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Performance evaluation of green supply chain management using integrated fuzzy multi-criteria decision making techniques

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ABSTRACT

Green Supply Chain Management (GSCM) predicates minimizing or preferably eliminating negative effects of supply chain operations on the environment. Companies have to enhance their capability on GSCM activities based on not only emerging environmental regulations but also enthusiastic politics of the companies about environmental practices. GSCM requires multi-dimensional approaches, thus multi-criteria decision making (MCDM) techniques should be implemented while evaluating GSCM performance of companies. Moreover, fuzzy group decision making methods should be implemented in order to seek solutions for vague and complex multi-attribute problems in fuzzy environment. In this study, a model based on integrated fuzzy MCDM methods is proposed for evaluating GSCM performance of companies in terms of green design, green purchasing, green transformation, green logistics and reverse logistics. The cause and effect interrelationship amongst GSCM dimensions is figured out using fuzzy DEMATEL method. Then, based on this interrelationship, fuzzy ANP method is implemented for calculating the weights of the related criteria. Finally, fuzzy TOPSIS method is applied by using the weights obtained from fuzzy ANP method, for evaluating and ranking the GSCM performance of alternative companies.

1. Introduction

Green Supply Chain Management (GSCM) has been defined as "integrating environmental thinking into supply-chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life" (Srivastava, 2007). In the literature there are many other definitions for GSCM. Ahi and Searcy (2013) have identified 22 definitions in their comparative literature analysis.

Companies need to evaluate effectiveness of their GSCM implementations to improve green performance of the supply chain. United States Environmental Protection Agency (US EPA, 2000) published a practical guide namely "Lean and Green Supply Chain" which concerns reducing costs and improving environmental performance for Materials and Supply Chain Managers. This guidebook gives the best practices of leading US companies who have saved while reducing or eliminating significant environmental impacts. On the other hand, Fahimnia, Sarkis, and Eshragh (2015) also presented tactical supply chain planning model for investigating trade-offs between cost and environmental degradation. They found that (1) not all lean interventions at the tactical supply chain planning level result in green benefits, and (2) a flexible supply chain is the greenest and most efficient alternative when compared to strictly lean and centralized situations.

Companies require to evaluate the effectiveness of their GSCM implementations which enables them to improve their green skills. Although there are studies in the literature on green supplier selection process (Büyüközkan & Cifci, 2012; Tseng & Chiu, 2013), there is a need for developing models for evaluating overall GSCM performance of any company. Since GSCM requires multi-dimensional approaches, multi-criteria decision making (MCDM) techniques should be implemented while evaluating GSCM performance of companies. Moreover, fuzzy group decision making methods should be implemented in order to seek solutions for vague and complex multi-attribute problems in fuzzy environment.

In this study such a model is proposed based on integrated fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS methods which is novel on assessing overall GSCM performance of companies. First of all, dimensions and involved criteria that effect GSCM performance are determined investigating the literature and by consulting both academic and industrial experts. Then, fuzzy DEMATEL

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method is used to obtain interrelationship amongst the dimensions, which is required during ANP method. Fuzzy DEMATEL method is a useful tool to gather group ideas and analyze the cause and effect relationship of complex problems in fuzzy environments (Lin & Wu, 2004, 2008). Based on this interrelationship network, fuzzy ANP method is conducted in order to calculate the weights of criteria associated with the dimensions. ANP method is preferred to overcome the problem of interrelation among criteria or factors. And finally, fuzzy TOPSIS method is implemented for evaluating and ranking alternative companies in respect with their ability on GSCM activities. TOPSIS has a systematic procedure with simple computation process, and represents a reasonable outcome.

During the fuzzy DEMATEL and fuzzy ANP implementation four academic and four industrial experts are consulted in order to figure out interrelationship amongst the GSCM dimensions and then calculating the weights of associated criteria. Four alternative companies are investigated by two academic experts for evaluating GSCM activities of the companies in respect of predefined criteria. The companies are small and medium sized enterprises in the sector of machine manufacturing which are located in Sakarya city of Turkey.

2. Green supply chain management

GSCM implies minimizing and preferably eliminating the negative effects of the supply chain on the environment (Andic, Yurt, & Baltacıoglu, 2012). Kainuma and Tawara (2006) proposed the multiple attribute utility theory method and evaluated the performance of a supply chain in both managerial and environmental viewpoints. GSCM practices are in relation with technological innovation too. GSCM practices enhance firms' technological innovation whilst green activities improve the environment and produce a positive effect on the manufacturing establishment (Lee, Ooi, Chong, & Seow, 2014).

Multi-criteria decision making methods offer suitable implementation tools for GSCM domain. Sarkis (2003) presented a strategic decision framework by using the analytical network process (ANP) which focused on the components and elements of GSCM. Chen, Shih, Shyur, and Wu (2012) used ANP for solving complex strategy selection problems of GSCM and evaluating the most important activities of business functions. Diabat and Govindan (2011) developed a model of the drivers which affects the implementation of GSCM using an Interpretive Structural Modeling (ISM) framework. Shang, Lu, and Li (2010) investigated crucial GSCM capability dimensions and firm performance on the basis of a factor analysis and identified six dimensions namely green manufacturing and packaging, green marketing, environmental participation, green suppliers, green stock, and green ecodesign. On the other hand, Mathiyazhagan, Govindan, NoorulHaq, and Geng (2013) analyzed the barriers for the implementation of GSCM concept and identified twenty-six barriers.

One of the most important issues in GSCM is evaluation and selection process of green suppliers. Shen, Olfat, Govindan, Khodaverdi, and Diabat (2013) proposed a fuzzy TOPSIS approach for green suppliers' evaluation by examining GSCM. Büyüközkan and Cifci (2012) developed an integrated methodology and applied in a real case study in fuzzy environment by using DEMATEL, ANP and TOPSIS methods for green supplier evaluation. Tseng and Chiu (2013) used grey relational analysis for ranking alternative suppliers by identifying and evaluating the appropriate environmental and non-environmental GSCM criteria for a case firm.

Lin (2013) claimed that economic and environmental performance of proactive firms would be improved as they adopt GSCM. He examined the influential factors among eight criteria using the fuzzy set theory and DEMATEL method. Mathiyazhagan, Diabat, Al-Refaie, and Xu (2015) aimed to investigate the pressures for GSCM adoption and to rank the pressures based on experts' opinion through AHP technique in the mining and mineral industry context.

Barari, Agarwal, Zhang, Mahanty, and Tiwari (2012) aimed to provide integrated and holistic conceptual framework by using evolutionary game approach with the objective of profit maximization of the entities of the supply chain. Jamshidi, Fatemi Ghomi, and Karimi (2012) utilized a memetic algorithm in combination with the Taguchi method to solve a multi-objective optimization problem for green supply chain considering cost and environmental effects. Wang, Lai, and Shi (2011) interested in decisions during design phase for environmental investments and proposed a multi-objective optimization model which represents the tradeoff between the total cost and the environment influence.

The approach proposed by Yuce and Mastrocinque (2015) which combines the Fuzzy Analytic Hierarchy Process (AHP) and the Bees Algorithm in order to solve the supplier selection problem could be adopted for green suppliers by amending the criteria convenient with GSCM. Mastrocinque, Yuce, Lambiase, and Packianather (2013) and Yuce, Mastrocinque, Lambiase, Packianather, and Pham (2014) proposed the Bees Algorithm for multi-objective supply chain optimization which also be considered for applying in GSCM domain.

Our study contributes to the literature by providing GSCM dimensions and related criteria in a new perspective by proposing a model based on integrated fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS methods which is novel on assessing overall GSCM performance of companies.

3. Proposed approach

The main steps of GSCM evaluation approach are illustrated in Fig. 1. The initial step of the methodology is identifying the evaluation dimensions and related criteria of GSCM. Then Fuzzy DEMATEL method is used for revealing interactions among the dimensions. On the basis of the main interactions, Fuzzy ANP method is implemented in order to calculate the local weights of each criterion. At the following step, the case firms are investigated in terms of the predefined GSCM criteria for obtaining evaluation inputs for the Fuzzy TOPSIS method. This final method gives the ranking of the case firms regarding their GSCM activities.

3.1. Main drivers of GSCM

According to the literature survey of GSCM and the experts' opinions, five main dimensions are identified namely Green Design, Green Purchasing, Green Transformation, Green Logistics and Reverse Logistics. Each dimension has its own criteria which are used while evaluating the firms in more detail. All the dimensions and their corresponding criteria are shown in Fig. 2.

Green Design is considering the environmental issues during the design phase, such as product features, material selection, manufacturing operations, and energy usage. The consideration also involves life-cycle design, eco-design, and design-for-environment (Chen et al., 2012). *Green Purchasing* is procurement of recycled, reusable or recyclable materials (Min & Galle, 2001). *Green Transformation* consists of green manufacturing (Shang et al., 2010), *green packaging* (Shang et al., 2010) *and green stock politics* (Shang et al., 2010) implementations while transforming raw-materials into final products. *Green Logistics* (Chen et al., 2012) is minimizing the routes, using less polluting vehicles, etc. *Reverse Logistics* (Ahi & Searcy, 2013) consists of the stages after a product has been used. It is about the activities performed in terms of reusing the materials of the products.