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Combining Bayesian Networks and Total Cost of Ownership method for supplier selection analysis ☆

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ABSTRACT

In this study, we analyze the supplier selection process by combining Bayesian Networks (BN) and Total Cost of Ownership (TCO) methods. The proposed approach aims to efficiently incorporate and exploit the buyer's domain-specific information when the buyer has both limited and uncertain information regarding the supplier. This study examines uncertainty from a total cost perspective, with regards to causes of supplier performance and capability on buyer's organization. The proposed approach is assessed and tested in automotive industry for tier-1 supplier for selecting its own suppliers. To efficiently facilitate expert opinions, we form factors to represent and explain various supplier selection criteria and to reduce complexity. The case study in automotive industry shows several advantages of the proposed method. A BN approach facilitates a more insightful evaluation and selection of alternatives given its semantics for decision making. The buyer can also make an accurate cost estimation that are specifically linked with suppliers' performance. Both buyer and supplier have clear vision to reduce costs and to improve the relations.

1. Introduction

Effective operations for companies are vital for success in the marketplace. This can only be achieved by integrating suppliers who provide high quality products, flexible operations, and systems; who maintain close relations, and who contribute to the product design operations (Stevenson, 2009). Therefore, selecting the right suppliers has become one of the most important purchasing functions in supply chain management (Boer, Labro, & Morlacchi, 2001; Chen, Lin, & Huang, 2006). With the increasingly important role of suppliers in supply chain management, the selection process strategy has changed; other than scanning a series of pricelists, a wide range of qualitative, quantitative and environmental criteria has now been folded into the process (Ho, Xu, & Dey, 2010; Humphreys, Wong, & Chan, 2003).

Researchers have proposed a number of methods to measure the suppliers' performance and select them according to the determined criteria (Degraeve & Roodhooft, 1999; Roodhooft & Konings, 1997). Although each approach has advantages in terms of selecting and evaluating the supplier, ultimately they also have some limitations. First, none explicitly consider the uncertain nature of the problem context. Uncertainty in supplier selection primarily arises in two different ways: uncertainty of supplier performance on a specific criterion such as uncertainty in delivery reliability of the supplier, and uncertainty of the resulting poor performance effects of a supplier on the purchasing company, such as uncertainty in costs at the buyer due to the delivery performance of the supplier. Second, the buyer sometimes needs to make a decision about a supplier with only limited experience or information regarding the supplier. However the buyer might have some domain-specific knowledge that makes a difference and needs to be accounted for in the selection process. Current selection models do not explicitly account for this type of variation in the process. Furthermore, supplier selection criteria have specific causal relations and consequences with relationship to the buyer, and many models have shortcomings in terms of formalizing these relations. For example, if the supplier shows poor performance on a delivery capability, this drawback can easily increase multiple cost items: downtime costs, operation costs, logistics costs, etc. Modeling and exploring the interdependencies among variables, the supplier and buyer recognize accurate effects of supplier performance. This results in improved operations and relations between supplier and buyer.

In this study, we propose an integrated approach combining Bayesian Networks (BN) and Total Cost of Ownership (TCO) to overcome the aforementioned limitations of current approaches. Our goal is to more clearly identify uncertainty issues, and integrate and utilize the buyer's domain-specific knowledge. Even if the buyer has incomplete information, he can still evaluate and select alternatives with the proposed approach. The model will also

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explore the interdependent relations between supplier selection and different cost items in the selection process. The application process is presented for a tier-1 supplier in automotive industry.

Bayesian Networks (BN) are very powerful for making inferences and drawing conclusions based on available information (Jensen, 1996). They are effective for modeling uncertainty by accepting probability distributions. BN can combine expert and domain knowledge that allows flexible inference even with partial and limited information (Lauritzen, 1995). The domain knowledge of a buyer normally encodes in the form of conditional statements. BN allow modeling of probabilistic causal relations among variables (Bishop, 2006). Therefore, BN can facilitate a more insightful evaluation and selection of alternatives given the semantics used for decision making.

On the other hand, TCO provides a better inspection opportunity for determining the total cost caused by supplier activities on a buyer's organization. The TCO approach is a structured methodology for determining the true cost of acquisition of a product, considering all the costs related to purchasing and using the product. TCO considers the buyer's entire value chain and mainly evaluates the supplier performance by taking into account all the costs caused by a supplier (Degraeve, Labro, & Roodhooft, 2000). These costs are not limited to the purchasing price but also include cost elements such as: quality, transportation, maintenance, and administration (Degraeve et al., 2000; Ellram, 1995). As opposed to an initial-price perspective that mainly accepts short term approach, TCO allows for a long-term perspective selecting different buying situations (Ferrin & Plank, 2002).

The remainder of this paper is structured as follows. In Section 2, we present the relevant research concerning the supplier selection. In Section 3, we provide a brief overview of Bayesian Networks, including inference. In Section 4, we explain the details of our model. In Section 5, we test our proposed framework using an illustrative example, and present the results and detailed sensitivity analyses to identify the critical factors in the supplier selection process. The value of information is discussed for both mean and variance points of views. The last section is allocated for a summary and conclusion of the proposed method.

2. Literature review

Due to its key importance to manufacturers' cost management strategies, the supplier selection problem has received significant interest in both academia and industry. Several studies have been presented to firms to gain competitive advantage and to decrease system wide costs in supply chains while forming group of healthy suppliers. Multi-Criteria Decision Making (MCDM) methods such as Analytical Hierarchical Process (AHP), Multi-Attribute Utility Theory (MAUT), Analytical Network Process (ANP), and other methods such as TCO, Activity Based Costing (ABC), Case Based Reasoning (CBR), Data Envelopment Analysis (DEA), fuzzy logic, mathematical programming, and the combined approaches such as Fuzzy-AHP, Fuzzy-ANP, Fuzzy-ABC, Fuzzy-Multi Objective mathematical programming are among the methods that are employed by the researchers in supplier selection problem.

A popular approach to supplier selection problem is the use of AHP (Akarte, Surendra, Ravi, & Rangaraj, 2001; Barbarosoglu & Yazgac, 1997; Chan, 2003; Chan & Chan, 2004; Chan, Kumar, Tiwari, Lau, & Choy, 2008; Liu & Hai, 2005; Muralidharan, Anantharaman, & Deshmukh, 2001; Nydick & Hill, 1997; Tam & Tummala, 2001) and ANP (Bayazit, 2006; Bottani & Rizzi, 2008; Gencer & Gurpinar, 2007; Sarkis & Talluri, 2002). AHP is the method that ranks the suppliers by pairwise comparisons. AHP forms the supplier selection problem in a hierarchy that allows structuring and modeling of the complex decisions. For example, Tam and Tummala (2001) employ AHP for vendor selection problem in telecommunications system to assist in group decision making process. Chan (2003) combines AHP with the method of Chain of Interaction to help decision makers to include human judgment. Although AHP method is very systematic process, one of the drawbacks of AHP is the ignorance of the dependencies in both higher-level elements such as selection criteria and lower-level elements such as alternatives, and the elements within the same cluster. These dependencies within and between elements are considered in ANP where the problem is structured as a network. For example, Sarkis and Talluri (2002) employ ANP for a strategic supplier selection problem and showed the execution of the procedure with a detailed empirical case. Though both these approaches allow considering multiple objectives in selection processes, they are both deterministic and ignore the randomness in the decision process.

These models are enhanced with using fuzzy set theory to include the ambiguity in supplier selection process (Chan, Chan, Ip, & Lau, 2007; Chan & Kumar, 2007; Chen et al., 2006; Kahraman, Cebeci, & Ulukan, 2003; Lee, 2009; Mikhailov, 2002; Mohanty, Agarwal, Choudhury, & Tiwari, 2005; Morlacchi, 1999; Sarkis & Talluri, 2002; Yu & Tzeng, 2006). Kahraman et al. (2003) utilize fuzzy AHP to address supplier selection issues in the Turkish manufacturing industry. In their study, decision makers have a chance to state their favorites among the evaluated criteria. A hierarchical model based on fuzzy set theory is introduced by Chen et al. (2006), who use a fuzzy decision-making approach to address the supplier selection problem. They consider many quantitative and qualitative factors such as quality, price, and performance on flexibility and delivery; they also use linguistic values to assess the ratings and weights for these factors. In this study, they benefit from the fuzzy theory to address the linguistic values. Sarkar and Mohapatra (2006) employ fuzzy set theory to measure the imprecision of different subjective suppliers' performance and capability characteristics. Chan and Kumar (2007) apply fuzzy AHP to the supplier selection problem. The proposed model provides not only a structure for the company to select the supplier but also has the ability to organize the company's strategy to its supplier.

Fuzzy logic has been integrated with many other decision making methodology in supplier selection literature. Jain, Tiwari, and Chan (2004) apply Genetic Algorithm (GA) to the supplier selection problem using fuzzy logic. The goal of using GA is to help the decision makers to set up the rule set for evaluating the performance of suppliers. Kwong, Ip, and Chan (2002) employ fuzzy SMART, Kumar, Vrat, and Shankar (2004) use fuzzy goal programming, and Bevilacqua, Ciarapica, and Giacchetta (2006) apply fuzzy quality function deployment (QFD) approaches to supplier selection problem. Dogan and Sahin (2003) and Amid, Ghodsypour, and O'Brien (2007) developed an integrated approach by combining ABC and fuzzy set theory. Bottani and Rizzi (2008) integrate cluster analysis and AHP to reduce the amount of the alternatives and determine the best cluster and fuzzy logic to resolve the intangible measures of the problem. Amid, Ghodsypour, and O'Brien (2007) integrate fuzzy set theory with a multi objective programming model for the supplier selection process in order to deal with vagueness and ambiguity within the problem. In all these fuzzy methods, the researchers address uncertainty by using rules that are operated with linguistics variables. Building a fuzzy system to address the supplier selection problem requires combining multiple rules to outline the problem and the tuning of many membership functions for inference. The inference process is not clear or straightforward to the model builder, nor is the representation of uncertainty in fuzzy logic based on plain probability distribution. It is also not possible to account for the interrelationship between supplier selections criteria and cost elements with fuzzy logic, which is critical in understanding cause and effect relations.