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Technical, environmental and eco-efficiency measurement for supplier selection: An extension and application of data envelopment analysis

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ABSTRACT

With increased global awareness of environmental sustainability, green supply chain management (GSCM) has received considerable attention in the literature over the decade. Green supplier selection and assessment in GSCM is one of the most significant and complex challenges for supply chain managers. This paper provides a new model and approach for green supplier selections by decomposing their efficiency indicators into technical, environmental and eco-efficiency scores. We show that the models in the literature are computationally intensive and are not able to measure eco-efficiency properly. Instead of running three different models, linear goal programming is used to integrate technical, environmental and eco-efficiency objectives into a multiple objective linear programming (MOLP) data envelopment analysis (DEA) model. Therefore, the model proposed in this paper is less computationally intensive than the models in the literature. The new model provides a more valid eco-efficiency indicator of decision-making units (DMUs) by utilizing a better combination of the technical and environmental efficiency objectives compared to the conventional models. Unlike the conventional models, the new model identifies DMUs as being eco-efficient if, and only if, they are both technically and environmentally efficient. We also discuss the non-dominated weights as the solutions of the MOLP model and use them to construct technical, environmental and eco cross-efficiency matrices of the DMUs. In order to illustrate the effectiveness and applicability of the proposed model, we present the real world business case of the Hyundai Steel Company and its suppliers.

1. Introduction

In recent years, sustainability or sustainable development has become a lexicon for many purchasing and supply chain managers. In particular, environmental and social standards such as the ISO 14000 and the SA 8000 are in common practice in the purchasing and supply chain contracts between buyers and suppliers (Lee and Kim, 2009). The concept of sustainable development has evolved during the last decade, and one of the most accepted definitions of sustainable development is "a development that meets the needs of the present without compromising the ability of the future generation to meet their own needs" (WCDE, 1987). Some scholars from the discipline of supply chain management have attempted to explore sustainable development within supply chain management, and they have often referred to sustainable supply chain management (SSCM). For example, Seuring and Müller (2008) define SSCM as "the management of material, information and capital flows, as well as cooperation among companies along the supply chain, while taking into account goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account (p. 1700)". Seuring and Müller (2008) showed that social factors under SSCM are dominated by environmental issues among academics and also in industrial practice. They continue to argue that economic and environmental aspects of sustainability are dominant, and this is called 'green supply chain management (GSCM)'.

The successful implementation of sustainable or green supply chain management depends significantly on the selection of the 'right' suppliers from the perspective of sustainability (Seuring and Müller, 2008; Lee and Wu, 2014). Supplier selection is the process of selecting the 'right' strategic suppliers to the focal company to increase competitive advantage (Baskaran et al., 2012; Bai and Sarkis, 2010; Lee and Kim, 2011). Seuring and Müller (2008) found a positive relationship between selection of green suppliers and green supply chain practices and outcomes. It is the difficult job of the purchasing or supply chain managers to control the trade-off between the cost of supplied material, as representative of economic sustainability, and the social and environmental sustainability of suppliers. If a supplier is

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not socially or environmentally sustainable, buying the supplied materials at the lowest price may risk reputational damage, resulting in negative financial performance for the focal company (Goebel et al., 2012; Lee and Kim, 2009).

Supplier selection is a multiple criteria decision-making (MCDM) issue. It is a complex assessment to make since it is generally necessary to take into consideration various criteria in making the final decision. In the extant literature, many methodologies for supplier selections have been developed and include analytic hierarchy process (AHP), analytical network process (ANP), case-based reasoning (CBR), artificial neural network (ANN), and data envelopment analysis (DEA), among the most well-known methodologies (Mahdiloo et al., 2014). Some academics have studied innovative applications of the existing methodological tools while others have focused on improvements in those tools. In the next section, we provide a brief review of the tools and approaches used for supplier selection.

1.1. Supplier selection evaluation in green and sustainable supply chain management

Handfield et al. (2002) proposed the use of the AHP to assist managers to make environmentally friendly purchasing decisions. They discussed how the purchasing decision in a GSCM is not only based on the cost, quality and delivery factors, but also on the environmental performance of the suppliers. Wu et al. (2007) used AHP and fuzzy logic in their assessment of environmentally aware suppliers. They considered the environmental impact of products supplied by suppliers during the life cycle of these products. Hsu and Hu (2009) used ANP to evaluate suppliers in GSCM. They conducted their research in two stages: first, recognizing suppliers' evaluation criteria and then developing an ANP-based framework for the evaluation and selection of suppliers. Lee et al. (2009) proposed a green supplier selection model for high-tech industries using the Delphi method and fuzzy AHP. Tuzkaya et al. (2009) modeled the environmental performance evaluation of suppliers in fuzzy ANP and fuzzy preference ranking organization method for enrichment evaluation (PROMETHEE) methodology. Sarkis et al. (2012) used both AHP and ANP in the selection of sustainable sub-contractors. All three dimensions of the triple bottom line (i.e. economic, environmental, and social dimensions) are used in the developed framework. Both tools are MCDM techniques and use pairwise comparisons to the relative importance of different criteria and ranking of alternatives. ANP differs from AHP since it allows for interdependencies among attributes. Shen et al. (2013) used the fuzzy TOPSIS model to evaluate the performance of suppliers in GSCM. Vague and subjective human judgments and preferences are changed to crisp numbers by the use of the fuzzy set theory. TOPSIS, as the decision-making tool, is used to integrate experts' ideas regarding relative weight of factors and suppliers' performance.

Kuo et al. (2010) selected green suppliers for a camera manufacturer using a combination of DEA, ANN and ANP. This hybrid method is called ANN–MADA. They showed that ANN–MADA outperforms the other two hybrid methods tested in their study, i.e. ANN–DEA and ANP–DEA. They also demonstrated that their proposed approach has more discriminatory power than DEA. Decision makers' preferences are also incorporated into the model as additional constraints. Kumar et al. (2014) developed green DEA (GDEA) to evaluate suppliers in the steel industry. They called this ‘a comprehensive DEA model’ because it has three features: (i) the feasible region of the final solution of factors' weights is limited by some weight restriction constraints, (ii) the carbon footprint is modeled as a dual-role factor, rather than considering it as a strict input or undesirable output, therefore, the behavior of this factor as an input or output factor is determined by the weighting mechanism of the developed GDEA model, and (iii) the model accounts for non-homogeneity of suppliers when some of the suppliers do not use the same type of inputs to supply the same type of outputs. The non-homogeneity of the suppliers lacking some of the input or output factors is handled by considering the corresponding data as being missing values.

1.2. DEA and modeling undesirable outputs

For the analysis of the dataset of this research, DEA is chosen as an analytical tool and this is because the objectivity arising from the DEA weighting system makes it distinguishable from others (Wong and Wong, 2008; Lee and Farzipoor Saen, 2012).

One of the steps to be taken before running each type of DEA model is to recognize inputs and outputs. In the classical forms of DEA models, the factors incorporated into the models are separated as inputs and outputs while outputs with larger values represent better performance. However, this is not the case for all the outputs produced in the production process. In an evaluation of the efficiency of production units, as a by-product there might be some undesirable (bad) outputs which necessitate careful modeling. The suppliers' carbon emissions are an example of this.

Different ways of modeling undesirable outputs have been developed and are discussed in the literature (e.g. Färe et al., 1989; Seiford and Zhu, 2002; Färe and Grosskopf, 2004; Korhonen and Luptacik, 2004; Kuosmanen and Kortelainen, 2005; Zhang et al., 2008; Yang and Pollitt, 2009). Many studies discussed how to consider inputs, desirable and undesirable outputs simultaneously in the efficiency evaluations of decision-making units (DMUs). Among the studies, Korhonen and Luptacik (2004) and Zhang et al. (2008) provided useful insights into the efficiency of DMUs by obtaining information about the technical, environmental and eco-efficiency scores. They proposed that technical efficiency be measured as the ratio of desirable outputs to inputs, and environmental efficiency as the ratio of desirable outputs to undesirable outputs. They called the combination of these two measures (i.e. technical and environmental efficiencies, eco-efficiency), and they introduced different ways of measuring it.[1] In one of their suggested methods, eco-efficiency is measured by treating undesirable outputs as inputs. We call this approach ‘the three-step methodology’ to measure technical, environmental and eco-efficiency scores.

1.3. Gaps in the literature

Research gaps are found both in the supplier selection and in the DEA literature. The three-step methodology gives useful insights into decomposing the efficiency of DMUs from different aspects. However, we believe that there still is room for improvement in the methodology. First, the three-step method is computationally intensive since it is required that three different models are run to measure the technical, environmental and eco-efficiency scores of each DMU. Therefore, for a dataset with n DMUs, $3\times n$ linear programming is required. Application and implementation of $3\times n$ linear programming, especially for large scope applications, can be cumbersome. Second, it will be shown that the eco-efficiency model, which is a combination of the technical and environmental efficiency models, is unable to provide a valid score as the combination of them. Basically, the three-step methodology picks out the maximum value between technical and environmental efficiency scores of each DMU and

[1] Different terminologies are used in different papers to refer to technical and environmental efficiencies. Operational, resource and technology efficiencies are in general referred to as technical efficiency. Ecological efficiency is used to refer to environmental efficiency.