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An Integrated Approach for Sustainable Supplier Selection Using Fuzzy Logic and Fuzzy AHP

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Abstract. Supplier selection is one of the important processes in supply chain management**.** Regarding the emergence of sustainability issues in recent decades, companies have incorporated these issues in conventional supplier selection in order to meet governmental legislations and market demands. These issues have been noticed by various researchers. However, there are limited research activities which considered all aspects of sustainability for supplier selection problem as an integrated assessment. In this paper, an integrated approach of Fuzzy Analytical Hierarchy Process and fuzzy logic has been proposed in order to solve sustainable supplier selection problem. Fuzzy analytical hierarchy process has been used to calculate the weight of sustainable criteria and sub criteria. Then, fuzzy logic was utilized in order to assess the suppliers based on the weights acquired by Fuzzy analytical hierarchy process. Finally, a case study of petroleum industry has been carried out in order to show the validity of proposed approach.

1. Introduction

During recent years, companies have focused on integrating sustainability issues in their supply chain operations to improve their sustainability degree. Supplier selection is one the most important components of supply chain management (SCM) which affects supply chain performance [1]. Sustainable supplier selection problem can be defined as a traditional supplier selection problem in which environmental and social criteria are considered beside the economic criteria to select and measure suppliers' performances [2]. However, increasingly more authors are addressing supplier selection issues in the light of environmental aspects of sustainability [2-4]. Recently researchers are trying to incorporate these criteria in the process of supplier selection. Kuo *et al*. [5] developed a selection model based on neural network and decision making methods considering social sustainability appearing as corporate social responsibility criterion. Punniyamoorthy *et al.* [6] developed a strategic model using structural equation modelling and fuzzy logic in supplier selection. They used safety and environmental concern beside the traditional criteria of supplier selection. Their proposed four-phase methodology combines Analytic Hierarchy Process (AHP) with Quality Function Deployment (QFD). Amindoust *et al.* [7] developed a ranking model based on fuzzy inference system for sustainable supplier selection problem. They have considered environmental and social issues beside the traditional cost criteria. They validated they proposed method through a hypothetical example. According to our review about sustainable supplier selection, there are limited research activities existed in the literature which considered

environmental, social and economic criteria simultaneously to assess the suppliers. Consequently, it is possible to notice that the attention that has been devoted to this topic is still at an early stage. In order to deal with aforementioned issue, a weighted fuzzy approach has been proposed in order to solve sustainable supplier selection problem. In order to weigh all selected criteria and sub criteria fuzzy Analytic Hierarchy Process (FAHP) has been utilized. Fuzzy logic has been utilized to assess the suppliers based on acquired weight. It is worth to mention that this approach is capable to handle inherent subjectivity and vagueness of the expert perception with an exact number. Also, this approach has ability to evaluate qualitative and quantitative data simultaneously. The rest of this paper is organized as follows: Section 2 presents the proposed approach. Section 3 illustrates a case study. Section 4 draws conclusions and discussion.

2. Methodology

In this research activity, we tried to modify and apply one of our recently published methodologies in the field of sustainable supplier selection. Readers can refer to Ghadimi *et al.* [8] for a thorough and comprehensive explanation of the original sustainability assessment methodology, namely Weighted Fuzzy Assessment Method (WFAM). The research methodology of the current paper is based on the previous published paper but with some modifications. Steps of the modified methodology are presented in this section and it will be inclusively elucidated through a case study in petroleum industry. The steps of the modified WFAM for sustainable supplier selection are presented as follows:

- Step 1: selecting a product and identifying potential suppliers which provide the product
- Step 2: selecting appropriate elements and sub elements and their influencing factor
- Step 3: weighting the selected elements and sub elements
- Step 4: data collection
- Step 5: fuzzy evaluation
- Step 6: calculating supplier sustainability index regarding the product.
- Step 7: ranking suppliers based on obtained indices in step 6

3. Case study and results

In order to show the validity and usefulness of proposed and modified approach, a case study of a petroleum industry has been conducted. PAKABPEY Company is a technical and engineering company in the field of gas and oil pipeline construction located in Iran. Due to an outsourcing policy, some parts and components needed in their projects are provided by various suppliers. Regarding this, supplier selection has been identified as one of the crucial issues in the company. In order to meet the recently acted governmental legislation and also market pressure on sustainability issues, the company managers decided to incorporate sustainability issues in their activities and processes. To solve the problem of supplier selection and to meet sustainability regulations, modified WFAM was proposed to the CEOs of the company aimed to solve the aforementioned issues. As an illustration of the efficiency of the proposed method, a kind of valve which is used in most of the company's projects has been selected as the component to be assessed. There are six suppliers which provide this particular kind of valve for the company (step 1). Managers of the company wanted to rank and select the best suppliers based on sustainable criteria.

- Step 2: based on literature review and several discussions with CEOs of the company, Figure 1 shows the selected elements and sub elements appropriate for this research.

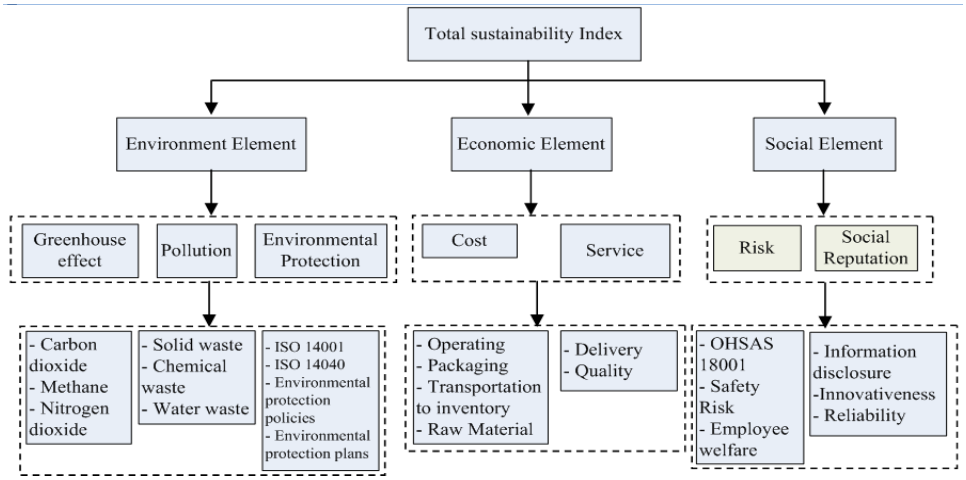

Figure 1. Selected elements and sub elements

- Step 3: in this step, Chang's [9] FAHP approach was utilized in order to weight sustainable elements and sub elements. It is one of the Linear Weighting Models which works based on pairwise comparisons of human judgments. Table 1 shows the triangular fuzzy scale and linguistic variables.

Table 1. Fuzzy triangular number

Triangular fuzzy scale	*Linguistic scale*
(1,1,1)	Just equal
(1/2,1,3/2)	Equally important
(1,3/2,2)	More important
(3/2,2,5/2)	Strongly more important
(2,5/2,3)	Very strongly more important
(5/2,3,7/2)	Absolutely more important

Owing to the limited space, only the final results of the elements and sub elements weights were shown in Table 2

Table 2 Final results of the elements and sub elements weights

Elements	Weight	Sub elements	Weight
Environment	0.38	Greenhouse effect	0.36
		Pollution	0.29
		Environmental protection	0.34
Economic	0.34	Cost	0.59
		Service	0.41
Social	0.28	Risk	0.41
		Social reputation	0.59

- Step 4: According to selected influencing factors for each sub element presented in Figure 1, all the relevant qualitative and quantitative data were gathered from company's ISO documentations, environmental regulation documentations and discussions with CEOs of the company.

- Step 5: this step acts as the main part of the methodology. All crisp data that are gathered in step 5 are transformed into grades of membership for linguistic terms of fuzzy sets. After determining the grades of membership, the target range or reference value is to be set for each input variable. This value indicates the minimum and maximum values of the input variable. The selection of reference value is usually based on the national and local policy or may be set by the organization or manufacturer to meet their objectives. Constructing the input variables' membership function is based on these reference values. Then, the linguistic value of zero to one (0 to1) is selected as a reference value for constructing the output membership function. After constructing the membership functions for input and output variables, fuzzy rule base system will be constructed based on the decision makers' knowledge inside the organization. These decision makers can be a group of the company owner, chief executive officer, general manager, system manager. Fuzzy inference system comes after constructing the rules. In this part, result of each rule is generated as fuzzified inputs and goes through the inference system. The output of fuzzy inference system is the input for defuzzification process. In order to perform the fuzzy evaluation MATLAB software has been utilized. Ultimately, scores of all sub elements will be calculated. The score of each sustainability element for each supplier calculated by the following equation

$$I_j = \sum_i w_{ij} I_{ij} \quad (1)$$

Where I_j equals to score of j^{th} sustainability element, w_{ij} denotes weight of i^{th} sub sustainability element of j^{th} sustainability element, I_{ij} represents score of i^{th} sub sustainability element of j^{th} sustainability element, i is index of sub sustainability criteria and j shows index of sustainability criteria. Due to limitation in space, results tables for element and sub element scores are skipped and the final sustainability indices for each supplier are presented in step 6

- Step 6: After that all three sub sustainability scores were obtained, the total sustainability index for the valve manufactured by each supplier was calculated by using Equation (2)

$$I_{sustainability} = \sum_j w_j I_j \quad (2)$$

Where, I_j is score of j^{th} sustainability element, w_j equals to weight of j^{th} sustainability element and $I_{sustainability}$ presents total sustainability index for each supplier. Table 3 illustrates final sustainability index of all valves manufactured by 6 suppliers.

Table 3 Total sustainability index

Supplier No.	Total sustainability index
1	0.56
2	0.47
3	0.43
4	0.59
5	0.31
6	0.45

- Step 7: according to Table 3, supplier number 4 is ranked as the first preferred supplier for the company. Accordingly, suppliers 1, 2, 6 and 3 are ranked as the second, third, fourth and fifth

preferred suppliers. Finally, supplier number 5 is placed as the least preferred one for the company. It is worth to mention that the final score scale is between zero and one.

4. Discussions and conclusion

In this paper a weighted fuzzy approach integrated with FAHP and fuzzy logic has been proposed in order to assess and select the suppliers based on sustainable elements and sub elements. This comprehensive approach can be used in any company. FAHP was utilized in order to determine the weight of sustainable elements and sub elements to achieve more precise results. Fuzzy logic has been used in order to assess the suppliers regarding sustainable issues. A case study of petroleum industry has been conducted to show the validity and usefulness of the proposed method. In the presented case study, six suppliers have been assessed by the proposed method and their scores have been determined regarding sustainability issues. Based on company's policy, the acceptance level of sustainability to work with suppliers is 0.5 or above and as it is shown in Table 3; only supplier 4 was able to meet the company's requirement. Based on each supplier's sustainability elements and sub elements scores, the company informed them to improve their weak point resulting in a better sustainability level. This research tried to cover all aspects of sustainability (social, environment and economic) for supplier selection problem which were rarely considered in previous research activities. For the future works, there are opportunities to develop a comprehensive model in order to assess whole supply chain in terms of sustainability.

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