The Journal of The Textile Institute

ISSN: 0040-5000 (Print) 1754-2340 (Online) Journal homepage: http://www.tandfonline.com/loi/tjti20

Textile supplier selection in sustainable supply chain using a modular fuzzy inference system model

Atefeh Amindoust & Ali Saghafinia

To cite this article: Atefeh Amindoust & Ali Saghafinia (2017) Textile supplier selection in sustainable supply chain using a modular fuzzy inference system model, The Journal of The Textile Institute, 108:7, 1250-1258, DOI: 10.1080/00405000.2016.1238130

To link to this article: http://dx.doi.org/10.1080/00405000.2016.1238130

Published online: 03 Oct 2016.

Submit your article to this journal

Article views: 90

View related articles

View Crossmark data

Full Terms & Conditions of access and use can be found at
http://www.tandfonline.com/action/journalInformation?journalCode=tjti20

Download by: [Atefeh Amindoust] **Date:** 20 April 2017, At: 23:13

THE JOURNAL OF THE TEXTILE INSTITUTE, 2017
VOL. 108, NO. 7, 1250–1258
http://dx.doi.org/10.1080/00405000.2016.1238130

Taylor & Francis
Taylor & Francis Group

Textile supplier selection in sustainable supply chain using a modular fuzzy inference system model

Atefeh Amindoust[a] and Ali Saghafinia[b]

[a]Department of Industrial Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran; [b]Department of Electrical Engineering, Majlesi Branch, Islamic Azad University, Majlesi, Iran

ABSTRACT

Today's fashion clothing market is highly competitive and the textile and clothing industry is a significant area of the world's economy. In addition, the sustainability issues have received a lot of attention in the textile supply chains. Since supplier evaluation and selection is a crucial decision in supply chain management, this paper proposes a framework for textile suppliers' sustainability evaluation criteria and a new model based on this framework onto ranking a given list of suppliers. The relative importance of criteria and the suppliers' performance with respect to criteria are considered based on decision-makers' preferences in the model. To cope with the subjectivity of decision-makers' opinions, fuzzy set theory has been applied and a modular model on the basis of Fuzzy Inference System is proposed. A real-life supplier selection problem for the textile industry is utilized to show the feasibility of the proposed model. Validation of the proposed model is studied through an existing literature model. The results show the effectiveness of the proposed model.

ARTICLE HISTORY
Received 18 April 2016
Accepted 14 September 2016

KEYWORDS
Textile supplier selection; sustainable supply chain; fuzzy inference system

Research highlights

This manuscript intends to propose a new ranking method for FIS and apply it to a sustainable supplier selection in textile industry. Briefly, the contributions of this manuscript are included:

- Proposes a framework for textile supplier sustainability evaluation criteria.
- Focusing on the limitations of other FIS based method to rank the suppliers and to propose a new ranking model based on FIS.
- Considering the importance weights of criteria and to allocate these weights in the new ranking method of FIS for supplier selection problem.
- Focusing on sustainability issue in supplier selection problem and applying a modular FIS system approach to solve it.

Introduction

In these days, sustainable development has become a buzzword in business and now is being discussed seriously in supply chain management (Amindoust, Ahmed, & Saghafinia, 2012b; Chaabane, Ramudhin, & Paquet, 2010; Wu & Pagell, 2010). Sustainable supply chain management is the management of material, information and capital flows, as well as cooperation among companies along the supply chain, while taking into account the goals from all three dimensions, such as economic, environmental, and social, of sustainable development derived from customer and stakeholder requirements (Buyukozkan & Çifçi, 2010; Saghafinia, Pingb, & Amindoustc, 2015). The ongoing corporate sustainability issue in the supply chain exerts pressure on purchasing managers in different industries to consider sustainability in their procurement activities. One of the central decisions for purchasing management in sustainable supply chain is supplier selection. Since the fashion clothing market is highly competitive in recent years, textile suppliers have critical roles in business activities and research on sustainable supplier selection in textile and clothing industry would be inevitable. In addition, in the supplier selection process, the relative importance of the selection criteria and the suppliers' performance with respect to these criteria must be considered. These two questions need to be answered with the purchasing managers as decision-makers. They normally prefer to answer the questions in linguistic terms instead of numerical form to express their perceptions (Amindoust, Ahmed, Saghafinia, & Bahreininejad, 2012). To cope with the subjectivity and vagueness that existed in their assessments, application of fuzzy logic is explored in this work. Some researchers have used fuzzy concepts for supplier selection issue (Amin, Razmi, & Zhang, 2010; Awasthi, Chauhan, & Goyal, 2010; Woo & Saghiri, 2011). In addition, Carrera and Mayorga (2008) applied the fuzzy logic through a modular fuzzy inference system (FIS) for supplier selection. However, they did not allocate any important degree for the selection criteria. In their model, the fuzzy rules for each FIS engine did not envelop all possible

CONTACT Atefeh Amindoust Atefeh_Amindoust@yahoo.com

© 2016 The Textile Institute

Table 1. The literature on supplier selection criteria from the sustainable point of view.

Researcher	Economic	Environmental	Social	Criteria
(Humphreys, Wong, & Chan, 2003)		√		Environmental costs, management competencies, green image, design for environmental, environmental management system, environmental competencies
(Hsu & Hu, 2009)		√		Procurement management, R&D management, process management, incoming quality control, management system
(Lee, Kang, Hsu, & Hung, 2009)	√	√		Quality, technology capability/pollution control, environment management, green product, green competencies
(Awasthi et al., 2010)		√		Use of environment friendly technology and materials, green market share, partnership with green organizations, environmental management, adherence to environmental policies, green R&D projects, staff training, lean process planning, design for environmental, environmental certification, pollution control initiatives
(Aydın Keskin et al., 2010)	√	√	√	Producing critical/safety part, producing similar part, having technically adequate employee and equipment, having adequate production capacity, existing test capability, measurement and control apparatus, ability of managing diversification, ability of design and improvement, financial capability to reach raw material, suitable price policy and payment periods, using/providing its certificates effective, existent dispatching performance or dispatching problems, ability of packing-transportation and logistics demands, geographical location/environmental effects and preventive actions/applications of work safety and labor health
(Bai & Sarkis, 2010)		√		Pollution controls, environmental management system, resource consumption
(Buyukozkan & Çifçi, 2010)	√	√		Organization, financial performance, service quality, technology/environmental competencies
(Kuo, Wang, & Tien, 2010)	√	√	√	Quality, cost, delivery, service/Eco-design requirements for energy using products, ozone depleting chemicals, restriction of hazardous substance, certified requirement of environmental management system, waste electrical and electronic equipment/ the interests and rights of employee, the rights of stakeholder, information disclosure, respect for the policy
(Punniyamoorthy, Mathiyalagan, & Vasishta, 2010)	√	√		Management and organization, quality, technical capability, production facilities and capacities, financial position, delivery, service, relationship, cost/ safety, and environmental concern
(Tseng & Chiu, 2010)	√	√		Value-adding practices to a firm, relationship, delivery reliability, quality, satisfy customer needs, service, communication, flexibility, management/green design, environmental certificates, green production plan, cleaner production, green purchasing, life cycle assessment, environmental management system, R& D capability, innovation
(Yeh & Chuang, 2010)	√	√		Production cost, production time, transportation cost, transportation time, average product quality/green image, product recycling, green design, green supply chain management, pollution treatment cost, environment performance assessment
(Zhu, Dou, & Sarkis, 2010)	√	√		Cost, quality, time, flexibility, process management, innovativeness, culture, technology, relationship/pollution controls, pollution prevention, environmental management system, resource consumption, pollution production
(Mafakheri, Breton, & Ghoniem, 2011)	√	√		Price, delivery, quality/environmental costs, management competencies, green image, design for environmental, environmental management system, environmental competencies

characteristics of suppliers (Carrera & Mayorga, 2008). Therefore, this paper intends to propose a modified ranking method for a modular FIS model considering the relative importance of criteria and apply this method to sustainable supplier selection in textile and clothing industry. Finally, the proposed model is validated through an existing supplier selection model in literature.

This paper is organized to design a framework for sustainable supplier selection criteria in textile industry through the literature survey. Then, a new ranking method for FIS is suggested using that framework for selecting the best suppliers.

Proposed framework for textile suppliers' sustainability evaluation criteria

In supplier selection literature, the majority of publications only considered economic aspects such as quality, cost, delivery, and service in the selection decision(Amindoust et al.; Amindoust, Ahmed, & Saghafinia, 2012a; 2012c, Amindoust, Ahmed, & Saghafinia, 2013; Amindoust & Saghafinia, 2014a, 2014b). However, today, there is a growth of interest towards sustainable merits for manufacturers to progress practices in their supply chain. The concept of sustainability consists of three dimensions: the protection of the natural environment, the maintenance of economic vitality, and observance of specific social considerations (Porsche, Fischer, Braga, & Häni, 2006). Therefore, companies must add the environmental and social aspects to the traditional supplier selection attributes. This paper intends to propose a comprehensive framework for supplier selection criteria as a sustainable point of view in textile and clothing industry. Therefore, the supplier selection literature has been surveyed and 14 related journal articles, which considered environmental and social aspects – separately or together – including economic aspects of selection decision were found. The criteria applied by these researchers are combined into three main groups (economic, environmental, and social) as shown in Table 1. In addition, published papers on the textile industry as seen in Table 2 are considered to design the proposed framework. On the other hand, to consider the experts' opinion about the popular and practical criteria in textile supplier selection process, a meeting was arranged. Finally, during the scanning of the criteria in Tables 1 and 2 by removing the repetitions and considering the experts' knowledge, the final proposed criteria for textile industry were combined into three (economic, environmental, and social) groups in order to present a framework as shown in Figure 1.

Table 2. Existing supplier selection criteria in textile industry.

(Ding, Benyoucef, & Xie, 2005)	Order-to-delivery lead-time; ratio of on-time delivery; inventory position; resource utilization; cost
(Chen, 2010)	Quality; cost; delivery; service; technical and production capability, relation combination; organizational management/textile industry
(Baskaran, Nachiappan, & Rahman, 2012)	Discrimination; abuse of human right; child labor; long working hours; unfair competition(society); pollution(environmental)/textile and clothing industry
(Kumar, Singh, & Singh, 2012)	Consistency in product quality; improvement in incoming components; reduction in damaged components in transit; inventory level reduction; lot size reduction; reduction in plant stoppage due to shortage of material; on-time delivery; reduction in order lead time; reduction in product development cycle time/man-made fiber manufacturer
(Shaw, Shankar, Yadav, & Thakur, 2012)	Cost; quality rejection; percentage of late delivered item; greenhouse gas emission/garment manufacturing company

For economic group, four criteria – cost, quality, delivery, and inventory level reduction – were considered. For environmental group, two criteria were taken into account, 'pollution control' and 'environmental management system'. It is worthwhile to say that similar criteria are summarized here. For example, 'greenhouse gas emission' criterion is fallen in 'pollution control'. Finally, two criteria including 'social equities' and 'labor health and work safety' are derived from the social group. The 'social equities' term can be included 'discrimination', 'abuse of human right', and 'unfair competition'. Also, 'work safety and labor health' term is included 'child labor' and 'long working hours'.

Fuzzy set theory

Zadeh (1965) introduced fuzzy set theory to cope with the imprecision and uncertainty which is inherent to the human judgments in decision-making processes through the use of linguistic terms and degrees of membership. A fuzzy set is a class of objects with grades of membership. A normalized membership function is between zero and one (Zadeh, 1965). These grades present the degree of stability with which special element belongs to a fuzzy set. To express fuzzy sets from the mathematical point of view, consider a set of objects X. The set is explained as follows:

$$X = x_1, x_2, \dots, x_n, \tag{1}$$

where x_i is an element in the set X. A membership value (μ) expresses the grade of membership related to each element x_i in a fuzzy set A, which shows a combination as below:

$$A = (\mu_1(x_1), \mu_2(x_2), \dots, \mu_n(x_n)). \tag{2}$$

After Zadeh's work, Mamdani in 1974, investigated the feasibility of using the compositional rule of inference (Mamdani, 1974). The Mamdani FIS system has four parts as shown in Figure 2.

- Fuzzifier: the fuzzy sets of inputs are represented by membership functions to transfer crisp inputs into fuzzy inputs. Several functional forms of the membership function are available to represent different situations of fuzziness; for example, linear shape, concave shape, and exponential shape. Two commonly used types of membership function are linear triangular and linear trapezoid membership functions (Chen, 2009).
- Rules: the main part of the FIS model is 'Rules'. The fuzzy 'if-then' rules are defined on the basis of experts' knowledge in each area. A fuzzy rule can be written as 'if x_1 is a_1 and x_2 is b_1, then y is c_1' so that x_1 and x_2 are variables, y is a solution variable, and a_1, b_1, and c_1 are fuzzy linguistic terms.
- Interface engine: the fuzzy interface engine takes integrations of the identified fuzzy sets considering the fuzzy rule and allocates to integrate the related fuzzy area individually.
- Defuzzifier: transforms the fuzzy output to crisp output. Among the four parts of FIS, the defuzzification process has the most computational complexity. The defuzzifier finally identifies a numerical output value. Popular defuzzication approaches include the center of area method (COA), bisector of area method (BOA), mean of maximum method (MOM), smallest of maximum method

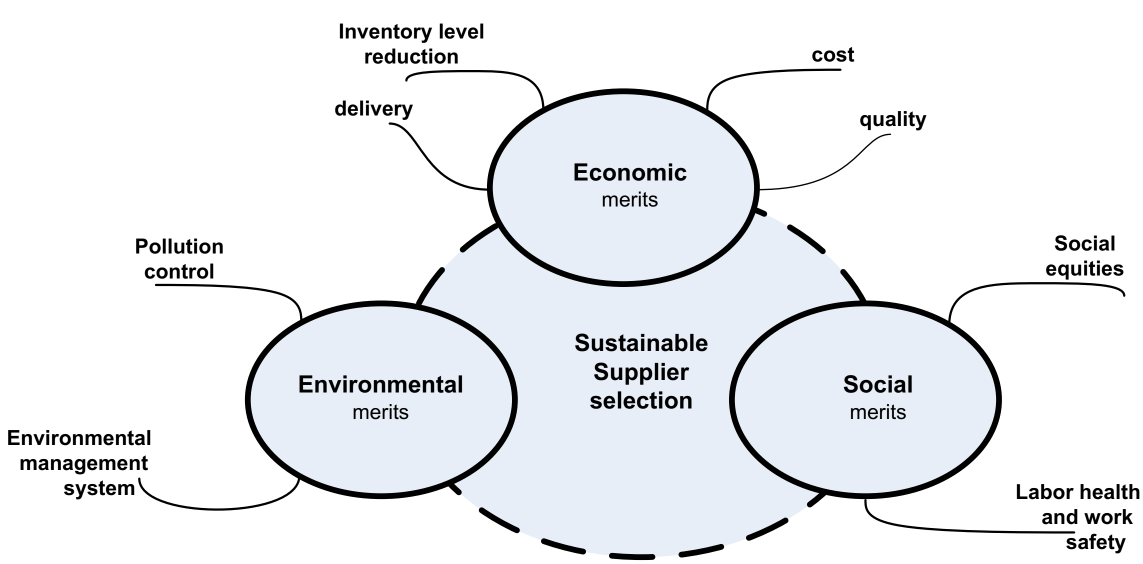

Figure 1. Framework for textile supplier sustainability evaluation criteria.

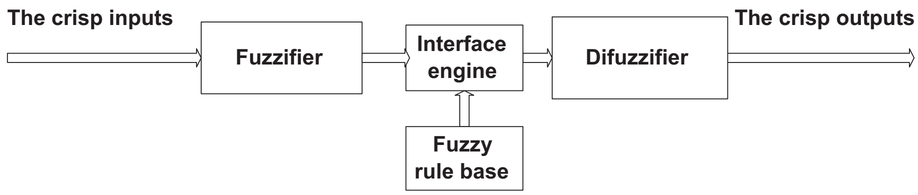

Figure 2. The Mamdani's fuzzy inference system.

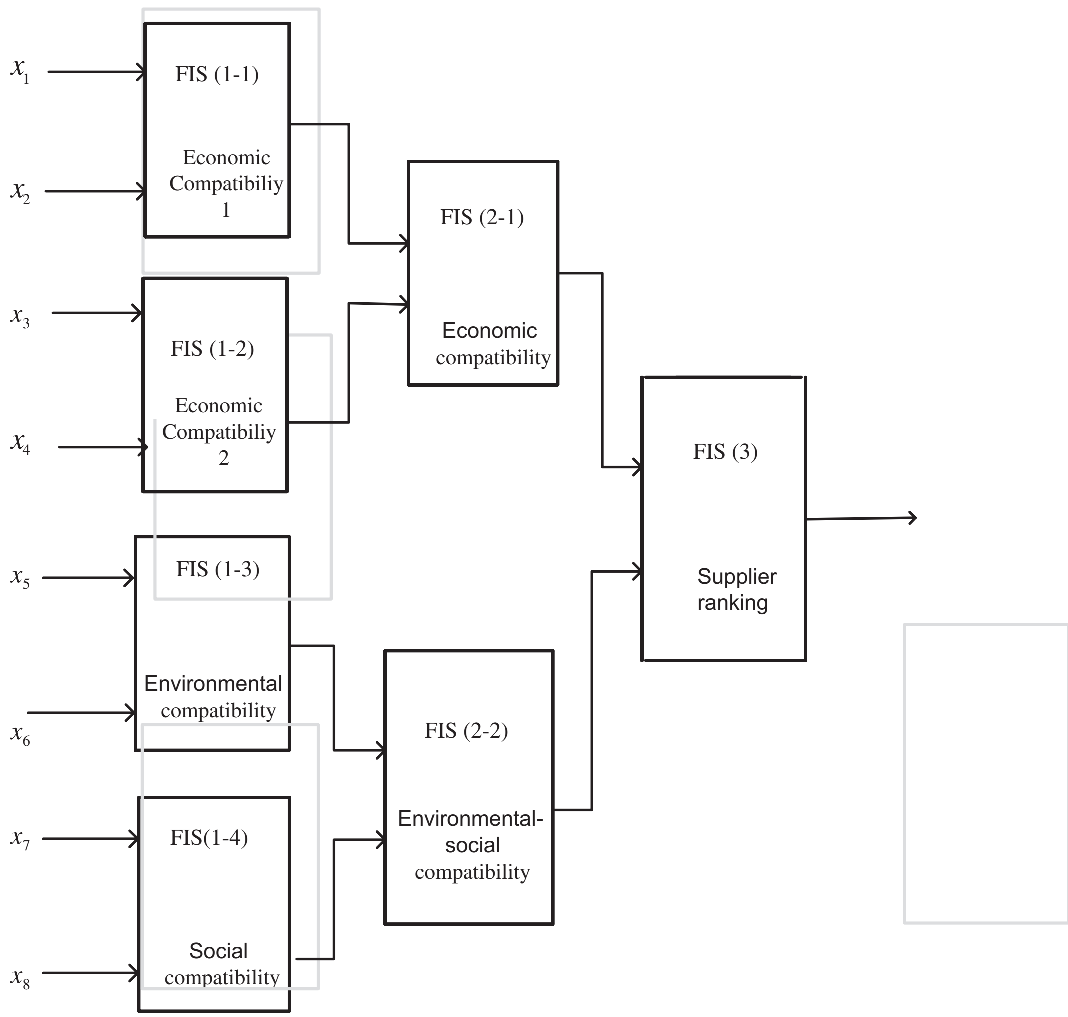

Figure 3. The proposed fuzzy ranking model.
Note: Input x_1, x_2, … x_8 refer to defuzzified and normalized values of the multiplication of the related criterion weight by its supplier performance for each supplier.

(SOM), and the largest of maximum method (LOM) (Sivanandam, Sumathi, & Deepa, 2007).

The preliminaries for the proposed model

To design the proposed fuzzy ranking model, some basic concepts must be considered. So these concepts are discussed in the next sub-sections and finally the description of the proposed model is presented in three stages and illustrated in Figure 3.

Fuzzy membership functions

In this work, the relative importance of the selection criteria and the supplier's performance with respect to the criteria, are implemented based on decision-makers' opinion. Thus, we set out two membership functions, one for estimation of the criteria weights and the other for the supplier's performance with respect to the criteria. It is noted that the membership functions are applied in the triangular form in this paper. A triangular fuzzy number can be shown as $\tilde{w} = (a^l, a^m, a^u)$ in Figure 4 and the triangular membership function is defined as Equation (3):

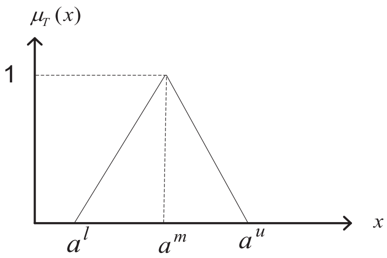

Figure 4. The triangular fuzzy membership function.

$$\mu_{\tilde{w}}(x) = \begin{cases} 0 & if \quad x < a^l \\ \frac{1}{a^m - a^l}(x - a^l) & if \quad a^l \le x \le a^m \\ \frac{1}{a^m - a^u}(x - a^u) & if \quad a^m \le x \le a^u \\ 0 & if \quad x > a^u \end{cases}. \tag{3}$$

Membership functions for the suppliers 'performance'

In the first stage of the model, five fuzzy sets of membership functions are applied for both inputs and outputs of the FIS systems. The fuzzy sets in the form of linguistic rating variables include weakly preferred (WP), low moderately preferred (LMP), moderately preferred (MP), strongly preferred (SP), and extremely preferred (EP). Regarding Figure 5 for example, 'WP' can be represented as (0, 10/6, 10/3) and 'SP' can be represented as (10/2, 20/3, 50/6). These variables are equivalent to fuzzy numbers on the numeric scale 0–10.

Like the first stage, we considered five fuzzy sets of membership functions both inputs and outputs of the FIS systems. In the third stage, we considered five fuzzy sets of membership functions for inputs, which are same as the outputs of second stage, and seven fuzzy sets of membership functions for the outputs of the FIS systems. The output fuzzy sets in the form of linguistic rating variables include very weakly preferred, WP, LMP, MP, high moderately preferred, SP, and EP as shown in Figure 6. The related fuzzy numbers are in the numeric scale 0–100. For example, LMP can be represented as (25, 37.5, 50).

Membership functions for the weights of criteria

In the first stage of the model, five fuzzy sets in the form of linguistic weighting variables, which include weak importance, low moderate importance, moderate importance, strong importance, and extreme importance, were utilized to evaluate the relative importance of the criteria. These variables are equivalent to fuzzy numbers on the numeric scale 0–1 as shown in Figure 7. For example, 'extreme importance' can be represented as (2/3, 5/6, 1).

Fuzzy operators

According to the definition of fuzzy numbers, suppose that $\tilde{X}$ and $\tilde{Y}$ are two triangular fuzzy numbers as:

$$\tilde{X} = (x^l, x^m, x^u). \tag{4}$$

$$\tilde{Y} = (y^l, y^m, y^u). \tag{5}$$

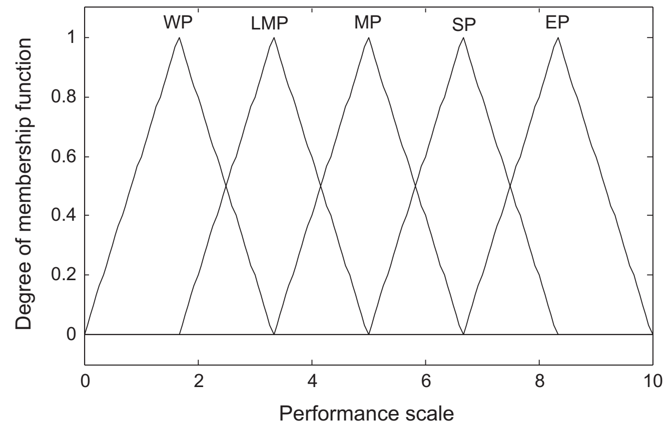

Figure 5. The membership functions in stage 1 and 2 for the supplier's performance.

The basic fuzzy operators are applied in the proposed model shown below:

$$\tilde{X} + \tilde{Y} = (x^i + y^i, x^m + y^m, x^u + y^u). \tag{6}$$

$$\tilde{X} * \tilde{Y} = (x^i * y^i, x^m * y^m, x^u * y^u). \tag{7}$$

Applied fuzzy rules

A set of the fuzzy linguistic rules based on expert knowledge are utilized to implement our fuzzy ranking model. The rules are adjusted on the preference of decision-makers to have the appropriate ranking for suppliers. Also, the rules are designed on the basis of averaging concept for each FIS system. For instance, when the supplier's performance with respect to 'delivery' is SP and the supplier's performance with respect to 'inventory level reduction' is SP then the FIS output is SP (see Table 3) or when the supplier's performance with respect to 'delivery' is WP and the supplier's performance with respect to 'inventory level reduction' is EP then the FIS output is MP (see Table 3). Moreover, the designed rules cover the changes in suppliers' performance completely and map their numeric scale of inputs to their numeric scale in outputs.

The rules for the related FIS engines are the same at each stage of the proposed model. The rules for first, second, and third stages are shown in Tables 3 and 4.

Defuzzification

To rank the fuzzy numbers for comparing the mentioned alternatives, the fuzzy numbers must be defuzzified to crisp numbers. In this paper, the COA method is used for defuzzification:

$$x_{\mathrm{COA}} = \frac{\sum_{i=1}^{n} x_i.\mu_i(x_i)}{\sum_{i=1}^{n} \mu_i(x_i)}, \tag{8}$$

where x_i is an element in the set X as mentioned in (1) and (2).

Development of the model

According to the proposed framework in Section 2, eight criteria are considered to rank the suppliers in textile industry. To begin

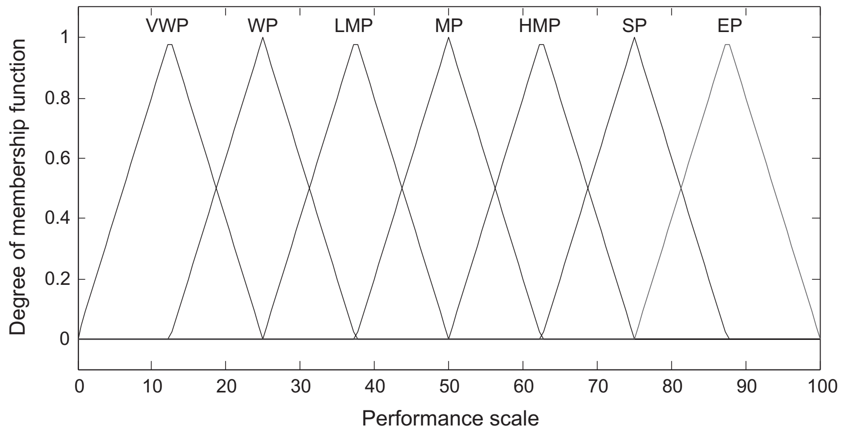

Figure 6. The membership functions in stage 3 for ranking the suppliers.

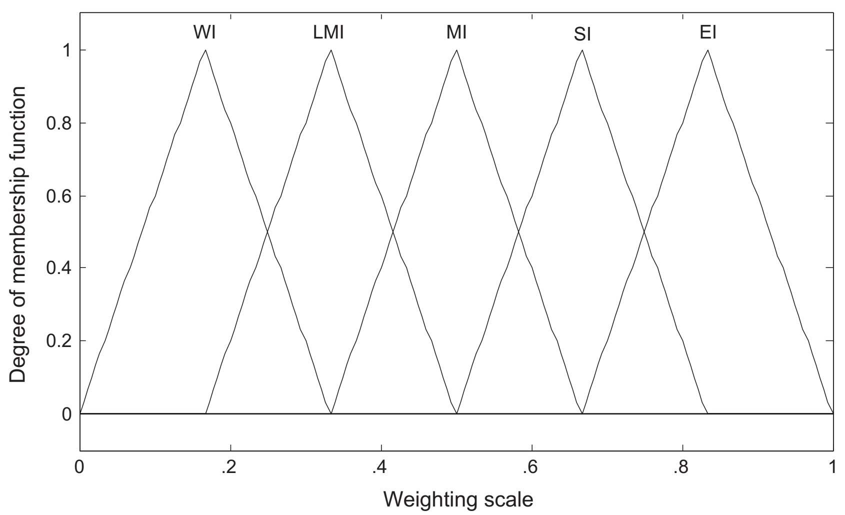

Figure 7. The membership functions for the weights of criteria.

the proposed supplier selection model, the relative importance of criteria and the supplier's performance with respect to criteria must be asked from decision-makers and provided to apply at the model. First, the decision-makers' opinions on the relative importance of each criterion and the supplier's performance with respect to the mentioned criterion must be averaged using Equation (6). Then, the relative importance of each criterion is multiplied by the supplier's performance with respect to the mentioned criterion using Equation (7). Finally, the obtained fuzzy numbers are defuzzified and normalized to the desired crisp numbers for using as crisp inputs of the FIS systems (see Figure 3). The proposed model explicitly shows a mathematical function in which the image of eight elements is the final result of the model. Therefore, we can suppose the value y as a function f of eight independent variables so that:

$$y = f(x_1, x_2, x_3, \dots, x_8). \tag{9}$$

Usually, in FIS models, the maximum number of fuzzy inputs is not considered more than two elements in order to decrease the number of fuzzy rules and design the rules more simply. Hence, we have taken this into account in the proposed model (Amindoust et al., 2012).

The proposed model is explained in the following stages and illustrated in Figure 3.

(1) The eight elements are classified into four groups. The inputs of the first group are 'cost' (x_1) and 'quality' (x_2) and the output (a) is named 'economic compatibility1' as shown in Figure 3. We can demonstrate Equation (10) for this group:

$$a = f_1(x_1, x_2). \tag{10}$$

In the second group, 'delivery' (x_3) and 'inventory level reduction' (x_4) are considered as inputs and the output (b) is named 'economic compatibility2' as shown in Figure 3. The illustrative equation for this group is:

$$b = f_1(x_3, x_4). \tag{11}$$

The inputs of the third group are 'pollution control' (x_5) and 'environmental management system' (x_6). We name the output 'environmental compatibility' as shown in Figure 3 and consider this relation as:

$$c = f_1(x_5, x_6). \tag{12}$$

Table 3. The fuzzy rule base matrix in first and second stages.

The second input	The first input				
	WP	LMP	MP	SP	EP
WP	WP	WP	LMP	LMP	MP
LMP	WP	LMP	LMP	MP	MP
MP	LMP	LMP	MP	MP	SP
SP	LMP	MP	MP	SP	SP
EP	MP	MP	SP	SP	EP

Table 4. The fuzzy rule base matrix in third stage.

The second input	The first input				
	WP	LMP	MP	SP	EP
WP	VWP	WP	LMP	LMP	MP
LMP	WP	LMP	LMP	MP	HMP
MP	LMP	LMP	MP	HMP	SP
SP	LMP	MP	HMP	SP	SP
EP	MP	HMP	SP	SP	EP

Table 5. Decision-makers' opinions for criteria weights.

Criteria	Decision-makers		
	DM1	DM2	DM3
Cost (C)	EI(4/65/6, 1)	EI(4/65/6, 1)	SI(3/6, 4/65/6)
Quality (Q)	EI(4/65/6, 1)	SI(3/6, 4/65/6)	EI(4/65/6, 1)
Delivery (D)	SI(3/6, 4/65/6)	EI(4/65/6, 1)	SI(3/6, 4/65/6)
Inventory level reduction (ILR)	SI(3/6, 4/65/6)	MI(2/63/64/6)	WI(0, 1/62/6)
Pollution control (PC)	SI(3/6, 4/65/6)	EI(4/65/6, 1)	SI(3/6, 4/65/6)
Environmental management system (EMS)	EI(4/65/6, 1)	SI(3/6, 4/65/6)	WI(0, 1/62/6)
Social equities (SE)	SI(3/6, 4/65/6)	WI(0, 1/62/6)	EI(4/65/6, 1)
Labor health and work safety (LH&WS)	MI(2/63/64/6)	SI(3/6, 4/65/6)	MI(2/63/64/6)

The inputs of fourth group are 'social equities' (x_7), and 'work safety and labor health' (x_8). We name the output 'social compatibility' as shown in Figure 3 considering the relation as:

$$d = f_1(x_7, x_8). \tag{13}$$

It is worthwhile to say that after multiplication of criteria weights by suppliers' performance, the range of the supplier's performance ([0 10]) is reduced. Therefore, the obtained results do not satisfy the aims of designed rules and causes inadequate precision for the FIS outputs. To tackle this problem, the FIS inputs are normalized for remaining in the previous scale of inputs.

(2) The four crisp outputs from the first stage are applied as inputs in second stage through two FIS engines. We name the outputs (e and g) 'economic compatibility' and 'environmental-social compatibility', respectively. This connection is shown by Equations (14) and (15):

$$e = f_1(a, b). \tag{14}$$

$$g = f_1(c, d). \tag{15}$$

(3) The two crisp outputs from second stage are passed to the FIS engine to have the final output (h) which is named 'supplier score'. The final relationship is given as:

$$h = f_2(e, g). \tag{16}$$

This methodology must be repeated for each candidate supplier to obtain its ranking.

Case study

To show the feasibility of the model, a real-life supplier selection decision from textile industry is solved by it. The necessary data are collected from a reputed textile industry in Malaysia. There are three decision-makers in the company's procurement team and five suppliers as candidates. The proposed supplier selection framework for criteria has been shown to procurement team to attain its preferences. The importance weights of criteria and the suppliers' performance with respect to these criteria based on purchasing managers' perceptions must be deducted using the linguistic terms as mentioned before. This information is presented in Tables 5 and 6.

It is worth to say that the mentioned information must be averaged among three decision-makers. So, the average of criteria weights multiply to the average of suppliers' performance as inputs passing into the FIS engines to have suitability index of each supplier. The proposed model has been exerted for five suppliers and the ranking results are obtained as shown in Table 7.

The proposed modular FIS model is executed through different defuzzification methods (Ordoobadi, 2009) such as COA, BOA, MOM, SOM, and LOM. As can be seen from Table 7, the obtained ranking results for all of the suppliers are same in different defuzzification methods. This shows the robustness and working of the proposed model.

Validation of the proposed modular FIS model

To validate the proposed model-based modular FIS, it is compared with the existing Fuzzy ART algorithm in literature for supplier selection (Aydın Keskin, İlhan, & Özkan, 2010). First, based on the decision-makers' preference about criteria (Table 5), eight criteria are considered for selection grades for each supplier candidate. The used grading scale is shown in Table 8. The data including decision makers' preference about supplier performance (Table 6) are averaged among three decision-makers for each criterion. Then, based on the grading in Table 8, decision-makers' preference are determined for each candidate and each criterion as shown in Table 9. It is noted that the necessary parameters for the Fuzzy ART selection algorithm are assigned as choice $\alpha = 1$; vigilance $\rho = .6$, and learning ratio $\beta = .6$.

The Fuzzy ART algorithm is implemented and executed step-by-step using the data given in Table 9 for five suppliers and eight evaluation criteria. Fuzzy ART Supplier Selection algorithm clustered the five suppliers in three supplier categories. Table 10 shows the generated categories, their labels, definitions, and calculated priority measures of the suppliers. Based on the results, suppliers A and B are the most appropriate suppliers. As seen from Table 10, these are members of the Category 1 and their assessment status is 'preferred'. The other suppliers are allocated in two other categories as 'recommended' and 'not recommended' as seen in Table 10. The obtained results from the

Table 6. Decision-makers' opinions with respect to criteria for candidate suppliers.

Criteria		Suppliers				
		A	B	C	D	E
C	DM1:	EP(20/3, 50/6, 10)	MP(10/3, 5, 20/3)	MP(10/35, 20/3)	SP(5, 20/3, 50/6)	EP(20/3, 50/6, 10)
	DM2:	EP(20/3, 50/6, 10)	MP(10/35, 0/3)	MP(10/3, 5, 20/3)	MP(10/35, 20/3)	SP(5, 20/3, 50/6)
	DM3:	EP(20/3, 50/6, 10)	MP(10/3, 5, 20/3)	MP(10/3, 5, 20/3)	EP(20/3, 50/6, 10)	SP(5, 20/3, 50/6)
Q	DM1:	EP(20/3, 50/6, 10)	MP(10/3, 5, 20/3)	MP(10/3, 5, 20/3)	WP(0, 10/6, 10/3)	SP(5, 20/3, 50/6)
	DM2:	EP(20/3, 50/6, 10)	MP(10/3, 5, 20/3)	MP(10/3, 5, 20/3)	MP(10/3, 5, 20/3)	LMP(10/610/3, 5)
	DM3:	EP(20/3, 50/6, 10)	MP(10/3, 5, 20/3)	MP(10/3, 5, 20/3)	LMP(10/6, 10/3, 5)	MP(10/3, 5, 20/3)
D	DM1:	EP(20/3, 50/6, 10)	MP(10/3, 5, 20/3)	MP(10/3, 5, 20/3)	MP(10/3, 5, 20/3)	SP(5, 20/3, 50/6)
	DM2:	EP(20/3, 50/6, 10)	MP(10/3, 5, 20/3)	MP(10/3, 5, 20/3)	EP(20/3, 50/6, 10)	EP(20/3, 50/6, 10)
	DM3:	EP(20/3, 50/6, 10)	MP(10/3, 5, 20/3)	MP(10/3, 5, 20/3)	SP(5, 20/3, 50/6)	SP(5, 20/3, 50/6)
ILR	DM1:	EP(20/3, 50/6, 10)	MP(10/3, 5, 20/3)	MP(10/3, 5, 20/3)	LMP(10/6, 10/3, 5)	MP(10/3, 5, 20/3)
	DM2:	EP(20/3, 50/6, 10)	MP(10/3, 5, 20/3)	MP(10/3, 5, 20/3)	LMP(10/6, 10/3, 5)	MP(10/3, 5, 20/3)
	DM3:	EP(20/3, 50/6, 10)	MP(10/3, 5, 20/3)	MP(10/3, 5, 20/3)	LMP(10/6, 10/3, 5)	MP(10/3, 5, 20/3)
EMS	DM1:	MP(10/3, 5, 20/3)	EP(20/3, 50/6, 10)	MP(10/3, 5, 20/3)	EP(20/3, 50/6, 10)	LMP10/6, 10/3, 5
	DM2:	MP(10/3, 5, 20/3)	EP(20/3, 50/6, 10)	MP(10/3, 5, 20/3)	SP(5, 20/3, 50/6)	WP(0, 10/6, 10/3)
	DM3:	MP(10/3, 5, 20/3)	EP(20/3, 50/6, 10)	MP(10/3, 5, 20/3)	SP(5, 20/3, 50/6)	MP(10/3, 5, 20/3)
PC	DM1:	MP(10/3, 5, 20/3)	EP(20/3, 50/6, 10)	MP(10/3, 5, 20/3)	MP(10/3, 5, 20/3)	LMP(10/610/3, 5)
	DM2:	MP(10/3, 5, 20/3)	EP(20/3, 50/6, 10)	MP(10/3, 5, 20/3)	EP(20/3, 50/6, 10)	LMP(10/610/3, 5)
	DM3:	MP(10/3, 5, 20/3)	EP(20/3, 50/6, 10)	MP(10/3, 5, 20/3)	SP(5, 20/3, 50/6)	LMP(10/610/3, 5)
SE	DM1:	MP(10/3, 5, 20/3)	MP(10/3, 5, 20/3)	EP(20/350/6, 10)	WP(0, 10/6, 10/3)	SP(5, 20/3, 50/6)
	DM2:	MP(10/3, 5, 20/3)	MP(10/3, 5, 20/3)	EP(20/350/6, 10)	WP(0, 10/6, 10/3)	SP(5, 20/3, 50/6)
	DM3:	MP(10/3, 5, 20/3)	MP(10/3, 5, 20/3)	EP(20/350/6, 10)	WP(0, 10/6, 10/3)	SP(5, 20/3, 50/6)
LH& WS	DM1:	MP(10/3, 5, 20/3)	MP(10/3, 5, 20/3)	EP(20/350/6, 10)	MP(10/3, 5, 20/3)	EP(20/3, 50/6, 10)
	DM2:	MP(10/3, 5, 20/3)	MP(10/3, 5, 20/3)	EP(20/350/6, 10)	WP(0, 10/6, 10/3)	SP(5, 20/3, 50/6)
	DM3:	MP(10/3, 5, 20/3)	MP(10/3, 5, 20/3)	EP(20/350/6, 10)	LMP(10/610/3, 5)	EP(20/3, 50/6, 10)

Table 7. Suppliers' ranking results of the proposed model.

Suppli-ers	Ranking results					
	COA	MOM	SOM	LOM	BOA	Ranking
A	80.3942	75.9001	88.4765	81.7083	78.6044	1
B	70.428	67.801	82.7952	76.7285	72.6363	2
C	35.8409	28.3939	55.648	20.4949	34.8666	5
D	45.5439	35	80.356	29.5617	44.1438	4
E	66.2524	59.7556	81.4765	73.4905	65.5586	3

Table 8. The grading and the status of the criteria.

Grading	Status
EP	1
SP	2
MP	3
LMP	4
WP	5

Table 9. Candidate suppliers and their grades according to the eight evaluation criteria.

Criteria	Suppliers				
	A	B	C	D	E
C	1	3	3	2	2
Q	1	3	3	4	3
D	1	3	3	2	2
ILR	1	3	3	4	3
EMS	3	1	3	2	4
PC	3	1	3	2	4
SE	3	3	1	5	2
LH & WS	3	3	1	4	1

Table 10. The category membership of the suppliers and the calculated priority measures.

Category Label	Supplier	Category definition	Priority measure
Category 1	A-B	Preferred	2.25
Category 2	E	Recommended	2.625
Category 3	D-C	Not recommended	2.8125

proposed model (Table 7) show that the suppliers A and B are the first and second suppliers. For other suppliers (C, D, and E), you can see this verification from comparison of both two Tables 7 and 10. Therefore, these comparisons show the validation of the proposed model. It is noteworthy that the Fuzzy ART only clusters the suppliers, but the proposed modular FIS model ranks the suppliers and gives their order.

Conclusion

In today's competitive environments, one of the main concerns of textile and clothing industries lie with their supply chain to achieve sustainability merits. To date, there are very few studies considering sustainable issue in the supplier selection problem in textile industry. In this paper, a set of appropriate sustainable criteria has been derived after rigorous literature searching for reliable sources, which considered the sustainability issue in supplier selection, and a new framework has been proposed for sustainable supplier selection criteria in textile and clothing industry. In addition, this paper proposes an applicable modular model based on FIS that not only ranks the suppliers on the basis of their performance ratings, but also assigns the important degree of criteria in the ranking process. Suppliers' ranking obtained under the proposed model is in agreement with the existing Fuzzy ART model. This validates the acceptance of the proposed modular FIS model. The proposed modular FIS model can be for supplier selection considering sustainability aspects in addition to the conventional economic or cost-based aspects.

Fuzzy set theory approach applies to convert decision-makers' opinions to meaningful results for using in the model. The proposed model can be executed for any number of suppliers in small, medium, and large companies. Although many attempts have been made for the supplier selection, considering sustainable issue for this problem remains a challenge. In addition, how to assign orders to the best suppliers in the model can be a subject for future research.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCiD

Atefeh Amindoust http://orcid.org/0000-0003-1791-4864
Ali Saghafinia http://orcid.org/0000-0002-5056-2672

References

Amin, S. H., Razmi, J., & Zhang, G. (2010). Supplier selection and order allocation based on fuzzy SWOT analysis and fuzzy linear programming. *Expert Systems with Applications, 38*, 334–342.

Amindoust, A., Ahmed, S., & Saghafinia, A. (2013). Supplier selection and quota allocation decisions under uncertainty: Review and future research directions. *The International Journal of Enhanced Research in Science Technology & Engineering (IJERSTE)*, *2*, 1–4.

Amindoust, A., Ahmed, S., & Saghafinia, A. (2012a). Location decision of supply chain management in the auto motive industry. *International Journal of Engineering, 1*, 2305–8269.

Amindoust, A., Ahmed, S., & Saghafinia, A. (2012b). Supplier performance measurement of palm oil industries from a sustainable point of view in malaysia. *BioTechnology: An Indian Journal, 6*, 155–158.

Amindoust, A., Ahmed, S., & Saghafinia, A. (2012c). A taxonomy and review on supplier selection methods under uncertainty. *International Journal of Information Technology and Business Management, 7*, 33–43.

Amindoust, A., Ahmed, S., & Saghafinia, A. (2013, Seprember). Supplier selection and order allocation scenarios in supply chain: A review. *Engineering Management Reviews (EMR), 2*, 75–80.

Amindoust, A., Ahmed, S., Saghafinia, A., & Bahreininejad, A. (2012). Sustainable supplier selection: A ranking model based on fuzzy inference system. *Applied Soft Computing, 12*, 1668–1677. doi: 10.1016/j.asoc.2012.01.023.

Amindoust, A., & Saghafinia, A. (2014a). Supplier evaluation and selection using a FDEA model. In A. Emrouznejad & M. Tavana (Ed.), *Performance measurement with fuzzy data envelopment analysis* (pp. 255–269). Verlag Berlin Heidelberg: Springer.

Amindoust, A., & Saghafinia, A. (2014b). Supplier evaluation using fuzzy inference systems. In C. Kahraman & B. Öztaysi (Ed.), *Supply chain management under fuzziness* (pp. 3–19). Verlag Berlin Heidelberg: Springer.

Awasthi, A., Chauhan, S. S., & Goyal, S. K. (2010). A fuzzy multicriteria approach for evaluating environmental performance of suppliers. *International Journal of Production Economics, 126*, 370–378. doi: 10.1016/j.ijpe.2010.04.029

Aydın Keskin, G., İlhan, S., & Özkan, C. (2010). The fuzzy ART algorithm: A categorization method for supplier evaluation and selection. *Expert Systems with Applications, 37*, 1235–1240.

Bai, C., & Sarkis, J. (2010). Integrating sustainability into supplier selection with grey system and rough set methodologies. *International Journal of Production Economics, 124*, 252–264.

Baskaran, V., Nachiappan, S., & Rahman, S. (2012). Indian textile suppliers' sustainability evaluation using the grey approach. *International Journal of Production Economics, 135*, 647–658. doi: 10.1016/j.ijpe.2011.06.012

Buyukozkan, G., & Çifçi, G. (2010). A novel fuzzy multi-criteria decision framework for sustainable supplier selection with incomplete information. *Computers in Industry*, *62*, 164–174.

Carrera, D. A., & Mayorga, R. V. (2008). Supply chain management: A modular fuzzy inference system approach in supplier selection for new product development. *Journal of Intelligent Manufacturing, 19*(1), 1–12.

Chaabane, A., Ramudhin, A., & Paquet, M. (2010). Design of sustainable supply chains under the emission trading scheme. *International Journal of Production Economics*, *135,* 37–49.

Chen, C. M. (2009). A fuzzy-based decision-support model for rebuy procurement. *International Journal of Production Economics, 122*, 714–724.

Chen, Y. J. (2010). Structured methodology for supplier selection and evaluation in a supply chain. *Information Sciences*, *181*, 1651–1670.

Ding, H., Benyoucef, L., & Xie, X. (2005). A simulation optimization methodology for supplier selection problem. *International Journal of Computer Integrated Manufacturing, 18*, 210–224.

Hsu, C. W., & Hu, A. H. (2009). Applying hazardous substance management to supplier selection using analytic network process. *Journal of Cleaner Production, 17*, 255–264.

Humphreys, P., Wong, Y., & Chan, F. (2003). Integrating environmental criteria into the supplier selection process. *Journal of Materials Processing Technology, 138*, 349–356.

Kumar, D., Singh, J., & Singh, O. P. (2012). A fuzzy logic based decision support system for the evaluation of suppliers in supply chain management practices. *Mathematical and Computer Modelling*, *57*, 2945–2960.

Kuo, R., Wang, Y., & Tien, F. (2010). Integration of artificial neural network and MADA methods for green supplier selection. *Journal of Cleaner Production*, *18,* 1161–1170.

Lee, A. H. I., Kang, H.-Y., Hsu, C.-F., & Hung, H.-C. (2009). A green supplier selection model for high-tech industry. *Expert Systems with Applications, 36*, 7917–7927. Retrieved from http://dx.doi.org/10.1016/j.eswa.2008.11.052

Mafakheri, F., Breton, M., & Ghoniem, A. (2011). Supplier selection-order allocation: A two-stage multiple criteria dynamic programming approach. *International Journal of Production Economics*, *132,* 52–57.

Mamdani, E. H. (1974). Application of fuzzy algorithms for control of simple dynamic plant. *Electrical Engineers, Proceedings of the Institution of 121, 121*, 1585–1588.

Ordoobadi, S. M. (2009). Development of a supplier selection model using fuzzy logic. *Supply Chain Management: An International Journal, 14*, 314–327.

Porsche, H., Fischer, M. Braga, F., & Häni, F. (2006). *Introduction of the sustainability assessment tool RISE into Canadian agriculture*. *J. Univ. Guelph,* 11, 11–19.

Punniyamoorthy, M., Mathiyalagan, P., & Vasishta, G. (2010). A strategic model using structural equation modeling and fuzzy logic in supplier selection. *Expert Systems with Applications*, *38,* 458–474.

Saghafinia, A., Pingb, H. W., & Amindoustc, A. (2015). Selection of electric energy production technologies using DEA (Case study: Iran). *International Journal of Renewable Energy Resources (formerly International Journal of Renewable Energy Research), 5*(1), 8–12.

Shaw, K., Shankar, R., Yadav, S. S., & Thakur, L. S. (2012). Supplier selection using fuzzy AHP and fuzzy multi-objective linear programming for developing low carbon supply chain. *Expert Systems with Applications*, *39,* 8182–8192.

Sivanandam, S., Sumathi, S., & Deepa, S. (2007). *Introduction to fuzzy logic using MATLAB*: Springer Verlag, Springer Berlin Heidelberg.

Tseng, M. L., & Chiu, A. S. (2010). Evaluating firm's green supply chain management in linguistic preferences. *Journal of Cleaner Production*, *40*, 22–31.

Woo, H. S., & Saghiri, S. (2011). Order assignment considering buyer, third-party logistics provider, and suppliers. *International Journal of Production Economics, 130*, 144–152. doi:10.1016/j.ijpe.2010.10.019

Wu, Z., & Pagell, M. (2010). Balancing priorities: Decision-making in sustainable supply chain management. *Journal of Operations Management*, *29*, 577–590.

Yeh, W. C., & Chuang, M. C. (2010). Using multi-objective genetic algorithm for partner selection in green supply chain problems. *Expert Systems With Applications*, *38*, 4244–4253.

Zadeh, L. A. (1965). Fuzzy sets. *Information and Control, 8*, 338–353.

Zhu, Q., Dou, Y., & Sarkis, J. (2010). A portfolio-based analysis for green supplier management using the analytical network process. *Supply Chain Management: An International Journal, 15*, 306–319.