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Multi-objective supplier selection and order allocation under disruption risk

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ABSTRACT

We formulate a multi-objective MILP model to find the optimal choice of suppliers and their order quantity allocation under disruption risk. Suppliers are evaluated and ranked, based on the preference values obtained using a hybrid fuzzy AHP-fuzzy PROMETHEE. Multi-objective Particle Swarm Optimization is then applied to yield a set of Pareto-optimal solutions for the choice of suppliers and their order allocation. Numerical experimentation suggests that the supplier failure probability affects the expected total cost more than supplier flexibility and loss cost. Sensitivity analysis is performed on the failure probability, the output flexibility, and loss cost of the suppliers.

1. Introduction

The risks in today's supply chain are numerous and are constantly evolving from sources within and outside of the supply chain. In a survey conducted by Deloitte, 71 percent of the respondents view supply chain risk as a crucial factor in their firm's strategic decision-making (Marchese and Paramasivam, 2013). The literature categorizes supply chain risk as either operational or disruption risk (Tang, 2006). Operational risk refers to the inherent uncertainties such as uncertain customer demand, supply, and cost. Disruption risk refers to the major disruptions caused by natural and man-made disasters. The efforts to identify and mitigate supply chain risk have traditionally focused on operational risk as disruption risk were viewed to be (probabilistically speaking) rare events. In recent years, disruption risks have been occurring more frequently and are receiving greater attention as suppliers, particularly those in Asia, tend to be clustered within a single locale for economies of supply. Succumbing to disruption risk can thus lead to a loss in productivity, quality, market share, and reputation for the suppliers and the supply chain (Chopra and Sodhi, 2014). This also leads to an increase in the purchasing and logistics cost as the manufacturers are often compelled to seek and select fresh suppliers quickly from elsewhere and to expedite the shipping to maintain service levels. The twin disasters (Japanese tsunami and Thailand flood) in 2011 attest to this effect. These two events have forced many leading automotive and computer makers to reassess their supply network strategies to effectively mitigate the risks arising from the clustering of suppliers in the two locations, in an attempt to contain costs of transportation and logistics, and to maintain customer service levels. Sourcing under disruption risk is a challenging task for the purchasing firms as it involves a trade-off between minimizing the expected loss of supplier disruption

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and maximizing the utility of the suppliers based on their cost, flexibility, and other criteria. We formulate this problem as the multi-objective Supplier Selection and Order Allocation (SSOA) model under disruption risk.

The research on SSOA under disruption risk is scant (Meena and Sarmah, 2014; Sawik, 2014a; Hamdi et al., 2015). For instance, Knemeyer et al. (2009) apply a proactive planning process to identify the key locations for catastrophic risk in a supply chain and to estimate the probability of its occurrence and impact. Chai et al. (2013) review the decision-making techniques in supplier selection. Li et al. (2015) have investigated the effects of decision sequence on a decentralized supply chain in which a supplier faces disruption risk. As such, our contribution to the body of knowledge is to develop a realistic multi-objective model that captures the associated effects arising from disruption risk at the upstream end of the supply chain, which will clearly affect the related transportation and logistics costs. We choose to focus on SSOA particularly in Asia as Asia is the sourcing hub of the global supply chain, and any disruption at this level would have a knock-on effect on the rest of the chain.

This paper is organized as follows. Section 2 reviews the SSOA literature under disruption risk and the methods of fuzzy AHP, fuzzy PROMETHEE, and MOPSO. Section 3 describes the problem and model formulation. Section 4 details the solution approach. Section 5 contains an illustrative example. Section 6 discusses the results. Section 7 concludes the paper.

2. Literature review

2.1. SSOA under disruption risk

Researchers have modeled supply disruption as either a super, semi-super, or unique event (Sarkar and Mohapatra, 2009). A super event causes the suppliers at all locations to be disrupted and cannot deliver the committed quantity to a manufacturer, hence they fail. A semi-super event causes all suppliers at a location to fail while a unique event causes only one supplier at a location to fail. Much of the literature on supply disruption risk concern super and unique events with equal and unequal failure probabilities. Recently, there have been studies considering the region specific supply disruptions due to a semi-super event (Sawik, 2014a, 2014b, 2014c; Kamalahmadi and Mellat-Parast, 2015). Sawik (2014a, 2014b, 2014c) proposed a stochastic Mixed Integer Programming (MIP) approach to integrated supplier selection and customer order scheduling in the presence of supply chain disruption risks. Kamalahmadi and Mellat-Parast (2015) present a two-stage MIP model to minimize the total network cost by integrating SSOA with transportation channel selection. Table 1 shows some recent SSOA models under supply disruption risk. Typically, supply disruption risks are measured by the expected monetary loss (Heckmann et al., 2015). All the SSOA models studied so far are limited to a single objective of either expected total cost minimization, expected worst-case cost minimization (Sawik, 2014c) or profit maximization (Ray and Jenamani, 2016).

Clearly, multi-objective models for SSOA under disruption need further study. Though the decision tree approach is the most common solution method for capturing the different scenarios to help determine the optimum supply base, typically an arbitrary allocation of orders is proposed in increments of 10% (Ruiz-Torres and Mahmoodi, 2006; Meena et al., 2011; Meena and Sarmah, 2016) or 1% (Lee, 2015) for computational expediency. The reason for this is that the computational complexity for SSOA increases with the number of suppliers, locations, failure probabilities, supply capacity, and supplier flexibility. Meena and Sarmah (2013) have shown that SSOA under supply disruption risk is NP-hard and proposed a Genetic Algorithm (GA) for solution. Particle Swarm Optimization (PSO), drawn from swarm intelligence, is another preferred algorithm given its simplicity and performance over the GA (Poli, 2008). In our study, we apply a PSO algorithm to solve a multi-objective SSOA under supply disruption due to super, semi-super, and unique events, in order to reflect a more realistic situation of supplier management under disruption. By employing MOPSO with time varying parameters, our proposed approach is novel as the current literature has yet to provide any evidence of multi-objective supplier selection under disruption using MOPSO.

2.2. Multi-objective SSOA under disruption risk

Several studies have modeled multi-objective SSOA without considering disruption risk (Sawik, 2010; Mafakheri et al., 2011; Jolai et al., 2011; Amin and Zhang, 2012; Azadnia et al., 2015). Torabi et al. (2015) developed a bi-objective mixed possibilistic, two-stage stochastic programming model to build a resilient supply base under operational and disruption risks considering the suppliers' business continuity plans, fortification of the suppliers, and contract with back-up suppliers. Nooraie and Mellat-Parast (2015) developed a multi-objective model to study the relationship among supply chain visibility, supply chain risk, and supply chain cost for a new product under probabilistic demand. Nooraie and Mellat-Parast (2016) further proposed a multi-objective stochastic model to determine the trade-off among the investments in improving supply chain capability and reducing the supply chain risks and to minimize the cost of supply chain disruptions. Khalili et al. (2016) presented a multi-objective mixed possibilistic, two-stage scenario based stochastic programming model to handle SSOA under operational and disruption risks.

However, all of the above studies are limited to the scenarios of individual supplier failures and did not consider region specific supply disruptions. Recently, on region specific supply disruptions, Sawik (2014b) proposed a bi-objective stochastic MIP to optimize the expected value and the expected worst-case value of the cost or customer service of a global supply chain network. Sawik (2016) extended his previous works on stochastic MIP for a bi-objective coordinated selection of