Expert Systems with Applications 39 (2012) 8182–8192

Contents lists available at SciVerse ScienceDirect

Expert Systems with Applications

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

Supplier selection using fuzzy AHP and fuzzy multi-objective linear programming for developing low carbon supply chain

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ARTICLE INFO

Keywords:
Supplier selection
Fuzzy multi-objective linear programming
Fuzzy AHP
Carbon emission
Green house gas
Textile supply chain

ABSTRACT

Environmental sustainability of a supply chain depends on the purchasing strategy of the supply chain members. Most of the earlier models have focused on cost, quality, lead time, etc. issues but not given enough importance to carbon emission for supplier evaluation. Recently, there is a growing pressure on supply chain members for reducing the carbon emission of their supply chain. This study presents an integrated approach for selecting the appropriate supplier in the supply chain, addressing the carbon emission issue, using fuzzy-AHP and fuzzy multi-objective linear programming. Fuzzy AHP (FAHP) is applied first for analyzing the weights of the multiple factors. The considered factors are cost, quality rejection percentage, late delivery percentage, green house gas emission and demand. These weights of the multiple factors are used in fuzzy multi-objective linear programming for supplier selection and quota allocation. An illustration with a data set from a realistic situation is presented to demonstrate the effectiveness of the proposed model. The proposed approach can handle realistic situation when there is information vagueness related to inputs.

1. Introduction

Supplier selection plays an important role to make a supply chain green (Rao, 2002). A positive relation between green supplier selection and green supply chain implementation has been observed in a study of Seuring and Müller (2008). Many researchers have addressed supplier selection issue in the green supply chain from the perspectives of environmental sustainability (Bai & Sarkis, 2010; Enarsson, 1998; Handfield, Walton, Sroufe, & Melnyk, 2002; Humphreys, Wong, & Chen, 2003a; Humphreys, McIvor, & Chan, 2003b; Hsu & Hu, 2009; Lee, Kang, Hsu, & Hung, 2009a; Noci, 1997; Rao, 2005; Walton, Handfield, & Melnyk, 1998). However, very few studies have addressed the carbon emission and the related issues for supplier evaluation. Recently, Lash and Wellington (2007) have discussed the impacts of climate change over the business operations. They suggested that companies have to handle climate change risk properly for gaining the competitive advantage. Some leading companies have already started working to develop next generation carbon emissions management for their supply chain to survive in the business.

An interesting survey conducted by a consulting company (Trucost, 2009) showed that only 19 percent of the total green house gas (GHG) emission in the supply chain is generated from direct operational activities of the company and rest of the 81 percent emission is generated from other indirect activities such as, emission from first tier supplier, electricity supplier and emission from other supply chain members. In this scenario, supplier selection plays an important role to minimize carbon emission in supply chain. According to a survey report CDP (2010), more than half of the participants said that in the future they would cease business with the suppliers, if they do not manage their carbon emissions. Due to increase consciousness about climate change, companies are imposing pressure on their suppliers to manage their GHG emissions as one of the conditions for doing business with them. Supplier propensity to minimize green house gas emission is becoming one of the criteria for supplier selection (CDP, 2010). Therefore, suppliers need to make a thorough assessment of their current capabilities in terms of carbon emission management and set appropriate targets for further reduction of their emissions. Wal–Mart in US can be taken as an example of a global supply chain which has been trying to achieve environmental sustainability. Its aim is to become a world leader in environmental sustainability. To achieve this, it has suggested the suppliers to reduce their energy consumption for processing of products (Wal–Mart, 2010). Suppliers who measure and publish their own emission are strategically more preferable than others because they help the buyers to manage their carbon emission. However, only a little number of supply chain members has extensive knowledge about

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doi:10.1016/j.eswa.2012.01.149

the low-carbon material procurement for their supply chain. This paper deals with the low-carbon material procurement and carbon management for supplier selection. The relevant literature on green supplier selection is discussed below.

Noci (1997) proposed a green vendor rating framework for the assessment of suppliers' environmental performance. Green competence, green image, life cycle cost, and environmental efficiency were the important considerations for supplier evaluation. Humphreys et al. (2003b) developed a knowledge-based system to evaluate suppliers' environmental performance. Cost, management competencies, green image, green design, environmental management system, and environmental competencies were considered as the evaluation factors in the model. Lu, Wu, and Kuo (2007) proposed an analytic hierarchy process (AHP) and fuzzy logic based model for Green supplier evaluation. Further, analytic network process (ANP) based framework was suggested by Hsu and Hu (2009) to construct an assessment framework of the supplier for Taiwanese Electronics Company. Five criteria such as procurement management, R& D management, process management, incoming quality control, and management system were considered in the model. Lee et al. (2009a) suggested an integrated model to select green suppliers for high-tech industry considering six factors. The considered factors were quality, technology capability, pollution control, environmental management, green product, and green competencies.

Bai and Sarkis (2010) developed a green supplier evaluation model considering economic, environmental, and social issues. Rough set theory was used to deal with the information vagueness. Kuo, Wang, and Tien (2010) developed a green supplier selection model applying artificial neural network (ANN) and two multi-attribute decision analysis (MADA) methods that consists of data envelopment analysis (DEA) and analytic network process (ANP). Awasthi, Chauhan, and Goyal (2010) developed a fuzzy multi-criteria model for evaluating environmental performance of suppliers. Fuzzy TOPSIS was applied in this model. Buyukozkan and Cifci (2011) proposed fuzzy multi-criteria decision framework for sustainable supplier selection considering incomplete information. Fuzzy analytic network process within the multi-person decision-making scheme under incomplete preference relations was used in their model.

Earlier studies have limited focus on the carbon management issue for supplier evaluation. Earlier studies have mostly focused on multi-criteria decision making approaches such as AHP, fuzzy AHP, fuzzy ANP, TOPSIS, Rough set theory etc. for supplier evaluation. These types of the models are less robust because quantification of order quantity to a particular supplier is not possible. To solve this drawback a hybrid model using fuzzy AHP, fuzzy linear programming is proposed for selection of supplier. In few of these studies, product carbon footprint is taken as one of the criteria of supplier selection. Product carbon footprint can be measured by using Publicly Available Specification (PAS) 2050 (2008) standard developed by British Standard Institution. The buyer can fix certain amount of carbon emission cap, which acts as a constraint in the decision model. The present article is organized as follows. Section 2 explores the literature related to supplier selection methodologies. Section 3 discusses the fuzzy set theory. In Section 4, multi-objective mathematical model is shown. Section 5 represents case study, related results and discussions. Section 6 presents the conclusions.

2. Supplier selection problem

Business environment is continuously changing due to diversification of customer demands. This diversification of demand leads to increase in operating cost and followed by the decrease in profit. Therefore, purchasing decision from a particular supplier is a crucial strategic decision to ensure profitability and long term survival of the company. Most of the companies are trying to reduce their operating costs while satisfying customer needs by increasing their core competencies and outsourcing other functions (Lee, 2009). A careful assessment is needed to select right supplier who can maintain a continuous replacement of product in proper time. Most of the times supplier strength and weakness are varied, which leads to complex decision making of supplier selection. Many researches in supplier selection area used mathematical programming.

Ghodsypour and O'Brien (1998) solved a supplier selection problem using a hybrid approach involving AHP and linear programming. A mixed integer non-linear programming model considering multiple sourcing opportunities was solved by Ghodsypour and O'Brien (2001). Total cost of logistics with budget constraint, quality, service, etc. were considered in their model. Karpak, Kumcu, and Kasuganti (1999) proposed a goal programming model that minimized costs and maximized delivery reliability and quality for supplier selection and quota allocation.

Gao and Tang (2003) formulated a multi-objective linear programming model to purchase raw materials for a large-scale steel plant in China. Kumar, Vrat, and Shankar (2004) developed a fuzzy goal programming approach for vendor selection considering the effect of information uncertainty in the decision making. Similar type of problem was solved by Amid, Ghodsypour, and O'Brien (2006). They used fuzzy multi objective linear programming to determine the order quantity from many suppliers by considering the criteria of lowest cost and highest quality. Hong, Park, Jang, and Rho (2005) proposed a mathematical model for supplier selection considering the change in suppliers' supply capabilities and customers' needs over a period of time. This model optimized the revenue and customer needs simultaneously.

There are numerous studies, which applied the dual methodologies for supplier selection.

Weber, Current, and Desai (2000) formulated a combined multi objective programming (MOP) and the DEA based framework for supplier selection. They applied MOP to calculate the order quantity and used DEA for suppliers' efficiency evaluation. Further, Cebi and Bayraktar (2003) solved a supplier order allocation problem considering the quantitative as well as qualitative criteria. Wang, Huang, and Dismukes (2004) applied AHP method to choose a strategy from agile/lean supply chain. Further, they used pre-emptive goal programming (PGP) to obtain the optimal order quantity from the suppliers.

Chan and Kumar (2007) developed a fuzzy extended analytic hierarchy process (FEAHP) model for global supplier selection. Further, Kumar, Shankar, and Yadav (2008) solved a supplier selection problem using AHP and fuzzy linear programming. Ku, Chang, and Ho (2010) and Lee, Kang, Hsu, and Hung (2009b) used fuzzy AHP and fuzzy goal for supplier selection. In their model, fuzzy AHP was applied first to calculate the weights of the criteria. The criteria's weights were subsequently used in fuzzy goal programming to select the supplier. Amin, Razmi, and Zhang (2011) developed a supplier selection model using fuzzy SWOT analysis and fuzzy linear programming. Yücel and Güneri (2010) proposed a weighted additive fuzzy programming approach for supplier selection. They used TOPSIS and fuzzy linear programming in their framework.

3. Fuzzy set theory

Decision making is very difficult for vague and uncertain environment. This vagueness and uncertainty can be handled by using fuzzy set theory, which was proposed by Zadeh (1965). Fuzziness and vagueness are normal characteristics of a decision making problem. This fuzziness and vagueness can be managed by increasing robustness of the model (Yu, 2002). If we do not consider the