate measure of all factors, including inputs and outputs. However, a production process usually involves complicated inputs and outputs, in that many factors are very difficult to measure in a precise manner. This makes an approach which is able to deal with inexact numbers, or numbers in ranges, desirable. One way to represent the uncertain values by membership functions of the fuzzy set theory (Zadeh, 1978; Zimmermann, 1996). When some observations are fuzzy, the goal and constraints in the decision process become fuzzy as well. Several researches (Kao & Liu, 2000; León, Liern, Ruiz, & Sirvent, 2003; Lertworasirikul, Fang, Joines, & Nuttle, 2003; Hougaard, 2005) have proposed the solution methods for the DEA with fuzzy observations. Conceptually, DEA methodology allows individual DMU to select the weights that are most favorable to them in calculating the ratio of the aggregated output to the aggregated input. In reality, there are cases where each factor must be maintained at a minimum level for the production mechanism to work. To cope with this, Thompson, Singleton, Thrall, and Smith (1986, 1990) proposed the concept of the assurance region (AR) to restrict the ratio of any two weights to some range derived from price/cost information or experts' opinions. The weight restriction is imposed to avoid the evaluated DMUs from ignoring or relying too much on any criterion in evaluation.

A robust MCDM procedure used for FMS selection should be able to incorporate quantitative as well as qualitative data. The fuzzy decision modeling enables the decision-makers to deal quantitatively with imprecision inherent in the expression of each criterion by translating vague data to numerical ones. In this paper, we develop a fuzzy DEA/AR method that is able to evaluate the performance of FMS alternatives when the input and output data are represented as convex fuzzy numbers since crisp values can be considered as degenerated fuzzy numbers. Based on Zadeh's extension principle (Zadeh, 1978; Zimmermann, 1996; Liu & Kao, 2004; Liu, 2006), a pair of two-level mathematical programs is formulated to calculate the lower and upper bounds of the fuzzy efficiency score. We transform this pair of two-level mathematical programs into a pair