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A decision support system for supplier selection and order allocation in stochastic, multi-stakeholder and multi-criteria environments

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ABSTRACT

Integrated supplier selection and order allocation is an important decision for both designing and operating supply chains. This decision is often influenced by the concerned stakeholders, suppliers, plant operators and customers in different tiers. As firms continue to seek competitive advantage through supply chain design and operations they aim to create optimized supply chains. This calls for on one hand consideration of multiple conflicting criteria and on the other hand consideration of uncertainties of demand and supply. Although there are studies on supplier selection using advanced mathematical models to cover a stochastic approach, multiple criteria decision making techniques and multiple stakeholder requirements separately, according to authors' knowledge there is no work that integrates these three aspects in a common framework. This paper proposes an integrated method for dealing with such problems using a combined Analytic Hierarchy Process–Quality Function Deployment (AHP–QFD) and chance constrained optimization algorithm approach that selects appropriate suppliers and allocates orders optimally between them. The effectiveness of the proposed decision support system has been demonstrated through application and validation in the bioenergy industry.

1. Introduction

Supplier selection is a typical multi-criteria decision problem (Liao and Rittscher, 2007). Weber and Current (1993) describe the supplier selection problem as which supplier(s) should be selected and how much order quantity should be assigned to each. The problem has attracted widespread interest from both academics and practitioners as firms outsource more and more of their functions to suppliers and continue to compete through supply chains (Wadhwa and Ravindran, 2007; Prajogo et al., 2012). Firms are also involving stakeholder groups in their decision making including bringing stakeholder opinion into the design of new products and services early in the design process (Marsillac and Roh, 2014), especially with regards to environmental and sustainability performance (Aschehoug et al., 2012). This practice has also made it into supply chain decision making as stakeholder influence has become recognized as important to supply chain performance (Polonsky and Ottman, 1998; Klassen and Vereecke, 2012; Miemczyk et al., 2012; Seuring and Gold, 2013). Given the complexity and length of some supply chains the stakeholders impacted by the supplier selection decision are equally complex and varied.

This study addresses the subset of supplier selection problems characterized as requiring multiple suppliers to allocate orders to multiple decision criteria and having multiple stakeholder groups to satisfy. These types of problem are encountered in situations where demand is greater than available supply from a single supplier and where multiple criteria are of interest to the decision maker. Mix and blending problems are a good example of where this type of problem is encountered; often there is also the added complication of uncertainty in the composition of materials being supplied with variation between delivery batch, variation over time and natural variation within deliveries all common. Further complexity is added where the quality criteria of the resulting products are not clearly or crisply defined and there may be some benefit or opportunity in exceeding constraints, alternatively some blending problems will have a tolerance associated with quality criteria of the final product (i.e. the constraint may be specified as ‘not exceeding the constraint in more than 2% of tested batches’).

Examples of industries facing this type of supplier selection problem include agriculture and the associated food and drink

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supply chain, metal ore purchasing for smelting, plastic and glass recycling and sourcing of feedstocks for chemical processes. Across these sectors millions of dollars' worth of bulk commodities are ordered, shipped, processed and blended before entering the supply chain for higher value products. Small improvements in practice in this area of the economy have a knock on effect efficiency in downstream areas. For example, variations in density of supplied materials can lead to the need for re-working of products or repackaging downstream of other value adding processes, resulting in significant inefficiency. Stakeholder issues also impact these sectors significantly. The agri-supply chain has stakeholder requirements made on it regarding animal rights, sustainable agriculture and disease control for instance, and the recycling industry faces significant issues of contamination and quality control as well as a chain of custody requirement to comply with packaging regulations. These industries have multiple stakeholders each holding a range of opinions, requirements and objectives (Validi et al., 2014). In many industries success against the stakeholder groups' requirements can define the success of the value supply chain. Stakeholder requirements are often not quantitative, rather they are tacit in nature and the supply chain manager must elicit and translate these requirements.

To our best knowledge, there is no comprehensive method for integrating stakeholder requirements into stochastic multi-stakeholder and multi-criteria problems. These are supplier selection problems where multiple suppliers must be selected, multiple stakeholders must be satisfied and the decision must include consideration of multiple quality criteria and those criteria and/or constraints are stochastic in nature. The questions that must be addressed are: (1) how can stakeholder requirements be incorporated into the supplier selection decision, and, (2) what method can be used to optimize multi-supplier selection under uncertain constraint multi-criteria? The contribution of the paper is to demonstrate the integration of methods answering these questions and build them into a decision support system. Specifically the AHP–QFD method is integrated with a multi-criteria chance constrained optimization algorithm. The system was validated by implementing it into the emerging biomass to energy industry.

The rest of the paper is structured as follows. Section 2 reviews the literature of supplier selection and order allocation problems, and identifies the knowledge gaps. Section 3 discusses the conceptual model of the decision support system. Section 4 presents the methodology and approach used in the decision support system. Section 5 applies the decision support system to the integrated problem faced by the bioenergy industry, and Section 6 concludes the paper.

2. Literature review

2.1. Supplier selection problem

Supply chain management in firms have been changing as requirements made of supply chains by customers change. Whilst traditionally firms have sought to increase the efficiency of logistics processes and supply chains to maximize value creation (Quariguasi Frota Neto et al., 2009) more recently value creation has started to come from less obvious avenues (Sundarakani et al., 2010), such as lower risk supply chains (Sundarakani et al., 2010), more robust supply chains (Pan and Nagi, 2010) and a wealth of research on sustainable and green supply chains (Ferretti et al., 2007; Lam et al., 2010; Sundarakani and Souza, 2010) as summarized by Miemczyk et al. (2012). The role of the supplier selection function of supply chain management in these newer supply chain practices has only been partly explored in the literature.

Whilst most literature on sustainable supply chain management considers stakeholders in some regards there are limited studies on multiple stakeholder requirements for supplier selection. Spence and Bourlakis (2009) showed how corporate social responsibility has moved from a focus on the firm to a focus on the supply chain, introducing more stakeholders and complicating the supplier selection process. Wolf (2011) showed how external and internal stakeholder needs, along with supplier characteristics, can be incorporated into supply chain strategy to reduce risk in the supply chain. Reuter et al. (2012) investigated how purchasing managers respond to different stakeholder groups and neatly capture the view that the various stakeholder and shareholder opinions are frequently in conflict, especially in the design of ethical or sustainable supply chains.

Operations research (OR) has an important role to play in supporting solving the supplier selection problem (de Boer et al., 2001). OR methods can enhance the effectiveness of purchasing decisions in several ways including improving the transparency of decision making and better communication about the justification of the outcome (Carter et al., 2000; de Boer et al., 2001), evaluation of suppliers (Bottani and Rizzi, 2008; Amid et al., 2011; Mafakheri et al., 2011; Golmohammadi and Mellat-Parast, 2012; Ekici, 2013). OR methods can also support changing decisions over time (Bottani and Rizzi, 2008; Vanteddu et al., 2011) and decisions made under uncertain conditions (Bai and Sarkis, 2010; Chen et al., 2006; Franca et al., 2010; Liao and Rittscher, 2007; Lin, 2012).

The supplier selection function is dominated by quantitative methods and mathematical modelling. Generally these focus on improvements to the accuracy of supplier assessment and performance or on the method used to rank and select suppliers. According to Ho et al. (2010) methods including AHP, data envelopment analysis, simple multi-attribute rating technique, case based reasoning have all been used to assess the performance of suppliers against multiple criteria. There are many studies in this area showing different methods for supplier selection in various contexts (Mafakheri et al., 2011; Vanteddu et al., 2011; Lin, 2012; Ekici, 2013; Qian, 2014).

2.2. Order allocation problem

Multiple suppliers are commonly required in blending or mixing problems. Often it is infeasible to meet either total demand or the criteria constraints from one single supplier, rather orders must be placed with several suppliers and the material from each blended together to create the final product. The classic example of a linear blending problem, also known as the mixing problem, is shown in Murty and Rao (2004) to blend barrels of different fuel types together to give a required octane rating. The decision maker must decide how many barrels of each constituent fuel type to purchase in order to make a final blend with the required characteristics. There may be limits, costs or constraints associated with the problem and these are represented by constraints for the linear programming model. Further complexity has been added to multiple supplier problems as models become more sophisticated and a better representation of the real business environment. General models for multiple supplier selection have been applied successfully to specific applications in industry, demonstrating the relevance of this approach (Dantzig and Thapa, 2003).

Methods such as linear programming (LP) and mixed integer linear programming (Talluri, 2002; Basnet and Leung, 2005; Hong et al., 2005), goal programming (GP) or genetic algorithms have been applied to help make decisions on supplier selection and order allocation. Extensions of these methods to include stochastic elements and uncertainty have also been made (Burke et al., 2009; Li et al., 2009; Xu and Nozick, 2009; Amin et al., 2011) including fuzzy methods for handling decision maker's fuzzy goals (Nazari-Shirkouhi