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Assessing business impacts of agility criterion and order allocation strategy in multi-criteria supplier selection

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ABSTRACT

This paper formulates supplier evaluation and selection as a multi-criteria decision-making (MCDM) problem with subjective and fuzzy preferences of decision makers over evaluation criteria. As an outcome, this paper provides decision makers with a decision support system that presents the Pareto fronts, a set of best possible high-quality suppliers and optimized business operation levels from such suppliers. In addition, this paper quantifies the importance of the agility criterion and its sub-criteria in the process of evaluating and selecting agile suppliers by measuring the magnitude of bullwhip effect and inventory costs. The proposed system uses a fuzzy analytic hierarchy process (fuzzy AHP) and fuzzy technique for order of preference by similarity to ideal solution (fuzzy TOPSIS) to successfully determine the priority weights of multiple criteria and selects the fittest suppliers by taking the vagueness and imprecision of human assessments into consideration. More importantly, it presents approximated Pareto fronts of the resulting supplier chains for varying priority weights of the agility criterion and its sub-criteria. Finally, we compare business costs of agile and non-agile supply chains before and after reconfigurations of original supply chains in response to unexpected disruptions under two order allocation strategies, a skewed order allocation (SOA) strategy and an even order allocation (EOA) strategy.

1. Introduction

Due to increasing reliance on outsourcing of many complex services and products, evaluating and selecting qualified suppliers becomes an essential part of building a successful supply chain (Araz, Mizrak Ozfirat, & Ozkarahan, 2007). Often, the supplier evaluation and selection problem is formulated as a multi-criteria decision-making (MCDM) problem with various quantitative and qualitative evaluation criteria. In this approach, the ultimate goal is to present the decision maker with a set of high-quality suppliers from which to choose and approximate *Pareto front* that represents the optimized business operation levels from chosen suppliers.

Various methods to select the best-fit suppliers have been proposed from diverse disciplines (Araz et al., 2007; Bottani & Rizzi, 2008; Chan, Kumar, Tiwari, Lau, & Choy, 2008; Chen, Lin, & Huang, 2006; Ha & Krishnan, 2008). In particular, turbulent and volatile markets enforce organizations to restructure their supply chains to be more responsive to customer needs through a high level of maneuverability. Naturally, agility defined as the ability to respond rapidly to change in demand volume and variety becomes one of the most critical evaluation criteria for supplier evaluation and selection (Christopher, 2000). Note that change in demand may come from several different sources such as marketplace, competition, customer desire, technology and social factors (Lin, Chiu, & Chu, 2006). Therefore, agility in these days is regarded as a business-wide capability that embraces organizational structures, information systems, logistics processes and mindsets (Christopher, 2000). This implies that it is imperative for organizations to cooperate and leverage complementary competencies along the up- and down-stream of their supply chains (Yusuf, Gunasekaran, Adeleye, & Sivayoganathan, 2004).

Based on these observations, this study intends to quantify the importance of agility criterion in the process of evaluating suppliers and estimate the business impact of resulting supply chains. To this end, we measure the magnitude of bullwhip effect and inventory cost of agile supply chain that is supposed to rapidly respond to change in demand and supply shortage, and hence is less likely to suffer from high bullwhip effect or high inventory cost. Note that bullwhip effect is a phenomenon in which variance of demand information is amplified when moving upstream in supply chains (Chen, Drezner, Ryan, & Simchi-Levi, 2000; Lee, Padmanabhan, & Whang, 1997; Luong, 2007) due to the invisibility of end demand, order batching, supply shortage, or other behavioral causes (Chen

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& Lee, 2012; Croson & Donohue, 2006; Klein & Rai, 2009; Yao & Zhu, 2012). We also consider other criteria such as general management capability, manufacturing capability and collaboration capability to evaluate candidate suppliers from an MCDM perspective.

To quantify subjective and vague preferences of decision makers over multiple criteria with linguistic assessments, we calculate the prior weights of decision criteria with a fuzzy analytic hierarchy process (AHP) method (Chan et al., 2008). Then we determine the rankings of candidate suppliers using another fuzzy technique for order of preference by similarity to ideal solution (TOPSIS) (Chen et al., 2006) and select the fittest suppliers. By successfully integrating AHP and TOPSIS based on the fuzzy theory, we not only consider the imprecision of human assessments but also reflect the subjective preferences of decision makers, making the presented model generalizable to the cases of decision makers with different preferences.

More importantly, we intend to visualize the importance of agile criterion by comparing differences of bullwhip effect and inventory cost from two supply chains: an agile supply chain with the suppliers chosen considering agility and other criteria, and a non-agile supply chain built without considering agility. In particular, we approximate the Pareto fronts of agile and non-agile supplier chain as we vary the relative importance of agility criterion in the evaluation process of candidate suppliers. This way, decision makers easily identify a set of high-quality suppliers from which to choose as their strategic preferences over agility criterion change.

After validating our concepts in a simple supply chain consisting of one buyer and one supplier, we expand our simple supply chain into a more realistic supply chain consisting of multiple suppliers. In particular, we compare business costs of agile and non-agile supply chains before and after reconfigurations of original supply chains in response to unexpected disruptions. For example, we imagine that when the fittest supplier in the current supply chain cannot serve as a business partner, the buyer replaces it with new suppliers. If the buyer allocates most of order to the fittest supplier and the remaining orders to the other suppliers in the supply chain (i.e., taking a skewed order allocation (SOA) strategy), its reconfiguration business impacts could be serious. In contrast, if it evenly allocates order among suppliers in the supply chain (i.e., taking an even order allocation (EOA) strategy), the reconfiguration impact could be tolerable. In this study, we intend to present the Pareto fronts of original and reconfigured supply chains associated with SOA and EOA strategy, and compare changes in bullwhip effect for both agile and non-agile supply chains before and after disruption.

The remainder of this paper is organized as follows. In Section 2, we provide a literature review on agile supply chain, supplier evaluation and selection with fuzzy multi-criteria decision making and bullwhip effect of supply chain. Then we describe the framework of the proposed decision support system (DSS) that helps decision makers configure agile supply chains by evaluating and selecting candidate suppliers based on fuzzy multi-criteria in Section 3. Business impacts of agile and non-agile supply chains are assessed by measuring the magnitude of the bullwhip effect and inventory cost in Sections 4 and 5, respectively. In Section 6, a simple supply chain is expanded into a more complex supply chain consisting of multiple suppliers which is used to compare business impacts of agile and non-agile supply chains in response to unexpected disruptions. Finally, we provide concluding remarks and suggest future research direction in Section 7.

2. Literature review

This study takes a holistic approach to leverage three closely related domains toward successful agile supply chain construction. The first relevant domain is agile supply chain management discipline that recognizes the importance of an agile supply chain that responds rapidly to change in demand both in terms of volume and variety. Note that it is imperative for companies to cooperate and leverage complementary competencies because the resources required for agility are often difficult to retain by single company (Yusuf et al., 2004). To this regard, many studies have acknowledged that agility is a business-wide capability that embraces organizational structures, information systems, logistics processes and mindsets (Krishnamurthy & Yauch, 2007; Power, Sohal, & Rahman, 2001). A number of ways of streamlining a traditional supply chain into agile supply chain have been presented. For example, Galan, Racero, Eguia, and Garcia (2007) presented the concept of reconfigurable manufacturing systems (RMSs) that make it possible to produce any quantity of customized products while allowing mass production. Similarly, Kristianto, Gunasekaran, Helo, and Sandhu (2012) presented the need to incorporate the manufacturing process (e.g., assembly planning) into logistics design (e.g., demand planning and inventory allocation process) to improve the agility of a supply chain. While these studies recognize the importance of agility and present an innovative manufacturing process to enhance the agility, they are limited in a sense that they mainly focus on the improvement of internal manufacturing process rather than the entire supply chain management. In addition, these studies do not explicitly consider multiple and often fuzzy criteria in the process of supplier evaluation. In particular, none of these studies considered the effects of order allocation strategies in agile supply chain in respond to unexpected disasters.

The second associated domain is the multi-criteria decision making (MCDM) domain that has garnered researchers' interests in marketing, management science, operation management and engineering disciplines (Bottani & Rizzi, 2008; Kim, Street, Russell, & Menczer, 2005; Tan, Lee, & Goh, 2012; Wallenius et al., 2008). In fact, several studies already formulated the supplier selection problem as an MCDM problem (Ho, Xu, & Dey, 2010; Hong & Lee, 2013; Jadidi, Zolfaghari, & Cavalieri, 2014; Ware, Singh, & Banwet, 2014). For example, Hong and Lee (2013) presented a decision support system that helps procure managers identify, assess, mitigate and monitor supply risk. In addition, several other studies (Arikan, 2013; Labib, 2011; Pitchipoo, Venkumar, & Rajakarunakaran, 2013; Shen & Yu, 2012; Önüt, Kara, & Işik, 2009) presented various fuzzy methods to consider the ambiguity of evaluating decision alternatives and determining relative weights of multiple criteria. In particular, analytic hierarchy process (AHP) first introduced by Saaty (1980) has been a popular approach for supplier evaluation and selection, though it was extended with fuzzy theory to suitably address the ambiguities involved in the linguistic assessment of the data (Chan et al., 2008). For example, Kar (2014) applied group decision support theory with fuzzy AHP to the supplier selection problem, and Deng, Hu, Deng, and Mahadevan (2014) extended AHP based on Dempster–Shafer theory to handle uncertainties due to the inability of human's subjective judgment. While methods (e.g., fuzzy AHP and fuzzy TOPSIS) from this domain are adopted for this study without modification, our study is still useful for two reasons. First, many of these fuzzy MCDM studies did not consider agility as one of evaluation criteria and mainly focused on developing an evaluation method. However, our study intends to help decision makers evaluate candidate suppliers based on agility explicitly and understand a trade-off between conflicting criteria (agility vs. other criteria). Second, this study presents decision makers with a set of high-quality suppliers from which to choose and approximated Pareto front that *visually* represents the optimized business operation levels.

The third domain considered in this study is the mathematical approach (Bray & Mendelson, 2012; Lee, So, & Tang, 2000; Lee