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An innovative integration of fuzzy-logic and systems dynamics in sustainable supplier selection: A case on manufacturing industry

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ABSTRACT

Globally, supply chains compete in a complex and rapidly changing environment. Hence, sustainable supplier selection has become a decisive variable in the firm's financial success. This requires reliable tools and techniques to select the best sustainable supplier and enhance understanding about how supplier behavior evolves with time. System dynamics (SD) is an approach to investigate the dynamic behavior in which the system status alterations correspond to the system variable changes. Fuzzy logic usually solves the challenges of imprecise data and ambiguous human judgment. Thus, this work presents a novel modeling approach of integrating information on supplier behavior in fuzzy environment with system dynamics simulation modeling technique which results in a more reliable and responsible decision support system. Supplier behavior with respect to relevant sustainability criteria in the past, current and future time horizons were sourced through expert interviews and simulated in Vensim to select the best possible sustainable supplier. Simulation results show that an increase in the rate of investment in sustainability by the different suppliers causes an exponential increase in total sustainability performance of the suppliers. Also, the growth rate of the total performance of suppliers outruns their rate of investment in sustainability after about 12 months. A dynamic multi-criteria decision making model was presented to compare results from the systems dynamics model.

1. Introduction

Today, industries consider how to manage supply chain operations more efficiently to improve organizational performance. Sustainable supplier selection is a very critical agent to ensuring the profitability and survival of a company. However, a major problem while implementing sustainable supplier selection is how to insure that suppliers maintain their status for a long period.

The success of green manufacturing lies hugely on selecting sustainable suppliers. An effective supplier selection model is a critical success factor for supply chains in a complex environment by providing fast response to the business system changes in predominant dynamic environment. A reliable decision making process requires understanding of a complex situation of the business. Thus, static mathematical modeling techniques in operations research might not be deemed reliable given their inability to integrate all the variables of a real situation into the decision support models.

There exist in the literature many approaches to the topic of sustainable supplier selection most of which are based on multi-criteria decision making models (Amindoust, Ahmed, Saghafinia, & Bahreininejad, 2012; Awasthi, Chauhan, & Goyal, 2010; Bottani & Rizzi, 2008; Büyüközkan & Çifçi, 2011; Campanella, Pereira, Ribeiro, & Varela, 2012; Campanella & Ribeiro, 2011; Chang, Chang, & Wu, 2011; Chen, 2009; Javad, Rita, & Leonilde, 2014; Mani, Agrawal, & Sharma, 2014; Zhang, Hamid, Bakar, & Thoo, 2014). The basic assumption in applying decision making models is that both criteria and alternatives are fixed a priori and that decision occurs only once i.e., does not involve spatial or temporal considerations. This assumption undoubtedly limits the validity of the result, specifically when the values change over time and the decision matrix is not fixed or static as in sustainable supplier selection problems. In addition, the multi-criteria decision-making model conception of the supplier selection problem focuses on the cause and effect relationship between the system components individually; it is thus not regarded as a broad model. Multi-criteria decision making models usually does not provide a complete understanding of the complex nature of the supplier selection problem with respect to economic, social and environmental factors. Thus, multi-criteria decision making models cannot reliably provide information on insuring suppliers maintain their status for a long period of time.

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In efforts towards ensuring more effective decision making, research efforts have involved applying soft operation research modeling techniques like; strengths weaknesses opportunities and threats (SWOT) analysis, decision tree and system dynamics (SD). Techniques that are predominantly rational, interpretative, structure and qualitative are employed by soft operations research models which usually interpret, define, and explore various perspectives of the problem (Heyer, 2004).

System dynamics is one of the promising soft operation research techniques. It was developed from the research carried out by Jay W. Forrester at the Massachusetts Institute of Technology. Jay W. Forrester defines Industrial Dynamics as involving the study of the information feedback characteristics of industrial activity to show how organizational structure, amplification (in policies), and time delays (in decision and actions) interact to influence the success of the enterprise (Forrester, 1971). The general belief that systems dynamics modeling is more suitable for modeling at the strategic level was countered by the survey of Tako and Robinson (2012) on the journal articles identified in the period (1996–2006) which shows that systems dynamics modeling has been applied more in the operational level. Systems dynamics modeling allows the researcher to analyze complex systems from a dynamic viewpoint, rather than from a static perspective. The two main reasons for System Dynamics popularity are the complex nature of the problem and the qualitative factors such as human beings evolvement in those processes (Khatie, Bulgak, & Segovia, 2010). The systems dynamics approach considers system as a whole by covering all of the interactions among the components of the system. It is a broad approach which incorporates all the elements of a system and thus considered a reliable decision making approach. The system dynamics approach has the ability to effectively model the feedback and feed forward information in a complex dynamic system. The expected outcomes of system dynamics modeling are not necessarily quantitative point predictions for particular variable, but rather a measure of the pattern of dynamic behavior of the system, given the variables and conditions in the model (Wareef, 2013). The systems dynamics model incorporates spatial or temporal considerations and assumes that criteria and alternatives are not fixed. Thus, the validity of the system dynamics model results is increased, specifically in sustainable supplier selection where the supplier performance values change over time and the decision matrix is not static. Therefore, systems dynamics can be applied in the sustainable supplier selection problem to insure suppliers can maintain their status for a long period of time.

A good decision-making model needs to tolerate vagueness or ambiguity because fuzziness and vagueness are common characteristics in many decision-making problems (Lee, Chen, & Chang, 2008). In proffering solution to many real world problems (like supplier selection) that involve some degree of imprecision and ambiguity, fuzzy logic is deemed essential (Bayrak, Celebi, & Taskin, 2007; Bevilacqua & Petroni, 2002; Kahraman, Cebeci, & Ulukan, 2003; Ordoobadi, 2009). Fuzzy theory is most preferred to solve the problems of imprecise data and ambiguous human judgments in supplier selection (Chang et al., 2011).

In this work, a novel modeling approach for integrating information on supplier behavior in fuzzy environment with system dynamics simulation modeling technique was developed to provide insight into how supplier behavior evolves with time. The proposed approach represents the total sustainability performance of suppliers in the past, present and future period in a green manufacturing environment. Simulation results show that an increase in the rate of investment in sustainability by the different suppliers causes an exponential increase in total sustainability performance of the suppliers. The systems dynamics modeling approach presented in this study can be applied to any green manufacturing environment regardless of the number of alternatives and relevant sustainability criteria. At the development of the systems dynamic model, time and cost resources could be demanding, but once installed, use of the model becomes less demanding. The remaining parts of this paper will discuss the novel approach which is capable of: (a) Estimating supplier behavior with respect to sustainability criteria in the past, present and future period. (b) Providing insight into how supplier behavior evolves with time.

It is believed that this work can support the selection of sustainable suppliers and insuring suppliers maintains their status for a long period of time.

2. Literature review

Although a rich supplier selection literature exists, there has been relatively little research that investigates how to insure sustainable suppliers maintain their status for a long period of time. Most past works employed multi-criteria decision making models in solving supplier selection problems. Bottani and Rizzi (2008) integrated fuzzy with cluster analysis and multi-criteria decision making model (MCDM) to solve the supplier selection problem. Awasthi et al. (2010) in their work integrated fuzzy with TOPSIS to evaluate environmental performances of suppliers. Wu and Liu (2011) proposed a supplier selection application based on two methods: VIKOR algorithm and fuzzy TOPSIS with vague sets methods. Khamseh and Mahmoodi (2014) presented hybrid model for green supplier selection based on fuzzy TOPSIS-TODIM employing fuzzy time functions. Aghajani and Ahmadpour (2011) proposed fuzzy-TOPSIS for ranking of suppliers in automobile companies in Iran. Wang, Cheng, and Huang (2009) presented a fuzzy hierarchical TOPSIS for supplier selection which is capable of evaluating uncertainty and choosing the best supplier. Wittstruck and Teuteberg (2011) presented an integrated model based on fuzzy-AHP-TOPSIS for recycling partner selection that accounts for sustainability factors. Azadnia, Saman, and Wong (2015) developed a mathematical programming model for sustainable supplier selection and order-lot sizing. Büyüközkan and Çifçi (2011) presented a novel model based on fuzzy analytic network process within multi-person decision-making environment under vague preference relations. Their model is able to make effective evaluations using available preference information and maintain consistency level of evaluations. Verdecho, Alfaro-Siaz, and Rodríguez-Rodríguez (2010) proposed a performance management model based on ANP for supplier selection in automotive industry in Spain.

Other decision approaches has been applied to supplier selection problem. Jauhar, Pant, and Abraham (2014) presented a novel approach for sustainable supplier selection based on differential evolution to select the efficient sustainable suppliers and provide the maximum fulfillment for the sustainable criteria determined in a pulp and paper industry. Foerstl, Reuter, Hartmann, and Blome (2010) hinged on the dynamic capabilities view (DCV) to propose that management capabilities of sustainable suppliers are critical agents able to give competitive advantage. However, their approaches do not provide information on whether suppliers can maintain their status for a long period of time.

Several real world examples have proven the interdisciplinary nature and capability of systems dynamics modeling in solving real world complex problems. Systems dynamics was applied in analyzing the behavior of manufacturing in supply chain (Vashiranwongpinyo, 2010). Systems dynamics simulation was utilized to analyze the behavior of a generic short life cycle supply chain (Briano, Caballini, Giribone, & Revetria, 2010). The systems dynamics approach has been widely used to conduct policy experiments by many researches and policy makers for over 30 years (Trappey, Trappey, Hsiao, Ou, & Chang, 2012). System dynamics