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Sustainable supplier selection: A ranking model based on fuzzy inference system

Atefeh Amindoust [a,*], Shamsuddin Ahmed [a,1], Ali Saghafinia [b,2], Ardeshir Bahreininejad [a,3]

[a] Department of Engineering Design and Manufacture, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] Electrical Engineering Department, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

A R T I C L E I N F O

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A B S T R A C T

In these days, considering the growth of knowledge about sustainability in enterprise, the sustainable supplier selection would be the central component in the management of a sustainable supply chain. In this paper the sustainable supplier selection criteria and sub-criteria are determined and based on those criteria and sub-criteria a methodology is proposed onto evaluation and ranking of a given set of suppliers. In the evaluation process, decision makers' opinions on the importance of deciding the criteria and sub-criteria, in addition to their preference of the suppliers' performance with respect to sub-criteria are considered in linguistic terms. To handle the subjectivity of decision makers' assessments, fuzzy logic has been applied and a new ranking method on the basis of fuzzy inference system (FIS) is proposed for supplier selection problem. Finally, an illustrative example is utilized to show the feasibility of the proposed method.

1. Introduction

Due to the recent agile improvement of network technology and economic globalization, purchasing management has come to play a critical role as a key to business success in supply chain management (SCM). One of the crucial challenges confronted by purchasing managers is the evaluation and selection of the right kind of suppliers compatible to agile systems. Researches carried out in the field of supplier selection have been applying multi-criteria decision making methods, such as analytic hierarchy process (AHP), analytic network process (ANP), data envelopment analysis (DEA), and mathematical programming [1–6]. Readers are referred to visit [7] for a detailed account.

Nowadays, sustainable development has become a buzzword that received a lot of attentions in many domains such as manufacturing [8], business development [9], tourism [10], and agriculture [11]. Also, in SCM both academics and practitioners consider the sustainable issues in their works. Sustainable SCM 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 [12].

To achieve a sustainable supply chain, all of the members in the chain from suppliers to top managers must have affinity with sustainability. Even though many publications exist on supplier selection, the research on sustainable supplier selection [13,14] is not adequate.

To select the appropriate suppliers, two subjects including importance degree of the selection criteria, and suppliers' performance with respect to these criteria are essential [15]. These two subjects need to be verified with the relevant decision makers. Decision makers normally prefer to answer the questions in linguistic terms instead of numerical form. Linguistic term is simple and tangible for them to express their perceptions. This might be a way of securing the company's information. But very often, they are obligated to answer the qualitative questions in quantitative form. Therefore, the subjectivity of human assessments is missed. To handle this issue and deal with the vagueness that is being existed in the supplier selection process, application of fuzzy logic is explored in this article. Some researchers have used fuzzy concepts for supplier selection issue [16–20]. Also, Ordoobadi proposed a mathematical algorithm by applying fuzzy membership functions to rank the suppliers [15]. However, in case of large number of suppliers and criteria this method is quite time consuming and the final results of ranking are very close to each other. Therefore, the ranking results from this method may not be accurate. So, this paper focused on the said limitations and applies the FIS system to overcome the drawbacks of Ordoobadi's [15] model. Further, Carrera and Mayorga applied the FIS system for supplier selection. But, they did not assign the importance of weights for the selected indicators

* Corresponding author. Tel.: +60 17610 9257; fax: +60 37967 5282.
E-mail addresses: Atefeh_Amindoust@yahoo.com (A. Amindoust), Ahmed@um.edu.my (S. Ahmed), Saghafi_ali@yahoo.com (A. Saghafinia), bahreininejad@um.edu.my (A. Bahreininejad).
1 Tel.: +60 37967 4455; fax: +60 37967 5330.
2 Tel.: +60 37967 6866/17610 9257; fax: +60 37967 5282.
3 Tel.: +60 37967 4455; fax: +60 37967 5330.

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Table 1
The literature of selection indicators in supplier selection.

Criteria sub-criteria	References												
	[25]	[26]	[27]	[28]	[13]	[29]	[12]	[14]	[30]	[31]	[32]	[33]	[34]
Economic													
Cost/price					√			√	√		√	√	√
Quality			√				√	√	√	√	√	√	√
Technology capability					√		√		√			√	
Production facilities and capacity					√				√				
Financial capability					√		√		√				
Organization and management							√		√	√		√	
Delivery								√		√	√	√	√
Service								√	√	√			
Relationship									√	√		√	
Flexibility										√		√	
Environmental													
Environmental costs	√										√		√
Green design	√			√						√	√		√
Environmental management system	√	√	√	√		√		√		√	√	√	√
Environmental competencies	√	√	√				√		√				√
Green R&D				√						√			
Pollution control			√	√	√	√						√	
Green product			√							√		√	
Resource consumption						√						√	
ECO-design requirements for energy using product								√					
Ozone depleting chemicals								√					
Waste electrical and electronic equipment								√					
Recycling											√		
Green supply chain management										√	√		
Innovation										√			
Social													
The interests and rights of employee								√					
The rights of stakeholders								√					
Work safety and labor health					√								
Information disclosure								√					
Respect for the policy								√					

(criteria and sub-criteria). In their model, the fuzzy rules for each FIS system did not envelop all possible characteristics of suppliers [21]. So, this paper puts importance on weights of criteria and sub-criteria that are allocated in the proposed model considering sustainable issues. From the available literature it may be pointed that sustainable supplier selection issue was not yet considered in FIS system in earlier works.

This paper is organized to determine the sustainable supplier selection indicators through the literature survey. Then, a new ranking method for FIS is suggested using those criteria and sub-criteria onto selecting the best suppliers.

2. Determination of the sustainable supplier selection indicators

The traditional approach to supplier selection has solely considered economic aspects for many years. It is not enough because of globalization in business, competitive market situations, and the changing customers' demands in these days. Organizations must add the environmental/ecological and social aspects to the traditional supplier selection criteria such as quality, cost, delivery, and service to remain in the sustainable supply chain.

In our rigorous literature searches from reliable sources on supplier selection only 13 journal articles have been found which considered environmental and social aspects – separately or together – besides economic aspect to derive a set of appropriate sustainable (economic, environmental, and social) indicators. The sub-criteria applied by these researchers are combined in this work into three main sustainable criteria during the scanning of these sub-criteria by removing their duplications as shown in Table 1.

It is evident that choosing the indicators for supplier selection problem depends on the circumstances and situations and each organization may consider its individual indicators to select the best suppliers.

3. Fuzzy set theory

Zadeh 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 [22]. These grades present the degree of stability with which special element belongs to a fuzzy set. To express fuzzy sets on the mathematical point of view, consider a set of objects X. The set is explained as follows:

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

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:

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

After Zadeh' work, Mamdani in 1974, investigated the feasibility of using compositional rule of inference [23]. The Mamdani FIS system has 4 parts as shown in Fig. 1

- 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,

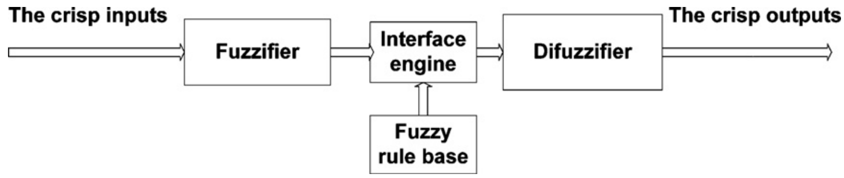

Fig. 1. The Mamdani's fuzzy inference system.

concave shape and exponential shape. Two commonly used types of membership function are linear triangular and linear trapezoid membership functions [18].

- 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 4 parts of FIS, defuzzification process has the most computational complexity. The defuzzifier finally identifies a numerical output value. Popular difuzzication approaches include the center of area method (COA), bisector of area method (BOA), mean of maximum

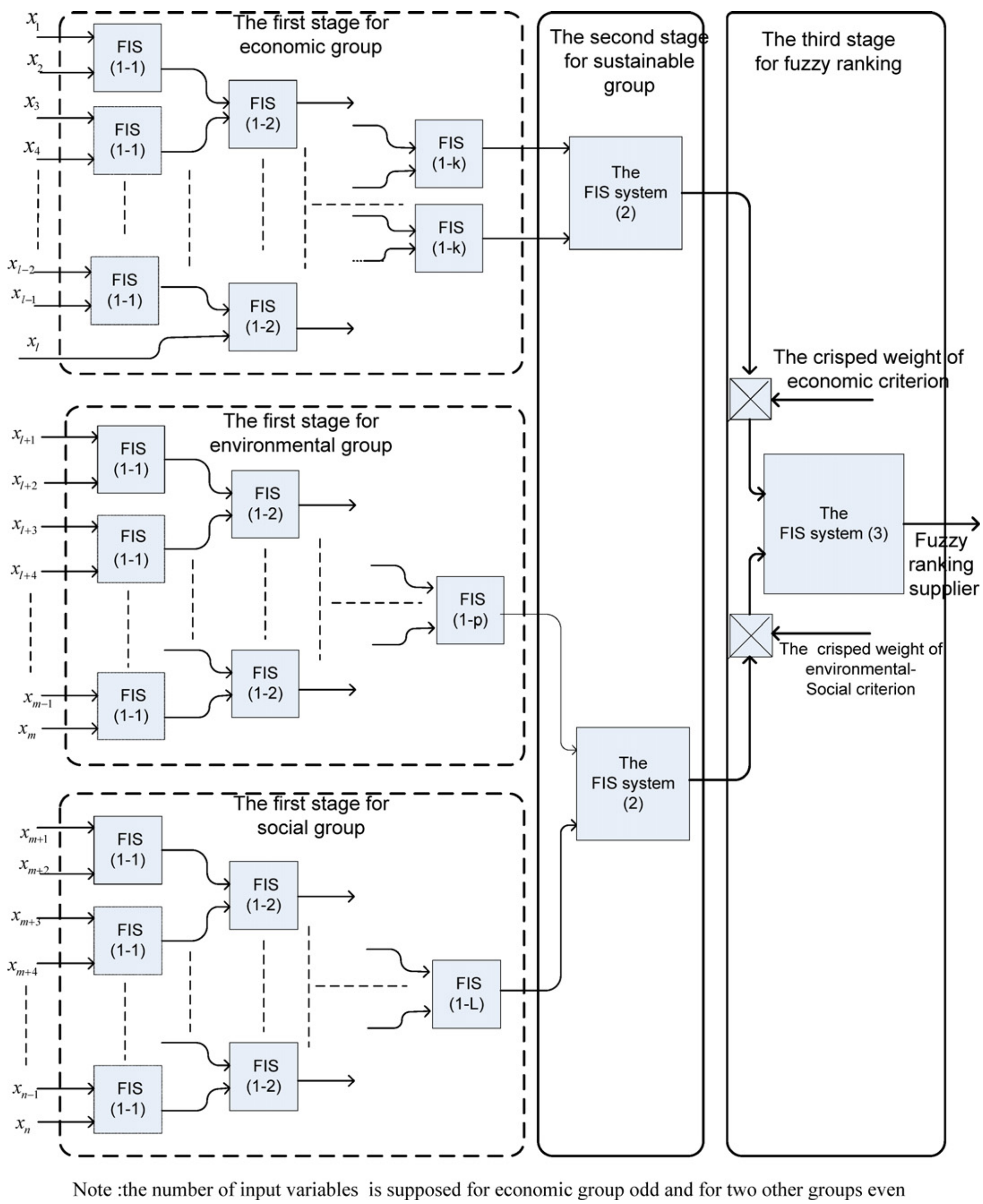

Fig. 2. The proposed fuzzy ranking model.

Table 2
The linguistic terms in stage 1 and stage 2 for the supplier's performance.

Weakly preferred (WP)	(0, 0, 2, 4)
Moderately preferred (MP)	(2, 4, 4, 6)
Strongly preferred (SP)	(4, 6, 6, 8)
Extremely preferred (EP)	(6, 8, 10, 10)

method (MOM), smallest of maximum method (SOM), and the largest of maximum method (LOM) [24].

4. The proposed fuzzy ranking model

To design our 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 proposed model is presented through three stages in Fig. 2.

4.1. Fuzzy membership functions in the proposed model

In this work the degree of importance of the selection criteria and sub-criteria and also the supplier's performance with respect to the sub-criteria, are implemented on the basis of decision makers' opinion. Thus we set out two membership functions, one for estimation of the criteria and sub-criteria weights and the other for the supplier's performance with respect to sub-criteria. It is noted that the membership functions are applied in the trapezoidal and triangular forms in this paper. A trapezoidal fuzzy number can be shown as $\tilde{w} = (a, b, c, d)$ in Fig. 3 and the trapezoidal membership function is defined as Eq. (3). According to Eq. (3), if $b = c$ then the number is called a triangular fuzzy number.

$$\mu_{\tilde{w}}(x) = \begin{cases} 0 & \text{if } x < a \\ \dfrac{1}{b-a}(x-a) & \text{if } a \le x \le b \\ 1 & \text{if } b \le x \le c \\ \dfrac{1}{c-d}(x-d) & \text{if } c \le x \le d \\ 0 & \text{if } x > d \end{cases} \quad (3)$$

4.1.1. Membership functions for inputs and outputs

In the first stage of the model four 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", "moderately preferred", "strongly preferred" and "extremely preferred" as shown in Fig. 4. These variables are equivalent to fuzzy numbers on the numeric scale 0–10 as presented in Table 2.

Like the first stage, we considered four fuzzy sets of membership functions for inputs in the second stage and six fuzzy sets of membership functions for outputs of the FIS systems. The output fuzzy sets in the form of linguistic rating variables include "weakly preferred", "low moderately preferred", "high moderately preferred", "strongly preferred", "very strongly preferred" and "extremely preferred" as shown in Fig. 5. The corresponding fuzzy numbers to these fuzzy sets are presented in Table 3.

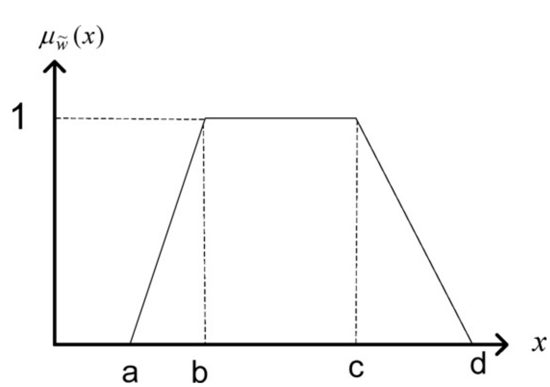

Fig. 3. The trapezoidal fuzzy membership function.

Table 3
The linguistic terms in stage 2 and stage 3 for the supplier's performance.

Weakly preferred (WP)	(0, 0, 1, 3)
Low moderately preferred (LMP)	(1, 2.5, 2.5, 4)
High moderately preferred (HMP)	(3, 4.5, 4.5, 6)
Strongly preferred (SP)	(4, 5.5, 5.5, 7)
Very strongly preferred (VSP)	(6, 7.5, 7.5, 9)
Extremely preferred (EP)	(7, 9, 10, 10)

In the third stage, we considered six fuzzy sets of membership functions for inputs which are same the outputs of second stage and seven fuzzy sets of membership functions for outputs of the FIS systems. The output fuzzy sets in the form of linguistic rating variables include "very weakly preferred", "weakly preferred", "low moderately preferred", "high moderately preferred", "strongly preferred", "very strongly preferred" and "extremely preferred" as shown in Fig. 6. The related fuzzy numbers are in the numeric scale 0–100 as shown in Table 4.

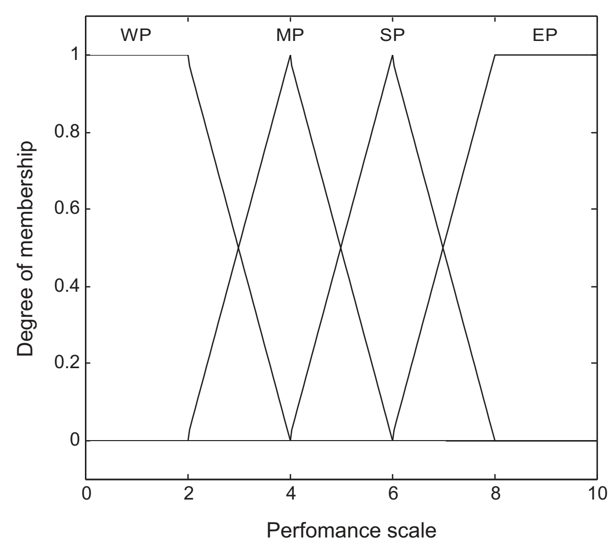

Fig. 4. The membership functions in stage 1 and stage 2 for the supplier's performance.

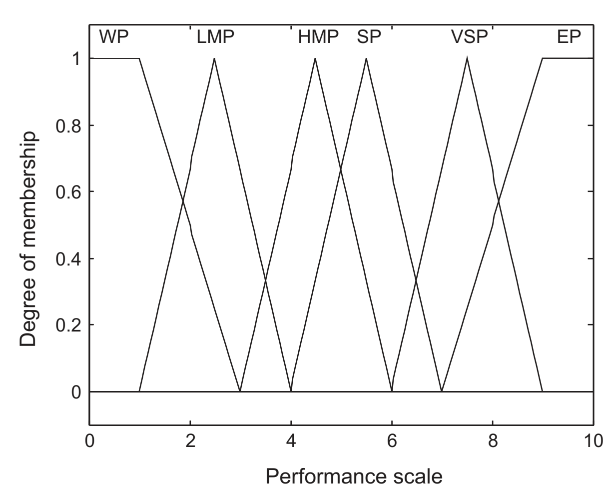

Fig. 5. The membership functions in stage 2 and stage 3 for the supplier's performance.

Table 4
The linguistic terms in stage 3 for ranking the suppliers.

Very weakly preferred (VWP)	(0, 0, 10, 20)
Weakly preferred (WP)	(10, 25, 25, 40)
Low moderately preferred (LMP)	(30, 40, 40, 50)
High moderately preferred (HMP)	(40, 55, 55, 70)
Strongly preferred (SP)	(60, 70, 70, 80)
Very strongly preferred (VSP)	(70, 80, 80, 90)
Extremely preferred (EP)	(80, 90, 100, 100)

4.1.2. Membership functions for the weights of criteria and sub-criteria

In the first and third stages of the model, four fuzzy sets in the form of linguistic weighting variables which include “weak importance”, “moderate importance”, “strong importance”, and “extreme importance” were utilized to evaluate the importance of sub-criteria and criteria. These variables are equivalent to fuzzy numbers on the numeric scale 0–1. Fig. 7 presents the four fuzzy sets and the linguistic weighting variables are shown in Table 5.

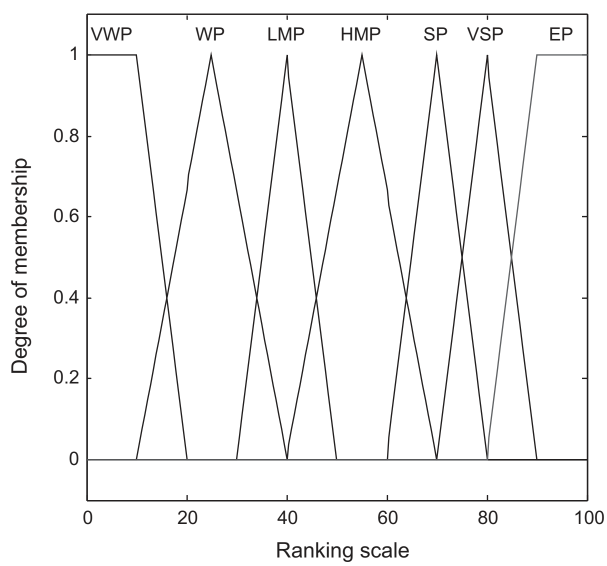

Fig. 6. The membership functions in stage 3 for ranking the suppliers.

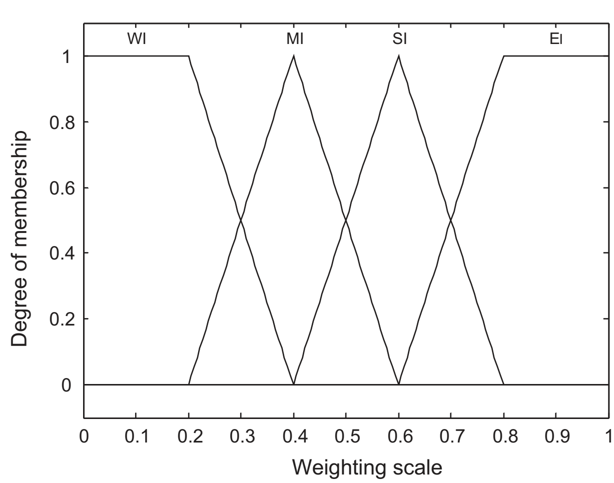

Fig. 7. Membership functions for the weights of criteria and sub-criteria.

Table 5
The linguistic weighting terms for criteria and sub-criteria.

Weak importance (WI)	(0, 0, 0.2, 0.4)
Moderate importance (MI)	(0.2, 0.4, 0.4, 0.6)
Strong importance (SI)	(0.4, 0.6, 0.6, 0.8)
Extreme importance (EI)	(0.6, 0.8, 1, 1)

Table 6
The fuzzy rule base matrix in stage 1.

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

Table 7
The fuzzy rule base matrix in stage 2.

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

4.2. Fuzzy operators

Addition and multiplication of fuzzy operations are utilized in our model. Suppose Eqs. (4) and (5) be two trapezoidal fuzzy numbers as

$$R = (r1, r2, r3, r4) \tag{4}$$

$$S = (s1, s2, s3, s4) \tag{5}$$

So, addition and multiplication of them are as follows respectively.

$$R + S = (r1 + s1, r2 + s2, r3 + s3, r4 + s4) \tag{6}$$

$$R * S = (r1 * s1, r2 * s2, r3 * s3, r4 * s4) \tag{7}$$

4.3. Applied fuzzy rules in the model

A set of the fuzzy linguistic rules based on expert knowledge are utilized to implement our fuzzy ranking model. To design the rules, it must be considered that each of the sub-criteria is preferred to be larger-is-better except the “cost” (smaller-is-better). Hence, the “cost” criterion is replaced by the “profit” which is calculated by subtracting the cost from income. 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 systems. For instance, when the supplier’s performance with respect to delivery is “strongly preferred” and the supplier’s performance with respect to service is “strongly preferred” then the FIS output is “strongly preferred” (see Table 6) or when the supplier’s performance with respect to delivery is “weakly preferred” and the supplier’s performance with respect to service is “strongly preferred” then the FIS output is “moderately preferred” (see Table 6). Moreover, the designed rules cover the changes of 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 6, 7, and 8, respectively.

Table 8
The fuzzy rule base matrix in stage 3.

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

4.4. Difuzzification

To rank the fuzzy numbers for comparing the mentioned alternatives, the fuzzy numbers must be difuzzified to crisp numbers. In this paper, the COA method is used for difuzzification as shown in (8).

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

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

4.5. Description of the proposed model

Our proposed model explicitly shows a mathematical function in which the image of n elements (n sub-criteria) is the final result of the model. Therefore, we can suppose the value y as a function f of n independent variables so that

$$y = f(x_1, x_2, x_3, \ldots, x_n) \tag{9}$$

To execute the proposed model, the list of selection sub-criteria in economic, environmental, and social groups must show to the decision makers and ask them to choose the ones pertinent to their company (Table 9).

Usually, in FIS models, the maximum number for fuzzy inputs are 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. The proposed model is done through three stages as presented in Fig. 2. First, the supplier's performance with respect to each sub-criterion is multiplied by the weight of the sub-criterion. Then, the obtained fuzzy numbers are defuzzified to the desired crisp numbers for using as input variables ($x_1, x_2, \ldots x_{l-1}, x_l, \ldots, x_{m-1}, x_m, \ldots, x_{n-1}, x_n$) for the FIS systems in the first stage. It is noted that after selecting two by two of input variables, if one of the input variables remains (when the number of input variables is odd), consider the remaining input variable as output variable for one of the FIS systems in that group as noted in Fig. 2 for economic group. First stage is continued and the FIS systems are applied until the number of FIS systems' outputs for economic group is equal to 2 and for both environmental and social groups equal to 1. So, four inputs including the two outputs of economic group, the one output of environmental group, and the one output of social group are considered for two FIS systems in the second stage.

To begin the third stage, the fuzzy weight of economic criterion is defuzzified to crisp number and multiplied by its related output value in the second stage. Also, the average between the weights of environmental and social criteria is defuzzified to crisp number and multiplied by its related output value in second stage (see Fig. 2).

It is worthwhile to say that after multiplication of criteria and sub-criteria weights by suppliers' performance in the first and third stages, the range of supplier's performance ([010]) is reduced. So, 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.

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

Table 9
A sample adjustment mechanism.

Criteria	Sub-criteria	Relevant?	
Economic			
	Cost/price (profitability of suppliers)	Yes	No
	Quality	Yes	No
	Technology capability	Yes	No
	Production facilities and capacity	Yes	No
	Financial capability	Yes	No
	Organization and management	Yes	No
	Delivery	Yes	No
	Service	Yes	No
	Relationship	Yes	No
	Flexibility	Yes	No
Environmental			
	Environmental costs	Yes	No
	Green design	Yes	No
	Environmental management system	Yes	No
	Environmental competencies	Yes	No
	Green R&D	Yes	No
	Pollution control	Yes	No
	Green product	Yes	No
	Resource consumption	Yes	No
	ECO-design requirements for energy using product	Yes	No
	Ozone depleting chemicals	Yes	No
	Waste electrical and electronic equipment	Yes	No
	Recycling	Yes	No
	Green supply chain management	Yes	No
	Innovation	Yes	No
Social			
	The interests and rights of employee	Yes	No
	The rights of stakeholders	Yes	No
	Work safety and labor health	Yes	No
	Information disclosure	Yes	No
	Respect for the policy	Yes	No

Note: please highlight the sub-criteria that are relevant to your firm. If there is any other sub-criterion that is relevant to your work but does not exist in the list, please add it.

5. Illustrative example

The proposed model can be executed for any number of suppliers and there is no limitation. However, here a supposed illustration is utilized to show the application of the proposed model. Suppose *Aco*. is a company which has five candidate suppliers. We want to rank the five suppliers and find the best ones. The suppliers are named supplier A, supplier B, supplier C, supplier D, and supplier E. There are three purchasing managers as decision makers in the company, hereafter referred to them as DMU1, DMU2, and DMU3. To execute the proposed model the deduction process is carried out to obtain the decision makers' inputs. The inputs are applied for fuzzy computations and FIS systems to rank the suppliers.

5.1. Deduction process

To execute this process, two steps must be done:

(1) The list of selection criteria and sub-criteria is shown to the decision makers and ask them to choose only the ones pertinent to their company. The adjustment mechanism is presented in Table 9.
(2) The decision makers' perceptions about the importance weights of the selected criteria and sub-criteria must be deducted. This process is presented in Table 10 and the results of

Table 10
Deduction process for criteria and sub-criteria importance weights.

Criteria	Importance				Sub-criteria	importance			
Economic	WI	MI	SI	EI					
					Profit	WI	MI	SI	EI
					Quality	WI	MI	SI	EI
					Delivery	WI	MI	SI	EI
					Service	WI	MI	SI	EI
Environmental	WI	MI	SI	EI					
					Environmental management system (EMS)	WI	MI	SI	EI
					Environmental competencies (EC)	WI	MI	SI	EI
Social	WI	MI	SI	EI					
					The rights of stakeholders (TRS)	WI	MI	SI	EI
					Work safety and labor health (WS&LH)	WI	MI	SI	EI

Table 11
Decision makers' opinions for criteria weights.

Criteria	Decision makers			The mean value
	DM1	DM2	DM3	
Economic criteria	EI (0.6, 0.8, 1, 1)	EI (0.6, 0.8, 1, 1)	SI (0.4, 0.6, 0.6, 0.8)	(0.534, 0.734, 0.867, 0.934)
Environmental criteria	SI (0.4, 0.6, 0.6, 0.8)	SI (0.4, 0.6, 0.6, 0.8)	EI (0.6, 0.8, 1, 1)	(0.467, 0.667, 0.734, 0.867)
Social criteria	SI (0.4, 0.6, 0.6, 0.8)	SI (0.4, 0.6, 0.6, 0.8)	SI (0.4, 0.6,0. 6, 0.8)	(0.4, 0.6, 0.6, 0.8)

Table 12
Decision makers' opinions for sub-criteria weights.

Sub-criteria	Decision makers			The mean value
	DM1	DM2	DM3	
Profit	EI (0.6, 0.8, 1, 1)	EI (0.6, 0.8, 1, 1)	SI (0.4, 0.6, 0.6, 0.8)	(0.534, 0.734, 0.867, 0.934)
Quality	EI (0.6, 0.8, 1, 1)	SI (0.4, 0.6, 0.6, 0.8)	EI (0.6, 0.8, 1, 1)	(0.534, 0.734, 0.867, 0.934)
Delivery	SI (0.4, 0.6, 0.6, 0.8)	EI (0.6, 0.8, 1, 1)	SI (0.4, 0.6, 0.6, 0.8)	(0.467, 0.667, 0.734, 0.867)
Service	SI (0.4, 0.6, 0.6, 0.8)	MI (0.2, 0.4, 0.4, 0.6)	WI (0, 0, 0.2, 0.4)	(0.3, 0.334, 0.4, 0.6)
EC	SI (0.4, 0.6, 0.6, 0.8)	EI (0.6, 0.8, 1, 1)	SI (0.4, 0.6, 0.6, 0.8)	(0.467, 0.667, 0.734, 0.867)
EMS	EI (0.6, 0.8, 1, 1)	SI (0.4, 0.6, 0.6, 0.8)	WI (0, 0, 0.2, 0.4)	(0.5, 0.7, 0.6, 0.734)
TRS	SI (0.4, 0.6, 0.6, 0.8)	WI (0, 0, 0.2, 0.4)	EI (0.6 0.8, 1, 1)	(0.334, 0.467, 0.6, 0.734)
WS&LH	MI (0.2, 0.4, 0.4, 0.6)	SI (0.4, 0.6, 0.6, 0.8)	MI (0.2, 0.4, 0.4, 0.6)	(0.267, 0.467, 0.467, 0.667)

it are illustrated in Tables 11 and 12. The mean values of fuzzy weightings for criteria and sub-criteria are also calculated. It is noted that the fuzzy numbers mean of environmental and social criteria is considered for weighted criterion of the second inputs in the third stage. It is worthwhile to mention that decision makers' perceptions of the suppliers' performance with respect to the sub-criteria are same and they agreed with each other.

5.2. Exertion and discussion process

The inputs which are obtained from deduction process are passed into the FIS engines to have ranking result. According to Tables 11 and 12, the illustrative example is derived from the proposed model (Fig. 2) as shown in Fig. 8. The illustrative example has been exerted for five suppliers in addition to virtual suppliers as shown in Table 13. The two virtual suppliers are defined as the best supplier (Ideal) and the worst supplier (anti-Ideal).

Finally, the performance score of each supplier is computed and ranking results for all suppliers are shown in Table 14. Except for two virtual suppliers including Ideal and anti-Ideal, the order of five suppliers is B, E, C, D, and A.

To show the structure of rule viewers in the model which present the roadmaps of FIS systems, we choose one of the FIS systems as an example. Fig. 9 illustrates the rule viewer of the related FIS to second stage of economic group for supplier E. Each rule is a row of plots and each column is a variable (Economic1, Economic2, and Economic Strategy) in Fig. 9. The input values can be varied by moving the red line and the FIS system gives the output value. As four membership functions are considered for inputs, the number

Table 13
Candidate supplier's performance.

Sub-criteria	Suppliers						
	A	B	C	D	E	Ideal	Anti-Ideal
Profit	SP	EP	MP	EP	WP	EP	WP
Quality	SP	EP	MP	EP	WP	EP	WP
Delivery	MP	EP	MP	WP	EP	EP	WP
Service	MP	EP	MP	WP	EP	EP	WP
EC	SP	MP	EP	WP	EP	EP	WP
EMS	SP	MP	EP	WP	EP	EP	WP
TRS	MP	MP	EP	WP	EP	EP	WP
WS&LH	MP	MP	EP	WP	EP	EP	WP

of rules will be 16 (4^2) to have the output value. After verifying the rules, it is clear that the output value (Economic Strategy) increases similar to results obtained from the input values (Economic1 and Economic2). The output surface of the related FIS to second stage of economic group for supplier E is shown in Fig. 10. Two input variables (Economic1 and Economic2) and also one output variable (Economic Strategy) vary between 0 and 10. Again, from Fig. 10, it can be seen that as the input values of Economic1 and Economic2 increase, the output value of the Economic Strategy for supplier E increases.

We have proved the robustness of the proposed model in two ways. First, the ranking results of five suppliers are between the Ideal and anti-Ideal ranking as shown in Table 14 and this shows the validity of our model. On the other hand, we applied some difuzzification methods to show validity of the model [15] such as COA, BOA, MOM, SOM, and LOM. As can be seen from Table 14, the obtained ranking results for all of the suppliers are the same in

Table 14
Validation and ranking of the final model.

Suppliers	Ranking results				
	COA	MOM	SOM	LOM	BOM
A	41.9175	33.6549	36.6868	30.9957	42.1126
Ranking of A	(6)	(6)	(6)	(6)	(6)
B	80.6922	77.7295	68.8258	80.5212	80.2445
Ranking of B	(2)	(2)	(2)	(2)	(2)
C	63.6929	55.2646	55.2686	55.4935	60.9659
Ranking of C	(4)	(4)	(4)	(4)	(4)
D	53.4466	53.4466	53.4466	53.4466	53.4466
Ranking of D	(5)	(5)	(5)	(5)	(5)
E	73.5763	68.6889	66.6121	73.8325	72.2455
Ranking of E	(3)	(3)	(3)	(3)	(3)
Ideal	100.0000	97.6695	83.8293	99.8726	99.6644
Ranking of ideal	(1)	(1)	(1)	(1)	(1)
Anti-ideal	11.4863	11.4863	11.4863	11.4863	11.4863
Ranking of anti-ideal	(7)	(7)	(7)	(7)	(7)

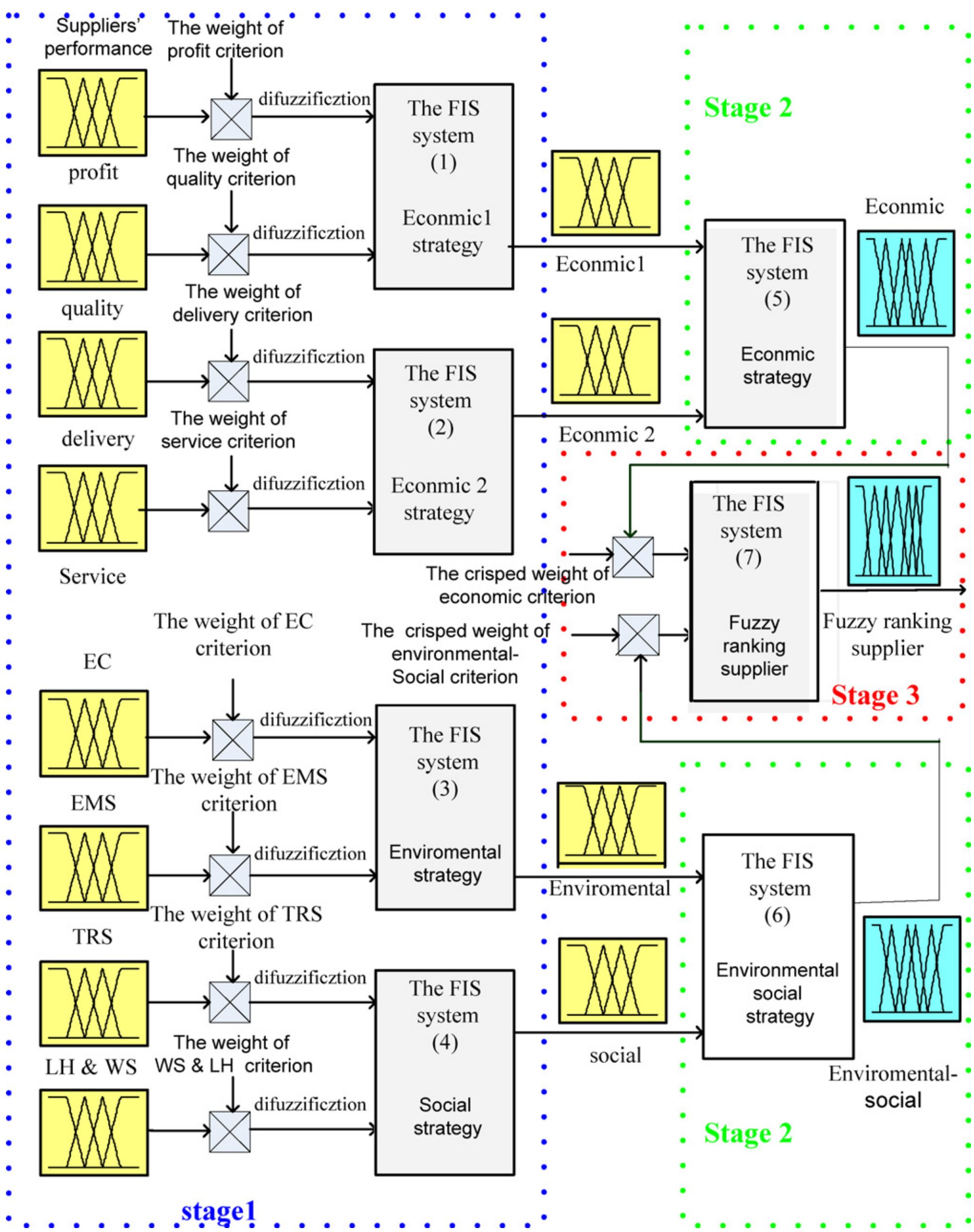

Fig. 8. The ranking model for illustrative example.

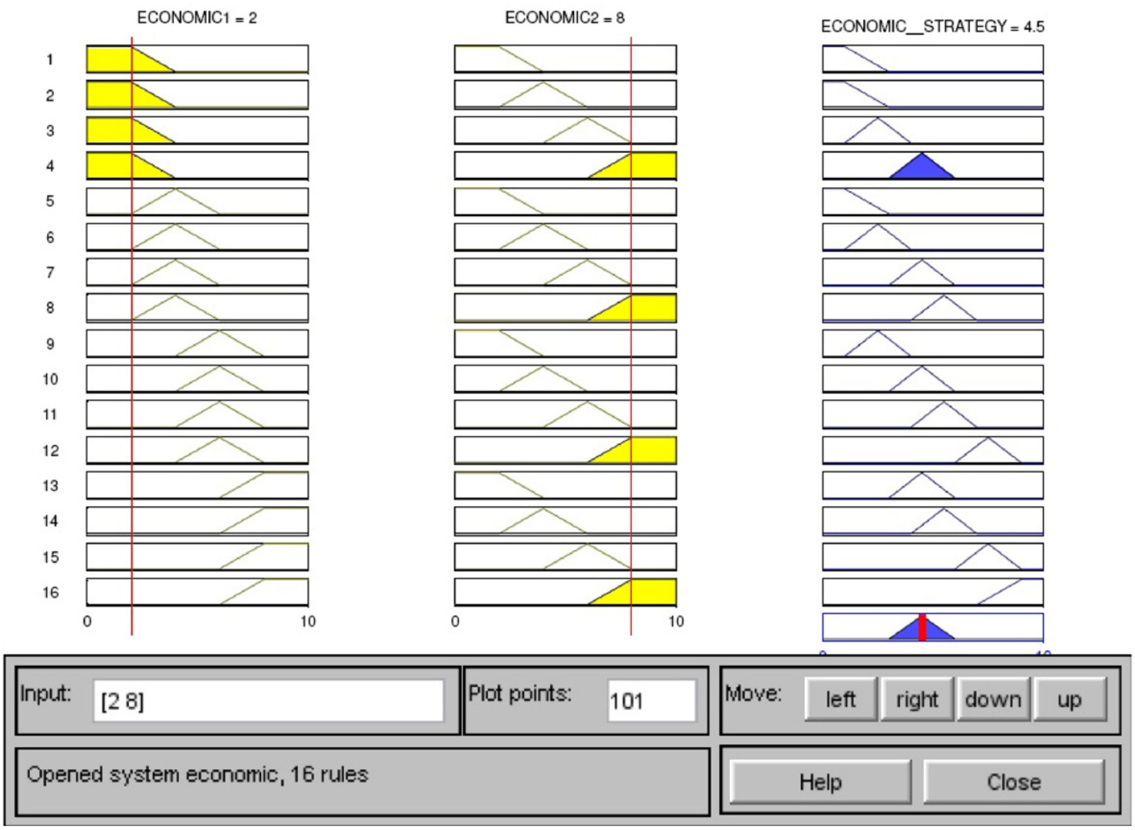

Fig. 9. Rule viewer of the FIS in the case example. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

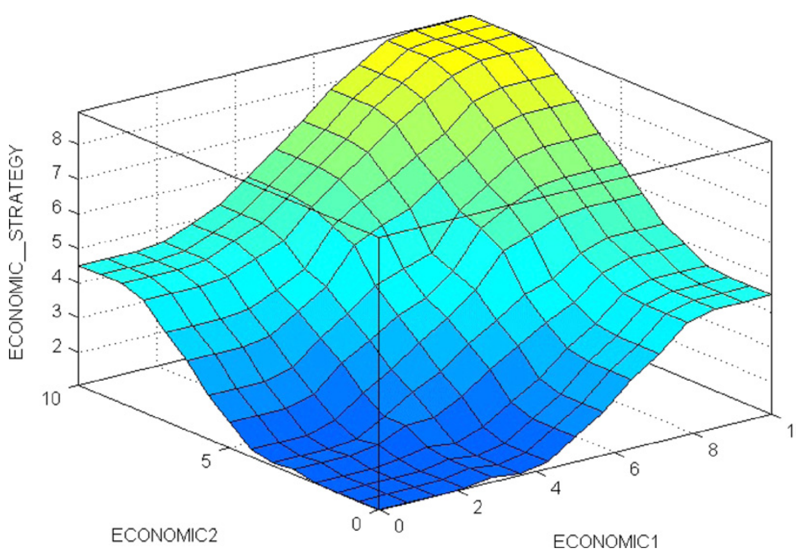

Fig. 10. The output surface of the FIS for the case of example.

different difuzzification methods and this also show the validity of our model.

6. Conclusion

This paper introduces a fuzzy ranking model for supplier selection in SCM. The main contributions of this work are summarized as follows:

(1) Sustainable supplier selection: to date, there are very few studies considering sustainable issue in the supplier selection problem. The selection indicators on the basis of sustainable aspect are gathered through the literature and these are passed to the model.
(2) Very often, the same relative importance of indicators is considered in supplier selection problem. But in practice it needs to be different from one indicator to another. The importance of criteria and sub-criteria weights depends on the decision makers' preference as proposed in the model.
(3) Normally decision makers express their assessments in linguistic term instead of pure numbers. Therefore, the degree of subjectivity is kept in the proposed model. This model paves

the way to mitigate the subjectivity in the decision making problems.

(4) The proposed model can be executed for any number of suppliers and indicators in large companies.

(5) 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.

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