Computers & Operations Research 54 (2015) 274–285

Contents lists available at ScienceDirect

Computers & Operations Research

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

# A new fuzzy DEA model for evaluation of efficiency and effectiveness of suppliers in sustainable supply chain management context

Majid Azadi [a], Mostafa Jafarian [b], Reza Farzipoor Saen [a,*], Seyed Mostafa Mirhedayatian [b]

[a] Department of Industrial Management, Faculty of Management and Accounting, Karaj Branch, Islamic Azad University, Karaj, Iran
[b] Department of Business and Management Science, NHH Norwegian School of Economics, 5045 Bergen, Norway

ARTICLE INFO

Available online 13 March 2014

*Keywords:*
Sustainable supply chain management (SSCM)
Sustainable supplier selection
Data envelopment analysis
Integrated enhanced Russell measure (ERM) model
Fuzzy productivity value

ABSTRACT

Sustainable supply chain management (SSCM) has received much consideration from corporate and academic over the past decade. Sustainable supplier performance evaluation and selection plays a significant role in establishing an effective SSCM. One of the techniques that can be used for sustainable supplier performance evaluation and selection is data envelopment analysis (DEA). In real world problems, the inputs and outputs might be imprecise. This paper develops an integrated DEA enhanced Russell measure (ERM) model in fuzzy context to select the best sustainable suppliers. A case study is presented to exhibit the efficacy of the proposed method for sustainable supplier selection problem in a resin production company. The case study demonstrates that the proposed model can measure effectiveness, efficiency, and productivity in uncertain environment with different $\alpha$ levels. Also, it shows that the proposed model aids decision makers to deal with economic, social, and environmental factors when selecting sustainable suppliers.



## 1. Introduction

Practitioners and scholars have largely focused on supply chain management (SCM). As Ageron et al. [1] addressed, outsourcing is the main part of SCM. Globalization forces SCM to focus not only on economic criteria but also on good labor conditions and environmentally friendly production. Sustainable development is a combination of economic, environmental, and social factors. Sustainable SCM (SSCM) has become a growing topic for firms in all settings. Achieving social and environmental touchstones within supply chain helps to reach SSCM. Producing sustainable products is a rejoinder to forces coming from governments, consumers, and non-governmental organizations (NGOs) [51].

As addressed by Dyllick and Hockerts [23], SSCM is the combination of sustainable development and supply chain management whereby sustainable development is defined as combining environmental, social, and economic factors. Seuring and Müller [52] discussed that research on SSCM appeared from 2002 onwards. Cetinkaya et al. [13] explained that sustainable supply chains are not limited to green supply chains, but they should consider financial issues and help to the society.

Over the past decades, due to rapid reduction of natural resources and concerns over wealth inequality and corporate social responsibility, sustainability has become important for researchers and scholars [31]. Dao et al. [20] discussed that this concern has forced to increase the responsibility of firms and developed theories to support sustainable managerial decision making. To increase competitive advantage of the firms, supplier selection decision is one of the important issues in SCM. Supplier selection techniques can be used to select suppliers of raw materials to end-of-life service providers. Supplier selection problems deal with both tangible and intangible factors [8].

Conventionally, companies consider criteria such as price, quality, flexibility, and supplier reputation when evaluating supplier performance. Sustainability factors play a critical role for long term achievement of a SCM and the purchasing process becomes more complicated with social and environmental pressures [8,52]. Table 1 demonstrates sustainable supplier selection criteria.

For the first time, data envelopment analysis (DEA) was proposed by Charnes et al. [17]. DEA has been broadly used to take into account multiple criteria in decision making problems. DEA is a nonparametric linear programming technique for evaluating the relative efficiency of decision making units (DMUs). Over the past three decades a variety of DEA models have been used to evaluate the technical efficiency or technical effectiveness of DMUs in different settings. However, most of these works evaluate the performance from the perspective of technical efficiency or technical effectiveness [19]. On the other hand, DEA may face with

* Corresponding author. Tel.: +98 26 34418144 6; fax: +98 26 344 18156.
*E-mail addresses:* majid.azadi.edu@gmail.com (M. Azadi), mstf.jafariaan@gmail.com (M. Jafarian), farzipour@yahoo.com (R. Farzipoor Saen), Seyed.Mirhedayatian@nhh.no (S.M. Mirhedayatian).

http://dx.doi.org/10.1016/j.cor.2014.03.002
0305-0548/

**Table 1**
Sustainable supplier selection criteria.

| Economic criteria | Environmental criteria | Social criteria |
|---|---|---|
| Cost/price [36,47,3,10] | Environmental costs [3] | The interests and rights of employees [40,3] |
| Quality [3,10,40,64,43] | Green design [34,64,43] | The rights of stakeholders [40,3] |
| Technology capability [41,40,64,66,43] | Environmental management system [34,41] | Work safety and labor health [36] |
| Organization and management [10,36] | Environmental competencies [33,7] | Information disclosure [40,3] |
| Production facilities and capacity [36,3] | Green R&D [10,43] | Respect for the policy [40] |
| Financial capability [36] | Pollution control [7,3] | |
| Reliability [31] | Green product [41,36,7,45] | |
| Flexibility [66,31] | Resource consumption [41,40,66] | |
| Total cost of shipments (TC) [28,2] | Ozone depleting chemicals [40,3] | |
| Number of shipments (NS) [44,5] | Recycling [3] | |
| | Water consumption [24] | |
| | Energy consumption [24,31] | |
| | Renewable energy [24] | |
| | Number of obtained ISO standards [24] | |

imprecise data. Generally speaking, uncertain information or imprecise data can be expressed in interval or fuzzy numbers [59,28].

The objective of this paper is to propose a new fuzzy integrated Russell model for sustainable supplier selection. This paper proceeds as follows. In Section 2, the literature review is presented. Section 3 introduces the proposed model. Case study is discussed in Section 4. In Section 5 concluding remarks are presented.

## 2. Literature review

This section is structured as follows. Section 2.1 presents the literature on various supplier selection approaches. Section 2.2 presents the literature on DEA approaches for supplier selection. Section 2.3 discussed sustainable supplier selection approaches. Finally, Section 2.4 presents the literature on fuzzy set theory and fuzzy DEA.

### 2.1. Supplier selection approaches

Some approaches have been used for supplier selection in the past. To provide a systematic way for scoring suppliers' performance, Yahya and Kingsman [63] used the analytic hierarchy process (AHP) method. To help decision makers with rating and selecting suppliers, a five-step AHP-based model was proposed by Muralidharan et al. [46]. Chan [14] used AHP to develop an interactive model to help decision-makers in selecting suppliers. To select the best suppliers, Liu and Hai [42] used AHP. Chan and Kumar [15] and Chan et al. [16] used fuzzy extended AHP (FEAHP) for a global supplier selection problem. Kull and Talluri [38], combining AHP and goal programming, proposed a tool for supplier selection in the presence of risk measures and product life cycle considerations. Kahraman et al. [35] suggested fuzzy AHP for selecting the best supplier.

Sarkis and Talluri [48] selected the best supplier with respect to organizational factors and strategic performance metrics. They applied analytic network process (ANP). Shyur and Shih [53] used ANP for supplier selection as well.

Chen et al. [18] proposed a fuzzy decision making method to deal with the supplier evaluation and selection problem in supply chain system. They used linguistic values to assess the ratings and weights for the criteria. Tuzkaya et al. [58] proposed a hybrid fuzzy multi-criteria decision approach for evaluating suppliers' environmental performance. Amindoust et al. [3] proposed a supplier evaluation selection method based on the fuzzy inference system. Ferreira and Borenstein [30] presented a new model based on the integration of influence diagram and fuzzy logic to rank and evaluate suppliers. The model was developed to support managers in exploring the weaknesses and strengths of each alternative, to assist the setting of priorities between conflicting criteria. Deng and Chan [21] proposed a fuzzy Dempster multi-criteria decision making (MCDM) method for supplier selection. To this end, they combined fuzzy set theory (FST) and Dempster Shafer Theory (DST).

### 2.2. The uses of DEA in supplier selection problems

As Kumar et al. [39] addressed, DEA provides a robust approach in supplier selection problems. Weber [61] proposed DEA to select suppliers based upon multiple criteria and determined benchmarks. Since then, a number of DEA approaches have been proposed for supplier selection. Table 2 summarizes a couple of papers on the use of DEA in supplier selection.

### 2.3. Sustainable supplier selection

In recent years, sustainability factors play vital role in supply chain management [62]. Amindoust et al. [3] proposed a ranking model based on the fuzzy inference system for sustainable supplier selection. Wen et al. [62] proposed an approach based on intuitionistic fuzzy sets' group decision methods for sustainable supplier evaluation. To select the best suppliers, Kumar et al. [39] proposed a unified green DEA (GDEA) model to deal with carbon footprints of suppliers as a dual-role factor.

**Table 2**
DEA approaches for supplier selection.

| Author(s) | Approaches | Descriptions |
|---|---|---|
| Kleinsorge et al. [37] | DEA | They used DEA to track performance of suppliers |
| Talluri et al. [54] | Chance constrained DEA (CCDEA) | Proposed a CCDEA model for supplier selection in the presence of stochastic data |
| Farzipoor Saen [26] | DEA | Proposed a DEA model for ranking suppliers in the presence of volume discount |
| weber et al. [61] | Multi-objective programming (MOP) and DEA | Proposed MOP and DEA to evaluate suppliers |
| Farzipoor Saen [29] | DEA | Proposed a DEA model for supplier selection in the presence of undesirable outputs and imprecise data |
| Azadi and Farzipoor Saen [4] | CCDEA | Proposed a CCDEA model for supplier selection in the presence of stochastic data and undesirable factors |
| Farzipoor saen [28] | DEA | Proposed a DEA model for ranking suppliers in the presence of imprecise data, weight restriction, and nondiscretionary factors |
| Azadi et al. [6] | CCDEA | Developed a CCDEA model for supplier selection in the presence of stochastic data and nondiscretionary factors |

### 2.4. Fuzzy set theory and fuzzy DEA

Zimmermann [67] discussed that traditional optimization techniques assume crisp data. For the first time, Bellman and Zadeh [9] suggested how to model the objective functions and/or constraints by fuzzy sets to deal with fuzzy data. As Hatami-Marbini et al. [32] addressed, there might be many applications in DEA that the data are fuzzy. Sengupta [49,50] incorporated fuzzy inputs and outputs into the DEA model by defining tolerance levels in objective function and constraint violations. Using Carlsson and Korhonen's [11] approach, Triantis and Girod [56] suggested fuzzy linear programming model to assess technical efficiency. Then, Triantis [55] developed his previous model to handle fuzzy non-radial DEA measures of technical efficiency.

Authors believe that this paper has significant contributions to an important and very much under-researched topic. The contributions of this paper are as follows:

- For the first time, an integrated non-radial DEA model is developed for sustainable supplier selection. The proposed model measures effectiveness, efficiency, and productivity in fuzzy context.
- The proposed model calculates a new efficiency score which is called fuzzy productivity value. The new model measures sustainability of suppliers.
- The proposed model deals with multiple criteria.
- A possibility approach is applied to convert unsolvable fuzzy proposed model to the solvable linear model. This makes the new model more applicable in real world applications.

## 3. Proposed model

As Wang and Li [60] addressed, the radial measures of traditional DEA models are not complete because they are split measures of input and output efficiency. Also, their efficiency index does not incorporate the non-zero input and output slacks into their models. The enhanced Russell graph measure (ERM) treats these issues.

Let us define $x_{ij}$ $(i=1,2,\ldots,m)$ as the amount of input $i$ used by $\mathrm{DMU}_j$. $y_{rj}$ $(r=1,2,\ldots,s)$ is the amount of output $r$ produced by $\mathrm{DMU}_j$. Assuming all the inputs and outputs to be positive, Esmaeili [25] proposed the dual of ERM as follows:

$$\begin{aligned}
\max\quad & E=\alpha-\beta \\
\text{s.t.}\quad & \sum_{r=1}^{s} u_r y_{rj}-\sum_{i=1}^{m} v_i x_{ij}\le 0, \quad j=1,\ldots,n \\
& v_i x_{io}-\mu_i\le \frac{1}{m}, \quad i=1,\ldots,m \\
& \frac{\propto}{s}-u_r y_{ro}+f_r\le 0, \quad r=1,\ldots,s \\
& \sum_{i=1}^{m}\mu_i-\sum_{r=1}^{s} f_r-\beta\le 0, \\
& \propto,\beta,\mu_i,f_r,u_r,v_i\ge 0, \quad \forall i,r.
\end{aligned} \tag{1}$$

where $u_r$ and $v_i$ are the $r$th output weight and $i$th input weight, respectively. $n$ is the number of DMUs, $(j=1, 2,\ldots, n)$. The dual variable $\propto$ is associated with the first constraint of primal model implying average output efficiency. Note that the primal of the Model (1) is in Esmaeili [25]. The dual variables $\beta$ and $f_r$ are associated with constraints in the primal of the Model (1) which have no practical implications. They have been proposed for only transforming a non-linear model to linear one. Table 3 provides nomenclatures.

The $E\in[0,1]$ represents the efficiency score of $\mathrm{DMU}_o$. If the objective function of the Model (1) equals 1, the $\mathrm{DMU}_o$ is relatively efficient. Otherwise, the DMU is relatively inefficient.

In many cases, measuring the effectiveness of each DMU is as important as the efficiency measurement. The effectiveness addresses how much a company can meet its predetermined goals. The traditional DEA models fail to measure the effectiveness of DMUs. In this paper, we define the effectiveness of a DMU as the ratio of the output to the predetermined goal as follows:

$$\text{Effectiveness}=\frac{\text{output}}{\text{goal}}$$

At this juncture, the new model is proposed. To measure both the efficiency and the effectiveness of the $\mathrm{DMU}_o$, the Model (1) is converted as follows:

$$\begin{aligned}
\max\quad & \alpha-\beta+\left(\frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{t=1}^{T}\eta_t g_{to}}\right) \\
\text{s.t.}\quad & \sum_{r=1}^{s} u_r y_{rj}-\sum_{i=1}^{m} v_i x_{ij}\le 0, \quad j=1,\ldots,n \\
& v_i x_{io}-\mu_i\le \frac{1}{m}, \quad i=1,\ldots,m \\
& \frac{\propto}{s}-u_r y_{ro}+f_r\le 0, \quad r=1,\ldots,s \\
& \sum_{i=1}^{m}\mu_i-\sum_{r=1}^{s} f_r-\beta\le 0, \\
& \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{t=1}^{T}\eta_t g_{tj}}\le 1, \quad j=1,\ldots,n \\
& \propto,\beta,\mu_i,f_r,u_r,v_i,\eta_t\ge 0, \quad \forall i,r,t.
\end{aligned} \tag{2}$$

where the $t$th goal of the $\mathrm{DMU}_o$ is denoted as $g_{to}$. The $\eta_t$ is weight of the $t$th goal. Model (2) can be rewritten as follows:

$$\begin{aligned}
\max\quad & P=\left[\sum_{t=1}^{T}\eta_t g_{to}(\alpha-\beta)\right]+\sum_{r=1}^{s} u_r y_{ro} \\
\text{s.t.}\quad & \sum_{t=1}^{T}\eta_t g_{to}=1, \\
& \sum_{r=1}^{s} u_r y_{rj}-\sum_{i=1}^{m} v_i x_{ij}\le 0, \quad j=1,\ldots,n \\
& v_i x_{io}-\mu_i\le \frac{1}{m}, \quad i=1,\ldots,m
\end{aligned}$$

**Table 3**
The nomenclatures.

| |
|---|
| $j\in J$, $j=1,\ldots,n$ collection of DMUs |
| $r=1,\ldots,s$ the set of outputs |
| $i=1,\ldots,m$ the set of inputs |
| $\mathrm{DMU}_o$ is the DMU under investigation |
| $y_{rj}$ is the $r$th output of $j$th DMU |
| $x_{ij}$ is the $i$th input of $j$th DMU |
| $y_{ro}$ is the $r$th output of $\mathrm{DMU}_o$ |
| $x_{io}$ is the $i$th input of $\mathrm{DMU}_o$ |
| $u_r$ is the weight for the $r$th output |
| $v_i$ is the weight for the $i$th input |
| $\propto,\beta,\mu_i$, and $f_r$ are the dual variables |
| $g_{to}$ is the $t$th goal of the $\mathrm{DMU}_o$ |
| $\eta_t$ is the weight of the $t$th goal |
| $\tilde{\xi}$ and $\tilde{\eta}$ are fuzzy variables |
| $\pi(A)$ is the possibility measure of fuzzy set $A$ |
| $(\Theta,\mathcal{P},\pi)$ is the possibility space of fuzzy set $\Theta$ |
| $\mu_{(\xi)}$ is the membership function of variable $\xi$ |
| $\varepsilon_1$ and $\varepsilon_2$ are predetermined acceptable levels of the possibility of objective functions |
| $\overline{\mathcal{G}}$ is the maximum value denoting return function of effectiveness |
| $\overline{\mathcal{F}}$ is the maximum value denoting return function of efficiency |
| $\tau_1,\ldots,\tau_5$ are predetermined acceptable levels of the possibility of constrains |
| $\tilde{x}_{io}$ is the $i$th fuzzy input of the $\mathrm{DMU}_o$ |
| $\tilde{x}_{ij}$ is the $i$th fuzzy input of the $\mathrm{DMU}_j$ |
| $\tilde{y}_{ro}$ is the $r$th fuzzy output of the $\mathrm{DMU}_o$ |
| $\tilde{y}_{rj}$ is the $r$th fuzzy output of the $\mathrm{DMU}_j$ |
| $\tilde{g}_{to}$ is the $t$th fuzzy output of $\mathrm{DMU}_o$ |
| $\tilde{g}_{tj}$ is the $t$th fuzzy output of $j$th DMU |

$$\begin{aligned}
&\frac{\propto}{s}-u_r y_{ro}+f_r \le 0, \quad r=1,\dots,s\\
&\sum_{i=1}^{m}\mu_i-\sum_{r=1}^{s}f_r-\beta \le 0,\\
&\sum_{r=1}^{s}u_r y_{rj}-\sum_{t=1}^{T}\eta_t g_{tj} \le 0, \quad j=1,\dots,n\\
&\propto,\beta,\mu_i,f_r,u_r,v_i,\eta_t \ge 0, \quad \forall i,r,t.
\end{aligned} \tag{3}$$

The $P \in [0, 2]$ represents the productivity score of $\text{DMU}_o$. If the optimal value of the Model (3) equals 2, the $\text{DMU}_o$ is relatively productive. Otherwise, the DMU is relatively unproductive. As addressed by Dittenhofer [22], there are two reasons to measure productivity of suppliers. One is because productivity is used to check whether or not a supplier is performing in a satisfactory way. The second reason is that measuring productivity is as a motivator for suppliers. Productivity measurement increases competition among suppliers.

Now, fuzzy numbers are incorporated into the Model (3). Considering fuzzy input and output data, the Model (3) can be developed as follows:

$$\begin{aligned}
\max \quad & P=\left[\sum_{t=1}^{T}\eta_t\tilde{g}_{to}(\alpha-\beta)\right]+\sum_{r=1}^{s}u_r\tilde{y}_{ro}\\
\text{s.t.} \quad & \sum_{t=1}^{T}\eta_t\tilde{g}_{to}=1,\\
&\sum_{r=1}^{s}u_r\tilde{y}_{rj}-\sum_{i=1}^{m}v_i\tilde{x}_{ij}\le 0, \quad j=1,\dots,n\\
&v_i\tilde{x}_{io}-\mu_i\le\frac{1}{m}, \quad i=1,\dots,m\\
&\frac{\propto}{s}-u_r\tilde{y}_{ro}+f_r\le 0, \quad r=1,\dots,s\\
&\sum_{i=1}^{m}\mu_i-\sum_{r=1}^{s}f_r-\beta\le 0,\\
&\sum_{r=1}^{s}u_r\tilde{y}_{rj}-\sum_{t=1}^{T}\eta_t\tilde{g}_{tj}\le 0, \quad j=1,\dots,n\\
&\propto,\beta,\mu_i,f_r,u_r,v_i,\eta_t\ge 0, \quad \forall i,r,t.
\end{aligned} \tag{4}$$

where $\tilde{x}_{ij}(i=1,\dots,m)$, $\tilde{y}_{rj}(r=1,\dots,s)$, and $\tilde{g}_{tj}(t=1,\dots,T)$ are fuzzy input, fuzzy output, and fuzzy goals of $\text{DMU}_j$ $(j=1,2,\dots,n)$, respectively. This fuzzy integrated DEA model cannot be solved like a crisp model. To overcome this problem, one can apply a possibility approach formulated in terms of fuzzy set theory proposed by Zadeh [65]. This procedure converts the fuzzy integrated DEA model to the standard linear programming (LP) by $\alpha-$cut technique. In this case, each fuzzy coefficient can be viewed as a fuzzy variable and each constraint can be considered as a fuzzy event. Using possibility theory, possibilities of fuzzy events (i.e., fuzzy constraints) can be determined.

Let $\Theta$ be a nonempty set, and $\mathcal{P}$ the power set of $\Theta$. Each element in $\mathcal{P}$ is called an event. To present an axiomatic definition of possibility, it is necessary to assign to each event $A$, a number $\pi(A)$ which indicates the possibility that $A$ will occur. Then the triplet $(\Theta,\mathcal{P},\pi)$ is called a possibility space.

**Definition 1.** Let $\tilde{\xi}$ be a fuzzy variable defined on a possibility space $(\Theta,\mathcal{P},\pi)$. The membership of this variable introduced by Zadeh [65] is as follows:

$$\mu_{\tilde{\xi}}(s)=\pi(\theta_i\in\Theta_i|\tilde{\xi}(\theta_i)=s)=\sup_{\theta_i\in\Theta_i}\{\pi(\theta_i)|\tilde{\xi}(\theta_i)=s\}, \quad \forall s\in R$$

**Definition 2.** Let $(\Theta,\mathcal{P},\pi)$ be a possibility space such that $\Theta=\Theta_1\times\Theta_2\times\cdots\times\Theta_n$, therefore, for any set $A$ we have

$$\pi(A)=\sup_{\theta_i\in\Theta_i}\{\pi_i(A_i)|A=A_1\times A_2\times\cdots\times A_n, A_i\in\mathcal{P}\}.$$

Considering the two above definitions, for variables $\tilde{\xi}$ and $\tilde{\eta}$ from two possibility spaces $(\Theta_1,\mathcal{P}_1,\pi_1)$ and $(\Theta_2,\mathcal{P}_2,\pi_2)$, the possibility of the fuzzy event $\tilde{\xi}\ge\tilde{\eta}$ is given by

$$\pi(\tilde{\xi}\ge\tilde{\eta})=\sup_{s,t\in R}\{\min(\mu_{\tilde{\xi}}(s),\mu_{\tilde{\eta}}(t))|s\ge t\},$$

Regarding the proposed model and the concept of possibility space of fuzzy event, some constraines are defined as a crisp value and other constrains are considered as an uncertain. For this reason, the objective function of fuzzy integrated model can be written as follows:

$$\begin{aligned}
\max \quad & \overline{\mathcal{G}}+\overline{\mathcal{F}}\\
\text{s.t.}: \quad & \pi\left(\sum_{t=1}^{T}\eta_t\tilde{g}_{to}(\alpha-\beta)\ge\overline{\mathcal{G}}\right)\ge\varepsilon_1\\
&\pi\left(\sum_{r=1}^{s}u_r\tilde{y}_{ro}\ge\overline{\mathcal{F}}\right)\ge\varepsilon_2
\end{aligned} \tag{5}$$

where $\varepsilon_1$ and $\varepsilon_2$ are predetermined acceptable levels of possibility for the two sections of the objective function. Therefore, the objective value $\overline{\mathcal{G}}$ is the maximum value that the return function $\Sigma_{t=1}^{T}\eta_t\tilde{g}_{to}(\alpha-\beta)$ can attain with "possibility" level $\varepsilon_1$ or higher.[1] Moreover, the objective value $\overline{\mathcal{F}}$ is the maximum value that the return function $\Sigma_{r=1}^{s}u_r\tilde{y}_{ro}$ can achieve with the "possibility" level $\varepsilon_1$ or higher, subject to the possibility levels of other fuzzy and crisp constraints. Adding the remaning constrains, fuzzy integrated model can be reformulated by the following form:

$$\begin{aligned}
\max \quad & P=\overline{\mathcal{G}}+\overline{\mathcal{F}}\\
\text{s.t.}: \quad & \pi\left(\sum_{t=1}^{T}\eta_t\tilde{g}_{to}(\alpha-\beta)\ge\overline{\mathcal{G}}\right)\ge\varepsilon_1\\
&\pi\left(\sum_{r=1}^{s}u_r\tilde{y}_{ro}\ge\overline{\mathcal{F}}\right)\ge\varepsilon_2\\
&\pi\left(\sum_{t=1}^{T}\eta_t\tilde{g}_{to}=1\right)\ge\tau_1\\
&\pi\left(\sum_{r=1}^{s}u_r\tilde{y}_{rj}-\sum_{i=1}^{m}v_i\tilde{x}_{ij}\le 0\right)\ge\tau_2 \quad \text{for } j=1,\dots,n\\
&\pi\left(v_i\tilde{x}_{io}-\mu_i\le\frac{1}{m}\right)\ge\tau_3 \quad \text{for } i=1,\dots,m\\
&\pi\left(\frac{\propto}{s}-u_r\tilde{y}_{ro}+f_r\le 0\right)\ge\tau_4 \quad \text{for } r=1,\dots,s\\
&\pi\left(\sum_{r=1}^{s}u_r\tilde{y}_{rj}-\sum_{t=1}^{T}\eta_t\tilde{g}_{tj}\le 0\right)\ge\tau_5 \quad \text{for } j=1,\dots,n\\
&\sum_{i=1}^{m}\mu_i-\sum_{r=1}^{s}f_r-\beta\le 0,\\
&\propto,\beta,\mu_i,f_r,u_r,v_i,\eta_t\ge 0, \quad \forall i,r,t.
\end{aligned} \tag{6}$$

where $\tau_1\dots,\tau_5$ are the predefined levels that the related constraints should attain the possibility level. In the crisp condition, the $\text{DMU}_o$ will be relatively productive if the optimal value of the Model (4) equals 2. Meanwhile, the objective value $[\Sigma_{t=1}^{T}\eta_t\tilde{g}_{to}(\alpha-\beta)]+\sum_{r=1}^{s}u_r\tilde{y}_{ro}$ is the productive criterion of the $\text{DMU}_o$. Also, the $\overline{\mathcal{G}}$ and $\overline{\mathcal{F}}$ in the fuzzy integrated model are used to determine if the $\text{DMU}_o$ is relatively productive (in the possibilistic sense) at the predetermined possibility level. Let $\epsilon$ be the set of $\varepsilon_1,\varepsilon_2,\tau_1,\dots$, and $\tau_5$. We define an $\in$-possibilistic productive DMU and an $\in$-possibilistic nonproductive DMU as follows:

**Definition 3.** A DMU is $\in$-possibilistic productive if its $P=\overline{\mathcal{G}}+\overline{\mathcal{F}}$ value at the $\epsilon$-possibility level is greater than or equal to 2; otherwise, it is $\in$-possibilistic nonproductive.

[1] To the best of our knowledge, usually in optimization problems, there is no discrimination among multiple constraints in terms of possibility level. But, if we have multiple objective functions (in particular in goal programming technique) we can consider different possibility levels for each objective function.

Considering the fuzzy theorem, there is a lemma that can be very useful to interpret the possibility function. Now, this lemma is represented.

**Lemma.** *Let $\tilde{\xi}_1, \tilde{\xi}_2, \ldots, \tilde{\xi}_n$ be normal and convex fuzzy variables. Then, for any given possibility levels $\tau_1, \tau_2, \tau_3$ $(0 \le \tau_i \le 1)$ we have*

$$\begin{aligned}
(1): &\quad \pi(\tilde{\xi}_1+\tilde{\xi}_2+\cdots+\tilde{\xi}_n \le a) \ge \tau_1 \quad \text{if and only if } (\tilde{\xi}_1)^L_{\tau_1}+\cdots+(\tilde{\xi}_n)^L_{\tau_1} \le a,\\
(1): &\quad \pi(\tilde{\xi}_1+\tilde{\xi}_2+\cdots+\tilde{\xi}_n \ge a) \ge \tau_2 \quad \text{if and only if } (\tilde{\xi}_1)^U_{\tau_2}+\cdots+(\tilde{\xi}_n)^U_{\tau_2} \ge a,\\
(1): &\quad \pi(\tilde{\xi}_1+\tilde{\xi}_2+\cdots+\tilde{\xi}_n = a) \ge \tau_3 \quad \text{if and only if } (\tilde{\xi}_1)^L_{\tau_3}+\cdots+(\tilde{\xi}_n)^L_{\tau_3} \le a \text{ and } (\tilde{\xi}_1)^U_{\tau_3}+\cdots+(\tilde{\xi}_n)^U_{\tau_3} \ge a,
\end{aligned}$$

where $(\tilde{\xi}_i)^L_{\tau_i}$ and $(\tilde{\xi}_i)^U_{\tau_i}$ are the lower and upper bounds of the $\tau_i$-level set of $\tilde{\xi}_i$ $(i=1,\ldots, n)$. Defining the above lemma, fuzzy integrated model can be rewritten as follows:

$$\begin{aligned}
\max\quad & P=\overline{\mathcal{G}}+\overline{\mathcal{F}}\\
\text{s.t.}:\quad & (\alpha-\beta)\left(\sum_{t=1}^{T}\eta_t\,\tilde{g}_{to}\right)^U_{\varepsilon_1} \ge \overline{\mathcal{G}}\\
& \left(\sum_{r=1}^{s}u_r\tilde{y}_{ro}\right)^U_{\varepsilon_2} \ge \overline{\mathcal{F}}\\
& \left(\sum_{t=1}^{T}\eta_t\tilde{g}_{to}\right)^U_{\tau_1} \ge 1\\
& \left(\sum_{t=1}^{T}\eta_t\tilde{g}_{to}\right)^L_{\tau_1} \le 1\\
& \left(\sum_{r=1}^{s}u_r\tilde{y}_{rj}-\sum_{i=1}^{m}v_i\tilde{x}_{ij}\right)^L_{\tau_2} \le 0 \quad \text{for } j=1,\ldots,n\\
& (v_i\tilde{x}_{io}-\mu_i)^L_{\tau_3} \le \frac{1}{m} \quad \text{for } i=1,\ldots,m\\
& \left(\frac{\propto}{s}-u_r\tilde{y}_{ro}+f_r\right)^L_{\tau_4} \le 0 \quad \text{for } r=1,\ldots,s\\
& \left(\sum_{r=1}^{s}u_r\tilde{y}_{rj}-\sum_{t=1}^{T}\eta_t\tilde{g}_{tj}\right)^L_{\tau_5} \le 0 \quad \text{for } j=1,\ldots,n\\
& \sum_{i=1}^{m}\mu_i-\sum_{r=1}^{s}f_r-\beta \le 0,\\
& \propto,\beta,\mu_i,f_r,u_r,v_i,\eta_t \ge 0, \quad \forall i,r,t. \qquad (7)
\end{aligned}$$

In next section, we present a case study to demonstrate the applicability of proposed model.

## 4. Case study

Azar Resin Chemical Industrial Co. (ARCIC) was established in 1995 in Qazvin province, Iran. The first phase of the company's productions started in 1996 which comprises amino resins (butylated urea formaldehyde and butylated melamine formaldehyde). This company is one of the most active and leading companies among the resin manufacturing factories in Iran.

The ARCIC wishes to select the most sustainable suppliers of raw materials. Table 4 depicts the data set related to inputs, fuzzy outputs, and its fuzzy targets. To select the best sustainable suppliers a list of criteria are provided by managers. The cardinal inputs include the total cost of shipments (TC),[2] the price, and the number of shipments per month (NS) as economic criteria. The environmental criterion is eco-design cost which is considered as an input. The social criteria include the cost of work safety and labor health that both are considered as inputs. The outputs used in this study are the number of shipments to arrive on time (NOT) and the number of bills received from the supplier without errors (NB). To deal with the uncertainty, in this study the outputs and the targets for outputs are considered as fuzzy numbers.

Considering the proposed model, we formulate the problem to calculate the productivity for the first DMU called National Iranian Oil Company as the following model.

Let $\tilde{g}_{tj}=(g^a_{tj},g^b_{tj},g^c_{tj})$ is a triangular fuzzy number for the $t$th goal of DMU$_j$, $\tilde{y}_{rj}=(y^a_{rj},y^b_{rj},y^c_{rj})$ is a triangular fuzzy number of the $r$th output of DMU$_j$, and $\tilde{x}_{ij}=(x^a_{ij},x^b_{ij},x^c_{ij})$ is a triangular fuzzy number of the $i$th input of DMU$_j$. In this case, the linear programming that is the conversion of fuzzy model is presented as follows[3]:

$$\begin{aligned}
\max\quad & P=\overline{\mathcal{G}}+\overline{\mathcal{F}}\\
\text{s.t.}:\quad & (\alpha-\beta)\sum_{t=1}^{T}\eta_t(g^c_{t1}-\varepsilon_1(g^c_{t1}-g^b_{t1})) \ge \overline{\mathcal{G}}\\
& \sum_{r=1}^{s}u_r(y^c_{r1}-\varepsilon_2(y^c_{r1}-y^b_{r1})) \ge \overline{\mathcal{F}}\\
& \sum_{t=1}^{T}\eta_t(g^c_{t1}-\tau_1(g^c_{t1}-g^b_{t1})) \ge 1\\
& \sum_{t=1}^{T}\eta_t(g^c_{t1}-\tau_1(g^c_{t1}-g^b_{t1})) \le 1\\
& \sum_{r=1}^{s}u_r(y^a_{rj}+\tau_2(y^b_{rj}-y^a_{rj}))-\sum_{i=1}^{m}v_i(x^a_{ij}+\tau_2(x^b_{ij}-x^a_{ij})) \le 0 \quad \text{for } j=1,\ldots,n\\
& v_i(x^a_{i1}+\tau_3(x^b_{i1}-x^a_{i1}))-\mu_i \le \frac{1}{m} \quad \text{for } i=1,\ldots,m\\
& \frac{\propto}{s}-u_r(y^a_{r1}+\tau_4(y^b_{r1}-y^a_{r1}))+f_r \le 0 \quad \text{for } r=1,\ldots,s\\
& \sum_{r=1}^{s}u_r(y^a_{rj}+\tau_2(y^b_{rj}-y^a_{rj}))-\sum_{t=1}^{T}\eta_t(g^a_{tj}+\tau_5(g^b_{tj}-g^a_{tj})) \le 0 \quad \text{for } j=1,\ldots,n\\
& \sum_{i=1}^{m}\mu_i-\sum_{r=1}^{s}f_r-\beta \le 0,\\
& \propto,\beta,\mu_i,f_r,u_r,v_i,\eta_t \ge 0, \quad \forall i,r,t. \qquad (8)
\end{aligned}$$

Due to the first non-linear constrain, this model has been run by the GAMS software. Furthermore, this model has been run by various solvers such as BARON, CONOPT, and INPOPT. According to the results, all the solvers have generated the same solution. A sample of proposed model for supplier #1 has been given in Appendix.

In this case study, all the fuzzy constraints should be satisfied with the same possibility level, i.e., $\varepsilon_1=\varepsilon_2=\tau_1=\ldots=\tau_5$. The results for five different possibility levels (0, 0.25, 0.5, 0.75, and 1) are provided in Table 5. In Table 5, the number in each cell is the productivity value (PV) of the corresponding DMU at the specified

[2] Note that the measures selected in this paper are not exhaustive by any means, but are some general measures that can be utilized to evaluate suppliers.

(*footnote continued*)
Decision makers should carefully identify appropriate inputs and outputs used in the decision-making process.

[3] To convert either fuzzy equations into crisp equations or to use fuzzy arithmetic, the third constraint of the Model (6) is divided into two parts which appeared in third and fourth constraints of the Model (8).

**Table 4**
The data set related to inputs, fuzzy outputs, and its fuzzy targets.

| No. | Supplier (DMU) | Inputs | | | | Outputs | | | | | | Goals | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | NOT | | | NB | | | Target NOT | | | Target NB | | |
| | | TC (1,000,000 rials) | NS | Eco-design cost (10,000 rials) | The cost of work safety and labor health (10000 Rials) | L | M | U | L | M | U | L | M | U | L | M | U |
| 1 | National Iranian Oil Company | 316 | 251 | 61 | 18 | 199 | 219 | 239 | 76 | 83 | 90 | 203 | 226 | 239 | 84 | 89 | 91 |
| 2 | Shazand Petrochemical Corporation | 281 | 164 | 45 | 21 | 153 | 173 | 193 | 28 | 35 | 42 | 153 | 179 | 202 | 32 | 38 | 44 |
| 3 | Esfahan Petrochemical Company | 309 | 198 | 83 | 40 | 203 | 223 | 243 | 78 | 85 | 92 | 208 | 224 | 243 | 80 | 87 | 96 |
| 4 | Farabi Petrochemical Company | 291 | 218 | 37 | 45 | 167 | 187 | 207 | 85 | 92 | 99 | 167 | 193 | 215 | 93 | 92 | 103 |
| 5 | Iran Petrochemical Commercial Company | 597 | 178 | 52 | 29 | 197 | 217 | 237 | 163 | 170 | 177 | 202 | 222 | 247 | 172 | 176 | 177 |
| 6 | Alborz Chelic Company | 341 | 142 | 19 | 33 | 129 | 149 | 169 | 129 | 136 | 143 | 132 | 154 | 171 | 136 | 139 | 150 |
| 7 | Chemical Aland Industrial Group | 475 | 149 | 74 | 18 | 193 | 213 | 233 | 111 | 118 | 125 | 203 | 216 | 237 | 113 | 127 | 134 |
| 8 | Movalledan Chemical Company | 254 | 172 | 53 | 35 | 134 | 154 | 174 | 250 | 257 | 264 | 134 | 160 | 176 | 252 | 260 | 264 |
| 9 | Chemical Carbon Acid Company | 328 | 135 | 83 | 47 | 184 | 204 | 224 | 58 | 65 | 72 | 191 | 214 | 228 | 68 | 65 | 76 |
| 10 | Nima Chemigostar Industrial Co. | 310 | 173 | 41 | 16 | 113 | 133 | 153 | 88 | 95 | 102 | 114 | 137 | 161 | 96 | 98 | 108 |
| 11 | Gipa Company | 321 | 121 | 57 | 45 | 125 | 145 | 165 | 153 | 160 | 167 | 129 | 153 | 174 | 162 | 164 | 177 |
| 12 | Farzam Chemical Group | 329 | 204 | 38 | 53 | 195 | 215 | 235 | 90 | 97 | 104 | 205 | 225 | 243 | 100 | 99 | 104 |
| 13 | Pars Pak Kimia Company | 475 | 212 | 32 | 42 | 156 | 176 | 196 | 139 | 146 | 153 | 162 | 184 | 200 | 142 | 155 | 162 |
| 14 | Shiraz Petrochemical Company | 259 | 189 | 56 | 85 | 129 | 149 | 169 | 97 | 104 | 111 | 134 | 152 | 170 | 103 | 112 | 113 |
| 15 | Tabriz Petrochemical Company | 274 | 217 | 38 | 51 | 85 | 105 | 125 | 68 | 75 | 82 | 85 | 110 | 135 | 74 | 83 | 83 |
| 16 | Razi Petrochemical Company | 264 | 158 | 25 | 35 | 193 | 213 | 233 | 45 | 52 | 59 | 201 | 217 | 234 | 55 | 56 | 62 |
| 17 | Hegmataneh Petrochemical Company | 327 | 124 | 32 | 16 | 107 | 127 | 147 | 271 | 278 | 285 | 110 | 133 | 155 | 281 | 281 | 289 |
| 18 | Jam Petrochemical Company | 429 | 207 | 57 | 49 | 142 | 162 | 182 | 46 | 53 | 60 | 146 | 168 | 189 | 49 | 63 | 65 |
| 19 | Laleh Petrochemical Company | 262 | 138 | 25 | 31 | 122 | 142 | 162 | 173 | 180 | 187 | 130 | 148 | 162 | 174 | 188 | 190 |
| 20 | Kharg Petrochemical Company | 385 | 238 | 74 | 22 | 106 | 126 | 146 | 119 | 126 | 133 | 115 | 130 | 150 | 128 | 135 | 136 |
| 21 | Marun Petrochemical Company | 249 | 217 | 69 | 72 | 150 | 170 | 190 | 90 | 97 | 104 | 154 | 177 | 194 | 93 | 97 | 110 |
| 22 | Karoon Petrochemical Company | 337 | 203 | 27 | 33 | 104 | 124 | 144 | 271 | 278 | 285 | 113 | 126 | 150 | 274 | 281 | 294 |
| 23 | Khuzestan Petrochemical Company | 365 | 292 | 85 | 71 | 185 | 205 | 225 | 143 | 150 | 157 | 188 | 212 | 227 | 147 | 156 | 163 |
| 24 | Fajr Petrochemical Company | 296 | 185 | 49 | 18 | 112 | 132 | 152 | 177 | 184 | 191 | 114 | 132 | 155 | 177 | 193 | 198 |
| 25 | Khorasan Petrochemical Company | 428 | 242 | 39 | 22 | 94 | 114 | 134 | 78 | 85 | 92 | 101 | 124 | 139 | 79 | 95 | 99 |
| 26 | Mobin Petrochemical Company | 327 | 218 | 43 | 48 | 173 | 193 | 213 | 113 | 120 | 127 | 182 | 193 | 223 | 116 | 122 | 131 |

possibility level. The 17th DMU (Hegmataneh Petrochemical Co.) is the most productive DMU in four possibility levels (0.25, 0.5, 0.75, and 1) with the productivity measures 1.97, 1.93, 1.89, and 1.83, respectively. Also, the productivity of the $DMU_{15}$ (Tabriz Petrochemical Co.) is the worst with productivity measures 0.98, 1.01, 1.04, 1.07, and 1.09, for all possibility levels.

### *4.1. The results of efficiency and effectiveness*

Here, we wish to present the results of the efficiency and the effectiveness separately. Assuming $\alpha=0.5$, Table 6 depicts the results of effectiveness, efficiency, and productivity of the suppliers. Also, rank of every supplier is given. Fig. 1 shows summary of the results. As Table 6 depicts, Hegmataneh Petrochemical Co. is the best DMU in terms of effectiveness. Esfahan Petrochemical Co. and Razi Petrochemical Co. are the most efficient DMUs. Generally, Hegmataneh Petrochemical Co. is the most productive and sustainable DMU. Therefore, it is selected as the best supplier of ARCIC.

### *4.2. Sensitivity analysis*

Here, we wish to analyze sensitivity of the results against changes in $\alpha$. We investigate five $\alpha$ different values. In decision making problems, if we deal with high risk the $\alpha$ should be close to zero. If we deal with low risk the $\alpha$ should be close to one. Table 7 depicts the results of changing $\alpha$ on effectiveness, efficiency, and productivity. As is seen, the $\alpha$ values are 0, 0.25, 0.5, 0.75, and 1. As Table 7 shows, changing $\alpha$ values do not have significant impact on ranking results. Therefore, decision maker is not concerned about selecting $\alpha$ value.

**Table 5**
Efficiency and effectiveness scores.

| No. | Supplier (DMU) | Alpha =1 | | Alpha =0.75 | | Alpha =0.5 | | Alpha =0.25 | | Alpha =0 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PV | Rank | PV | Rank | PV | Rank | PV | Rank | PV | Rank |
| 1 | National Iranian Oil Company | 1.46 | 16 | 1.46 | 14 | 1.46 | 14 | 1.47 | 13 | 1.46 | 12 |
| 2 | Shazand Petrochemical Corporation | 1.27 | 22 | 1.25 | 23 | 1.23 | 23 | 1.2 | 23 | 1.18 | 23 |
| 3 | Esfahan Petrochemical Company | 1.46 | 14 | 1.45 | 16 | 1.44 | 16 | 1.43 | 17 | 1.42 | 18 |
| 4 | Farabi Petrochemical Company | 1.49 | 12 | 1.48 | 12 | 1.47 | 13 | 1.46 | 14 | 1.43 | 15 |
| 5 | Iran Petrochemical Commercial Company | 1.56 | 8 | 1.56 | 8 | 1.56 | 7 | 1.55 | 7 | 1.54 | 7 |
| 6 | Alborz Chelic Company | 1.78 | 5 | 1.77 | 5 | 1.76 | 5 | 1.75 | 5 | 1.74 | 5 |
| 7 | Chemical Aland Industrial Group | 1.54 | 11 | 1.54 | 10 | 1.53 | 10 | 1.52 | 10 | 1.5 | 10 |
| 8 | Movalledan Chemical Company | 1.85 | 2 | 1.85 | 2 | 1.84 | 2 | 1.82 | 2 | 1.81 | 2 |
| 9 | Chemical Carbon Acid Company | 1.35 | 21 | 1.34 | 21 | 1.33 | 21 | 1.33 | 21 | 1.31 | 21 |
| 10 | Nima Chemigostar Industrial Complex | 1.46 | 15 | 1.45 | 15 | 1.44 | 17 | 1.43 | 19 | 1.41 | 19 |
| 11 | Gipa Company | 1.57 | 7 | 1.57 | 7 | 1.56 | 7 | 1.54 | 8 | 1.53 | 9 |
| 12 | Farzam Chemical Group | 1.48 | 13 | 1.47 | 13 | 1.47 | 12 | 1.47 | 12 | 1.46 | 13 |
| 13 | Pars Pak Kimia Company | 1.54 | 10 | 1.55 | 9 | 1.55 | 9 | 1.54 | 9 | 1.53 | 8 |
| 14 | Shiraz Petrochemical Company | 1.42 | 20 | 1.43 | 20 | 1.44 | 19 | 1.44 | 16 | 1.43 | 16 |
| 15 | Tabriz Petrochemical Company | 0.98 | 26 | 1.01 | 26 | 1.04 | 26 | 1.07 | 26 | 1.09 | 26 |
| 16 | Razi Petrochemical Company | 1.44 | 17 | 1.44 | 19 | 1.42 | 20 | 1.41 | 20 | 1.4 | 20 |
| 17 | Hegmataneh Petrochemical Company | 1.97 | 1 | 1.93 | 1 | 1.89 | 1 | 1.83 | 1 | 1.77 | 3 |
| 18 | Jam Petrochemical Company | 1.1 | 25 | 1.11 | 25 | 1.12 | 25 | 1.12 | 25 | 1.12 | 25 |
| 19 | Laleh Petrochemical Company | 1.81 | 4 | 1.82 | 4 | 1.82 | 3 | 1.82 | 3 | 1.82 | 1 |
| 20 | Kharg Petrochemical Company | 1.23 | 23 | 1.25 | 22 | 1.28 | 22 | 1.3 | 22 | 1.3 | 22 |
| 21 | Marun Petrochemical Company | 1.44 | 18 | 1.44 | 18 | 1.44 | 18 | 1.43 | 18 | 1.42 | 17 |
| 22 | Karoon Petrochemical Company | 1.83 | 3 | 1.83 | 3 | 1.82 | 4 | 1.79 | 4 | 1.77 | 4 |
| 23 | Khuzestan Petrochemical Company | 1.43 | 19 | 1.45 | 17 | 1.45 | 15 | 1.45 | 15 | 1.45 | 14 |
| 24 | Fajr Petrochemical Company | 1.7 | 6 | 1.69 | 6 | 1.68 | 6 | 1.67 | 6 | 1.65 | 6 |
| 25 | Khorasan Petrochemical Company | 1.14 | 24 | 1.16 | 24 | 1.17 | 24 | 1.18 | 24 | 1.18 | 23 |
| 26 | Mobin Petrochemical Company | 1.55 | 9 | 1.54 | 10 | 1.52 | 11 | 1.5 | 11 | 1.47 | 11 |

**Table 6**
The results with alpha=0.5.

| No. | Supplier (DMU) | Effectiveness | Rank | Efficiency | Rank | Productivity | Rank |
|---|---|---|---|---|---|---|---|
| 1 | National Iranian Oil Company | 0.462 | 15 | 0.995 | 5 | 1.457 | 14 |
| 2 | Shazand Petrochemical Corporation | 0.236 | 23 | 0.987 | 15 | 1.223 | 23 |
| 3 | Esfahan Petrochemical Company | 0.43 | 19 | 1 | 1 | 1.437 | 17 |
| 4 | Farabi Petrochemical Company | 0.479 | 13 | 0.985 | 17 | 1.464 | 13 |
| 5 | Iran Petrochemical Commercial Company | 0.554 | 9 | 0.988 | 13 | 1.542 | 8 |
| 6 | Alborz Chelic Company | 0.794 | 5 | 0.988 | 13 | 1.782 | 5 |
| 7 | Chemical Aland Industrial Group | 0.536 | 10 | 0.984 | 19 | 1.52 | 10 |
| 8 | Movalledan Chemical Company | 0.831 | 3 | 0.999 | 3 | 1.83 | 2 |
| 9 | Chemical Carbon Acid Company | 0.338 | 21 | 0.99 | 10 | 1.328 | 21 |
| 10 | Nima Chemigostar Industrial Co. | 0.465 | 14 | 0.974 | 22 | 1.439 | 16 |
| 11 | Gipa Company | 0.583 | 7 | 0.966 | 24 | 1.549 | 7 |
| 12 | Farzam Chemical Group | 0.481 | 12 | 0.985 | 17 | 1.466 | 12 |
| 13 | Pars Pak Kimia Company | 0.563 | 8 | 0.976 | 21 | 1.539 | 9 |
| 14 | Shiraz Petrochemical Company | 0.438 | 18 | 0.995 | 5 | 1.433 | 18 |
| 15 | Tabriz Petrochemical Company | 0.081 | 26 | 0.955 | 25 | 1.036 | 26 |
| 16 | Razi Petrochemical Company | 0.423 | 20 | 1 | 1 | 1.43 | 20 |
| 17 | Hegmataneh Petrochemical Company | 0.901 | 1 | 0.989 | 12 | 1.89 | 1 |
| 18 | Jam Petrochemical Company | 0.136 | 25 | 0.972 | 23 | 1.108 | 25 |
| 19 | Laleh Petrochemical Company | 0.837 | 2 | 0.991 | 9 | 1.828 | 3 |
| 20 | Kharg Petrochemical Company | 0.28 | 22 | 0.982 | 20 | 1.262 | 22 |
| 21 | Marun Petrochemical Company | 0.447 | 17 | 0.986 | 16 | 1.433 | 18 |
| 22 | Karoon Petrochemical Company | 0.816 | 4 | 0.998 | 4 | 1.814 | 4 |
| 23 | Khuzestan Petrochemical Company | 0.451 | 16 | 0.99 | 10 | 1.441 | 15 |
| 24 | Fajr Petrochemical Company | 0.679 | 6 | 0.993 | 7 | 1.672 | 6 |
| 25 | Khorasan Petrochemical Company | 0.205 | 24 | 0.952 | 26 | 1.157 | 24 |
| 26 | Mobin Petrochemical Company | 0.518 | 11 | 0.992 | 8 | 1.51 | 11 |

### 4.3. Managerial implications

In this subsection, an analysis of the results of this study is given. In recent years, SSCM has become an increasingly significant topic. Supplier evaluation and selection process is one of the crucial operational tasks in the context of SSCM. Selecting appropriate sustainable suppliers is a MCDM problem for any organization. This task should be easily and clearly understood and applied by managers. Mathematical models provide remarkable information that can be employed by managers in making strategic or operational decisions. Some mathematical programming approaches have been used for selecting suppliers. Nevertheless, because of intricacy of decision making process involved in supplier evaluation and selection, all the previous approaches, except for DEA models, rely on methods that assign subjective weights to multiple criteria. It is a daunting task for decision makers to assign precise numbers to criteria. However, none of the DEA models deal with efficiency, effectiveness, and productivity, simultaneously. Here, the proposed model measures efficiency, effectiveness, and productivity, simultaneously. On the other hand, in many supplier selection problems, the inputs and outputs might be fuzzy. As a result, selecting suitable supplier becomes too difficult for managers. The fuzzy model presented in this paper is a method to deal with fuzzy data. Moreover, to solve the proposed fuzzy model, a possibility approach is applied to convert the unsolvable fuzzy model to the solvable linear model. In addition, we used GAMS software for solving the proposed model.

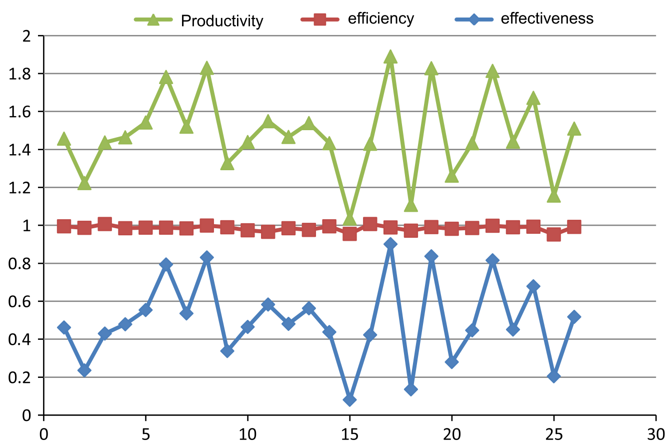

**Fig. 1.** The effectiveness, efficiency, and productivity of the suppliers ($\alpha$=0.5).

## 5. Concluding remarks

According to Carter and Easton [12], sustainability is a popular buzzword. The buzzword is because of some reasons such as supply and demand characteristics related to energy consumption, people understanding of climate change, and higher clearness related to environmental and the social actions of firms. These issues are relevant to decision makers since their shareholders, government, and their employees ask them to solve the environmental and social issues which are influenced by their operations. In particular, supply chain managers are in critical position to influence positively or negatively their environmental and social performance. As addressed by Ageron et al. [1], sustainability of supply chain management is vital for the success

**Table 7**
The result of changing $\alpha$ on ranking results.

| Suppliers (DMUs) | Alpha=0 | | | | Alpha =0.25 | | | | Alpha =0.5 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Effectiveness | Efficiency | Productivity | Rank | Effectiveness | Efficiency | Productivity | Rank | Effectiveness | Efficiency | Productivity | Rank |
| National Iranian Oil Company | 0.446 | 1.015 | 1.461 | 12 | 0.455 | 1.009 | 1.464 | 13 | 0.462 | 0.995 | 1.457 | 14 |
| Shazand Petrochemical Corporation | 0.209 | 0.974 | 1.183 | 23 | 0.223 | 0.98 | 1.203 | 23 | 0.236 | 0.987 | 1.223 | 23 |
| Esfahan Petrochemical Company | 0.411 | 1.005 | 1.416 | 18 | 0.421 | 1.01 | 1.431 | 17 | 0.43 | 1.007 | 1.437 | 17 |
| Farabi Petrochemical Company | 0.458 | 0.976 | 1.434 | 15 | 0.469 | 0.984 | 1.453 | 14 | 0.479 | 0.985 | 1.464 | 13 |
| Iran Petrochemical Commercial Company | 0.554 | 0.981 | 1.535 | 7 | 0.554 | 0.987 | 1.541 | 7 | 0.554 | 0.988 | 1.542 | 8 |
| Alborz Chelic Company | 0.754 | 0.984 | 1.738 | 5 | 0.774 | 0.988 | 1.762 | 5 | 0.794 | 0.988 | 1.782 | 5 |
| Chemical Aland Industrial Group | 0.524 | 0.98 | 1.504 | 10 | 0.53 | 0.986 | 1.516 | 10 | 0.536 | 0.984 | 1.52 | 10 |
| Movalledan Chemical Company | 0.81 | 0.998 | 1.808 | 2 | 0.82 | 1 | 1.82 | 3 | 0.831 | 0.999 | 1.83 | 2 |
| Chemical Carbon Acid Company | 0.32 | 0.991 | 1.311 | 21 | 0.33 | 0.993 | 1.323 | 21 | 0.338 | 0.99 | 1.328 | 21 |
| Nima Chemigostar Industrial Co. | 0.451 | 0.958 | 1.409 | 19 | 0.458 | 0.969 | 1.427 | 19 | 0.465 | 0.974 | 1.439 | 16 |
| Gipa Company | 0.573 | 0.953 | 1.526 | 9 | 0.578 | 0.962 | 1.54 | 8 | 0.583 | 0.966 | 1.549 | 7 |
| Farzam Chemical Group | 0.465 | 0.991 | 1.456 | 13 | 0.474 | 0.992 | 1.466 | 12 | 0.481 | 0.985 | 1.466 | 12 |
| Pars Pak Kimia Company | 0.551 | 0.977 | 1.528 | 8 | 0.557 | 0.979 | 1.536 | 9 | 0.563 | 0.976 | 1.539 | 9 |
| Shiraz Petrochemical Company | 0.433 | 1 | 1.433 | 16 | 0.435 | 1.001 | 1.436 | 16 | 0.438 | 0.995 | 1.433 | 18 |
| Tabriz Petrochemical Company | 0.147 | 0.947 | 1.094 | 26 | 0.113 | 0.954 | 1.067 | 26 | 0.081 | 0.955 | 1.036 | 26 |
| Razi Petrochemical Company | 0.391 | 1.01 | 1.401 | 20 | 0.407 | 1.009 | 1.416 | 20 | 0.423 | 1.007 | 1.43 | 20 |
| Hegmataneh Petrochemical Company | 0.798 | 0.968 | 1.766 | 3 | 0.85 | 0.98 | 1.83 | 1 | 0.901 | 0.989 | 1.89 | 1 |
| Jam Petrochemical Company | 0.152 | 0.966 | 1.118 | 25 | 0.144 | 0.972 | 1.116 | 25 | 0.136 | 0.972 | 1.108 | 25 |
| Laleh Petrochemical Company | 0.817 | 1 | 1.817 | 1 | 0.827 | 0.997 | 1.824 | 2 | 0.837 | 0.991 | 1.828 | 3 |
| Kharg Petrochemical Company | 0.325 | 0.978 | 1.303 | 22 | 0.306 | 0.983 | 1.289 | 22 | 0.28 | 0.982 | 1.262 | 22 |
| Marun Petrochemical Company | 0.436 | 0.981 | 1.417 | 17 | 0.442 | 0.987 | 1.429 | 18 | 0.447 | 0.986 | 1.433 | 18 |
| Karoon Petrochemical Company | 0.794 | 0.971 | 1.765 | 4 | 0.806 | 0.987 | 1.793 | 4 | 0.816 | 0.998 | 1.814 | 4 |
| Khuzestan Petrochemical Company | 0.458 | 0.992 | 1.45 | 14 | 0.454 | 0.994 | 1.448 | 15 | 0.451 | 0.99 | 1.441 | 15 |
| Fajr Petrochemical Company | 0.667 | 0.98 | 1.647 | 6 | 0.673 | 0.988 | 1.661 | 6 | 0.679 | 0.993 | 1.672 | 6 |
| Khorasan Petrochemical Company | 0.22 | 0.963 | 1.183 | 23 | 0.213 | 0.961 | 1.174 | 24 | 0.205 | 0.952 | 1.157 | 24 |
| Mobin Petrochemical Company | 0.501 | 0.97 | 1.471 | 11 | 0.51 | 0.984 | 1.494 | 11 | 0.518 | 0.992 | 1.51 | 11 |

| Suppliers (DMUs) | Alpha =0.75 | | | | Alpha =1 | | | |
|---|---|---|---|---|---|---|---|---|
| | Effectiveness | Efficiency | Productivity | Rank | Effectiveness | Efficiency | Productivity | Rank |
| National Iranian Oil Company | 0.47 | 0.982 | 1.452 | 14 | 0.478 | 0.969 | 1.447 | 17 |
| Shazand Petrochemical Corporation | 0.251 | 0.993 | 1.244 | 22 | 0.265 | 1 | 1.265 | 22 |
| Esfahan Petrochemical Company | 0.44 | 1.003 | 1.443 | 17 | 0.449 | 1 | 1.449 | 16 |
| Farabi Petrochemical Company | 0.49 | 0.985 | 1.475 | 12 | 0.5 | 0.984 | 1.484 | 12 |
| Iran Petrochemical Commercial Company | 0.553 | 0.987 | 1.54 | 8 | 0.551 | 0.979 | 1.53 | 9 |
| Alborz Chelic Company | 0.814 | 0.987 | 1.801 | 5 | 0.832 | 0.979 | 1.811 | 5 |
| Chemical Aland Industrial Group | 0.541 | 0.982 | 1.523 | 11 | 0.546 | 0.975 | 1.521 | 11 |
| Movalledan Chemical Company | 0.841 | 0.996 | 1.837 | 2 | 0.849 | 0.984 | 1.833 | 2 |
| Chemical Carbon Acid Company | 0.347 | 0.986 | 1.333 | 21 | 0.356 | 0.981 | 1.337 | 21 |
| Nima Chemigostar Industrial Co. | 0.472 | 0.978 | 1.45 | 15 | 0.478 | 0.975 | 1.453 | 15 |
| Gipa Company | 0.588 | 0.968 | 1.556 | 7 | 0.593 | 0.963 | 1.556 | 7 |
| Farzam Chemical Group | 0.488 | 0.978 | 1.466 | 13 | 0.495 | 0.969 | 1.464 | 13 |
| Pars Pak Kimia Company | 0.568 | 0.971 | 1.539 | 9 | 0.572 | 0.958 | 1.53 | 10 |
| Shiraz Petrochemical Company | 0.44 | 0.987 | 1.427 | 20 | 0.442 | 0.972 | 1.414 | 19 |
| Tabriz Petrochemical Company | 0.048 | 0.954 | 1.002 | 26 | 0.019 | 0.945 | 0.964 | 26 |
| Razi Petrochemical Company | 0.44 | 1.004 | 1.444 | 16 | 0.456 | 1 | 1.456 | 14 |
| Hegmataneh Petrochemical Company | 0.945 | 0.989 | 1.934 | 1 | 0.984 | 0.984 | 1.968 | 1 |
| Jam Petrochemical Company | 0.127 | 0.968 | 1.095 | 25 | 0.114 | 0.963 | 1.077 | 25 |
| Laleh Petrochemical Company | 0.847 | 0.984 | 1.831 | 3 | 0.855 | 0.967 | 1.822 | 4 |
| Kharg Petrochemical Company | 0.255 | 0.977 | 1.232 | 23 | 0.232 | 0.967 | 1.199 | 23 |
| Marun Petrochemical Company | 0.453 | 0.983 | 1.436 | 18 | 0.458 | 0.975 | 1.433 | 18 |
| Karoon Petrochemical Company | 0.825 | 1 | 1.825 | 4 | 0.833 | 1 | 1.833 | 2 |
| Khuzestan Petrochemical Company | 0.447 | 0.984 | 1.431 | 19 | 0.443 | 0.97 | 1.413 | 20 |
| Fajr Petrochemical Company | 0.686 | 0.996 | 1.682 | 6 | 0.692 | 0.993 | 1.685 | 6 |
| Khorasan Petrochemical Company | 0.198 | 0.938 | 1.136 | 24 | 0.191 | 0.919 | 1.11 | 24 |
| Mobin Petrochemical Company | 0.527 | 0.999 | 1.526 | 10 | 0.535 | 1 | 1.535 | 8 |

of entire supply chain management. Many practitioners and researchers have presented the benefits of SSCM. Finding an efficient and effective supplier in sustainability context is one of the most significant issues in order to increase the competitive advantage of companies. This study proposed a novel fuzzy integrated DEA model for evaluating the sustainability of suppliers.

Further researches can be done based on the results of this paper. Some of them are as follows:

- Similar research can be repeated for sustainable supplier evaluation and selection in the presence of stochastic data. Chance-constrained programming (CCP) is a kind of stochastic optimization approach. It is suitable for solving optimization problems with random variables included in constraints and sometimes in the objective function. Stochastic programming deals with optimization problems whose parameters take values from given discrete or continuous probability distributions.
- Similar research can be repeated for sustainable supplier evaluation and selection in the presence of dual-role factors. In real world problems, there might be flexible factors which play the role of both inputs and outputs. This sort of variable are called dual-role factors.
- In this study the proposed model was used in supplier selection problem. The proposed model can be used in other problems such as personnel selection, international market selection, and technology selection.

## Acknowledgments

The authors wish to thank two anonymous reviewers for the valuable suggestions and comments which improved the quality of this paper.

## Appendix

The GAMS code for $DMU_1$ at the level $a=1$ is as follows:

```
sets
T 'GOAL'/T1,T2/
R 'OUTPUT'/R1,R2/
I 'INPUT'/I1*I4/
J ' DMU'/J1*J26/;
```

TABLE A(J,I)

| | I1 | I2 | I3 | I4 |
|---|---|---|---|---|
| J1 | 301 | 241 | 56 | 15 |
| J2 | 266 | 154 | 40 | 18 |
| J3 | 294 | 188 | 78 | 37 |
| J4 | 276 | 208 | 32 | 42 |
| J5 | 582 | 168 | 47 | 26 |
| J6 | 326 | 132 | 14 | 30 |
| J7 | 460 | 139 | 69 | 15 |
| J8 | 239 | 162 | 48 | 32 |
| J9 | 313 | 125 | 78 | 44 |
| J10 | 295 | 163 | 36 | 13 |
| J11 | 306 | 111 | 52 | 42 |
| J12 | 314 | 194 | 33 | 50 |
| J13 | 460 | 202 | 27 | 39 |
| J14 | 244 | 179 | 51 | 82 |
| J15 | 259 | 207 | 33 | 48 |
| J16 | 249 | 148 | 20 | 32 |
| J17 | 312 | 114 | 27 | 13 |
| J18 | 414 | 197 | 52 | 46 |
| J19 | 247 | 128 | 20 | 28 |
| J20 | 370 | 228 | 69 | 19 |
| J21 | 234 | 207 | 64 | 69 |

| | | | | |
|---|---|---|---|---|
| J22 | 322 | 193 | 22 | 30 |
| J23 | 350 | 282 | 80 | 68 |
| J24 | 281 | 175 | 44 | 15 |
| J25 | 413 | 232 | 34 | 19 |
| J26 | 312 | 208 | 38 | 45; |

TABLE BLOW(J,R)

| | R1 | R2 |
|---|---|---|
| J1 | 199 | 76 |
| J2 | 153 | 28 |
| J3 | 203 | 78 |
| J4 | 167 | 85 |
| J5 | 197 | 163 |
| J6 | 129 | 129 |
| J7 | 193 | 111 |
| J8 | 134 | 250 |
| J9 | 184 | 58 |
| J10 | 113 | 88 |
| J11 | 125 | 153 |
| J12 | 195 | 90 |
| J13 | 156 | 139 |
| J14 | 129 | 97 |
| J15 | 85 | 68 |
| J16 | 193 | 45 |
| J17 | 107 | 271 |
| J18 | 142 | 46 |
| J19 | 122 | 173 |
| J20 | 106 | 119 |
| J21 | 150 | 90 |
| J22 | 104 | 271 |
| J23 | 185 | 143 |
| J24 | 112 | 177 |
| J25 | 94 | 78 |
| J26 | 173 | 113; |

TABLE CLOW(J,T)

| | T1 | T2 |
|---|---|---|
| J1 | 203 | 84 |
| J2 | 153 | 32 |
| J3 | 208 | 80 |
| J4 | 167 | 93 |
| J5 | 202 | 172 |
| J6 | 132 | 136 |
| J7 | 203 | 113 |
| J8 | 134 | 252 |
| J9 | 191 | 68 |
| J10 | 114 | 96 |
| J11 | 129 | 162 |
| J12 | 205 | 100 |
| J13 | 162 | 142 |
| J14 | 134 | 103 |
| J15 | 85 | 74 |
| J16 | 201 | 55 |
| J17 | 110 | 281 |
| J18 | 146 | 49 |
| J19 | 130 | 174 |
| J20 | 115 | 128 |
| J21 | 154 | 93 |
| J22 | 113 | 274 |
| J23 | 188 | 147 |
| J24 | 114 | 177 |
| J25 | 101 | 79 |
| J26 | 182 | 116; |

TABLE BUP(J,R)

| | R1 | R2 |
|---|---|---|
| J1 | 239 | 90 |
| J2 | 193 | 42 |
| J3 | 243 | 92 |
| J4 | 207 | 99 |
| J5 | 237 | 177 |
| J6 | 169 | 143 |
| J7 | 233 | 125 |
| J8 | 174 | 264 |
| J9 | 224 | 72 |
| J10 | 153 | 102 |
| J11 | 165 | 167 |
| J12 | 235 | 104 |
| J13 | 196 | 153 |
| J14 | 169 | 111 |
| J15 | 125 | 82 |
| J16 | 233 | 59 |
| J17 | 147 | 285 |
| J18 | 182 | 60 |
| J19 | 162 | 187 |
| J20 | 146 | 133 |
| J21 | 190 | 104 |
| J22 | 144 | 285 |
| J23 | 225 | 157 |
| J24 | 152 | 191 |
| J25 | 134 | 92 |
| J26 | 213 | 127; |

TABLE CUP(J,T)

| | T1 | T2 |
|---|---|---|
| J1 | 239 | 91 |
| J2 | 202 | 44 |
| J3 | 243 | 96 |
| J4 | 215 | 103 |
| J5 | 247 | 177 |
| J6 | 171 | 150 |
| J7 | 237 | 134 |
| J8 | 176 | 264 |
| J9 | 228 | 76 |
| J10 | 161 | 108 |
| J11 | 174 | 177 |
| J12 | 243 | 104 |
| J13 | 200 | 162 |
| J14 | 170 | 113 |
| J15 | 135 | 83 |
| J16 | 234 | 62 |
| J17 | 155 | 289 |
| J18 | 189 | 65 |
| J19 | 162 | 190 |
| J20 | 150 | 136 |
| J21 | 194 | 110 |
| J22 | 150 | 294 |
| J23 | 227 | 163 |
| J24 | 155 | 198 |
| J25 | 139 | 99 |
| J26 | 223 | 131; |

VARIABLES
AA , BB , GA , U , V , F , MU , P 'OBJECT' , G , FF

POSITIVE VARIABLES
AA , BB , GA , U , V , F , MU , GG , FF ;

```
EQUATIONS
OBJECTIVE
CONST1
CONST2
CONST3
*CONST4
CONST5(J)
CONST6(I)
CONST7(R)
CONST8(J)
CONST9;
OBJECTIVE.. P =e=GG+FF;
CONST1.. (AA–BB) * SUM(T,GA(T)*CUP('J1',T))=g=GG;
CONST2.. SUM(R, U(R)*BUP('J1',R)) =g=FF;
CONST3.. SUM(T, GA(T)*CUP('J1',T)) =e=1;
*CONST4.. SUM(T, GA(T)*CUP('J1',T)) =l=1;
CONST5(J).. SUM(R, U(R)*BLOW(J,R))-SUM(I, V(I)*A(J,I)) =l=0;
CONST6(I).. V(I)*A('J1',I)-MU(I)=l=(1/4);
CONST7(R).. (AA/2)-U(R)*BLOW('J1',R)+F(R) =l=0;
CONST8(J).. SUM(R, U(R)*BLOW(J,R))-SUM(T, GA(T)*
CLOW(J,T)) =l=0;
CONST9.. SUM(I, MU(I))- SUM(R, F(R))-BB =l=0;

MODEL LINEAR /ALL/;
SOLVE LINEAR using NLP maximizing P;
display p. l;
```

## References


[1] Ageron B, Gunasekaran A, Spalanzani A. Sustainable supply management: an empirical study. Int. J. Prod. Econ. 2012;140(1):168–82.
[2] Ahmady N, Azadi M, Sadeghi SAH, Saen Farzipoor. A novel fuzzy data envelopment analysis model with double frontiers for supplier selection. Int. J. Logist. Res. Appl. 2013;16(2):87–98.
[3] Amindoust A, Ahmed S, Saghafinia A, Bahreininejad A. Sustainable supplier selection: a ranking model based on fuzzy inference system. Appl. Soft Comput. 2012;12(6):1668–77.
[4] Azadi M, Farzipoor Saen R. Developing a new chance-constrained DEA model for suppliers selection in the presence of undesirable outputs. Int. J. Oper. Res. 2012;13(11):44–66.
[5] Azadi M, Farzipoor Saen R. Developing a worst practice DEA model for selecting suppliers in the presence of imprecise data and dual-role factor. Int. J. Appl. Decis. Sci. 2012;5(3):272–91.
[6] Azadi M, Farzipoor Saen R, Tavana M. Supplier selection using chance constrained data envelopment analysis with nondiscretionary factors and stochastic data. Int. J. Ind. Syst. Eng. 2012;13(2):167–96.
[7] Awasthi A, Chauhan SS, Goyal S. A fuzzy multicriteria approach for evaluating environmental performance of suppliers. Int. J. Prod. Econ. 2010;126(2):370–8.
[8] Bai C, Sarkis J. Integrating sustainability into supplier selection with grey system and rough set methodologies. Int. J. Prod. Econ. 2010;124(1):252–64.
[9] Bellman R, Zadeh L. Decision-making in a fuzzy environment. Manage. Sci. 1970;17(4):141–64.
[10] Büyüközkan G, Çifçi G. A novel fuzzy multi-criteria decision framework for sustainable supplier selection with incomplete information. Comput. Ind. 2011;62(2):164–74.
[11] Carlsson C, Korhonen P. A parametric approach to fuzzy linear programming. Fuzzy Sets Syst. 1986;20(1):17–30.
[12] Carter CR, Easton PL. Sustainable supply chain management: evolution and future directions. Int. J. Phys. Distrib. Log. Manage. 2011;41(1):46–62.
[13] Cetinkaya B, Cuthbertson R, Ewer G, Klaas-Wissing T, Piotrowicz W, Tyssen C. Sustainable Supply Chain Management. New York: Springer; 2011.
[14] Chan FTS. Interactive selection model for supplier selection process: an analytical hierarchy process approach. Int. J. Prod. Res. 2003;41(15):3549–79.
[15] Chan FTS, Kumar N. Global supplier development considering risk factors using fuzzy extended AHP-based approach. Omega (Westport) 2007;35(4):417–31.
[16] Chan FTS, Kumar N, Tiwari MK, Lau HCW, Choy KL. Global supplier selection: a fuzzy-AHP approach. Int. J. Prod. Res. 2008;46(14):3825–57.
[17] Charnes A, Cooper WW, Rhodes E. Measuring the efficiency of decision making units. Eur. J. Oper. Res. 1978;2(6):429–44.
[18] Chen CT, Lin CT, Huang SF. A fuzzy approach for supplier evaluation and selection in supply chain management. Int. J. Prod. Econ. 2006;102(2):289–301.
[19] Chiou YC, Lan LW, Yen BTH. A joint measurement of efficiency and effectiveness for non-storable commodities: integrated data envelopment analysis approaches. Eur. J. Oper. Res. 2010;201(2):477–89.
[20] Dao V, Langella I, Carbo J. From green to sustainability: information technology and an integrated sustainability framework. J. Strat. Inf. Syst. 2011;20(1):63–79.
[21] Deng Y, Chan FTS. A new fuzzy dempster MCDM method and its application in supplier selection. Expert Syst. Appl. 2011;38(8):9854–61.
[22] Dittenhofer M. Internal auditing effectiveness: an expansion of present methods. Manage. Audit. J. 2001;V16(8):443–50.
[23] Dyllick T, Hockerts K. Beyond the business case for corporate sustainability. Bus. Strat. Environ. 2002;11(2):130–41.
[24] Erol I, Sencer S, Sari R. A new fuzzy multi-criteria framework for measuring sustainability performance of a supply chain. Ecol. Econ. 2011;70(6):1088–100.
[25] Esmaeili M. An enhanced Russell measure in DEA with interval data. Appl. Math. Comput. 2012;219(4):1589–93.
[26] Farzipoor Saen R. Using super-efficiency analysis for ranking suppliers in the presence of volume discount offers. Int. J. Phys. Distrib. Logist. Manage. 2008;38(8):637–51.
[28] Farzipoor Saen R. A decision model for ranking suppliers in the presence of cardinal and ordinal data, weight restrictions, and nondiscretionary factors. Ann. Oper. Res. 2009;172(1):177–92.
[29] Farzipoor Saen R. Developing a new data envelopment analysis methodology for supplier selection in the presence of both undesirable outputs and imprecise data. Int. J. Adv. Manuf. Technol. 2010;51(9):1243–50.
[30] Ferreira L, Borenstein D. A fuzzy-Bayesian model for supplier selection. Expert Syst. Appl. 2012;39(9):7834–44.
[31] Govindan K, Khodaverdi R, Jafarian A. A fuzzy multi criteria approach for measuring sustainability performance of a supplier based on triple bottom line approach. J. Clean. Prod. 2013;47:345–54.
[32] Hatami-Marbini A, Emrouznejad A, Tavana M. A taxonomy and review of the fuzzy data envelopment analysis literature: two decades in the making. Eur. J. Oper. Res. 2011;214(3):457–72.
[33] Hsu CW, Hu AH. Applying hazardous substance management to supplier selection using analytic network process. J. Clean. Prod. 2009;17(2):255–64.
[34] Humphreys P, Wong Y, Chan F. Integrating environmental criteria into the supplier selection process. J. Mater. Process. Technol. 2003;138(1-3):349–56.
[35] Kahraman C, Cebeci U, Ulukan Z. Multi-criteria supplier selection using fuzzy AHP. Logist. Inf. Manage. 2003;16(6):382–94.
[36] Keskin GA, Ihan S, Özkan C. The fuzzy art algorithm: a categorization method for supplier evaluation and selection. Expert Syst. Appl. 2010;37(2):1235–40.
[37] Kleinsorge IK, Schary PB, Tanner RD. Data envelopment analysis for monitoring customer–supplier relationships. J. Account. Public Policy 1992;11(4):357–372.
[38] Kull T, Talluri S. A supply-risk reduction model using integrated multi criteria decision making. IEEE Trans. Eng. Manage. 2008;55(3):409–19.
[39] Kumar A, Jain V, Kumar SA. A comprehensive environment friendly approach for supplier selection. Omega (Westport) 2014;42(1):109–23.
[40] Kuo R, Wang Y, Tien F. Integration of artificial neural network and MADA methods for green supplier selection. J. Clean. Prod. 2010;18(12):1161–70.
[41] Lee AHI, Kang HY, Hsu CF, Hung HC. A green supplier selection model for high-tech industry. Expert Syst. Appl. 2009;36(4):7917–27.
[42] Liu FHF, Hai HL. The voting analytic hierarchy process method for selecting supplier. Int. J. Prod. Econ. 2005;97(3):4308–17.
[43] Mafakheri F, Breton M, Ghoniem A. Supplier selection-order allocation: a two stage multiple criteria dynamic programming approach. Int. J. Prod. Econ. 2011;132(1):52–7.
[44] Mahdiloo M, Noorizadeh A, Farzipoor Saen R. A new approach for considering a dual-role factor in supplier selection problem. Int. J. Acad. Res. 2011;3(1):317–22.
[45] Mirhedayatian SM, Azadi M, Farzipoor Saen R. A novel network data envelopment analysis model for evaluating green supply chain. Int. J. Prod. Econ. 2014;147:544–54.
[46] Muralidharan C, Anantharaman N, Deshmukh SG. A multi-criteria group decision-making model for supplier rating. J. Supply Chain Manage. 2002;38(4):22–33.
[47] Punniyamoorthy M, Mathiyalagan P, Vasishta G. A strategic model using structural equation modeling and fuzzy logic in supplier selection. Expert Syst. Appl. 2011;38(1):458–74.
[48] Sarkis J, Talluri S. A model for strategic supplier selection. J. Supply Chain Manage. 2002;38(1):18–28.
[49] Sengupta JK. A fuzzy systems approach in data envelopment analysis. Comput. Math. Appl. 1992;24(8 and 9):2259–66.
[50] Sengupta JK. Measuring efficiency by a fuzzy statistical approach. Fuzzy Sets Syst. 1992;46(1):73–80.
[51] Seuring S. A review of modeling approaches for sustainable supply chain management. Decis. Support Syst. 2013;54(4):1513–20.
[52] Seuring S, Müller M. From a literature review to a conceptual framework for sustainable supply chain management. J. Clean. Prod. 2008;16(15):1699–710.
[53] Shyur HJ, Shih HS. A hybrid MCDM model for strategic vendor selection. Math. Comput. Model. 2006;44(7 and 8):749–61.
[54] Talluri S, Narasimhan R, Nair A. Vendor performance with supply risk: a chance constrained DEA approach. Int. J. Prod. Econ. 2006;100(N2):212–22.
[55] Triantis K. Fuzzy non-radial data envelopment analysis (DEA) measures of technical efficiency in support of an integrated performance measurement system. Int. J. Automot. Technol. Manage. 2003;3(3-4):328–53.

[56] Triantis KP, Girod O. A mathematical programming approach for measuring technical efficiency in a fuzzy environment. J. Prod. Anal. 1998;10(1):85–102.

[58] Tuzkaya G, Ozgen A, Ozgen D, Tuzkaya UR. Environmental performance evaluation of suppliers: a hybrid fuzzy multi-criteria decision approach. Int. J. Environ. Sci. Technol. 2009;V6(3):477–90.

[59] Wang YM, Greatbanks R, Yang JB. Interval efficiency assessment using data envelopment analysis. Fuzzy Sets Syst. 2005;153(N3):347–70.

[60] Wang M, Li Y. Enhanced Russell measure in fuzzy DEA. Int. J. Data Anal. Techniq. Strat. 2010;2(2):140–54.

[61] Weber A, Current J, Desai A. An optimization approach to determining the number of vendors to employ. Int. J. Supply Chain Manage. 2000;5(2):90–8.

[62] Wen L, Xu L, Wang R. Sustainable supplier evaluation based on intuitionistic fuzzy sets group decision methods. J. Inf. Comput. Sci. 2013;10(10):3209–20.

[63] Yahya S, Kingsman B. Vendor rating for an entrepreneur development programme: a case study using the analytic hierarchy process method. J. Oper. Res. Soc. 1999;50(9):916–30.

[64] Yeh WC, Chuang MC. Using multi-objective genetic algorithm for partner selection in green supply chain problems. Expert Syst. Appl. 2011;38(4):4244–53.

[65] Zadeh LA. Fuzzy sets as a basis for a theory of possibility. Fuzzy Sets Syst. 1978;1(1):3–28.

[66] Zhu Q, Dou Y, Sarkis J. A portfolio-based analysis for green supplier management using the analytical network process. Supply Chain Manage.: Int. J. 2010;15(4):306–19.

[67] Zimmermann HJ. Fuzzy Set Theory and Its Applications. 3rd ed. Boston: Kluwer–Nijhoff Publishing; 1996.