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Simulation-based evolutionary algorithm approach for deriving the operational planning of global supply chains from the systematic risk management

Yang-Byung Park*, Hyung-Seok Kim

Department of Industrial and Management Systems Engineering, Kyung Hee University, 1 Seocheon-Dong, Giheung-Gu, Yongin-Si, Gyeonggi-Do 446-701, Republic of Korea

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A B S T R A C T

One of the most critical issues facing supply chain managers in today's globalized and highly-uncertain business environment is how to proactively deal with risks that might cause serious severances and distortions of material flows in a supply chain. This paper proposes a simulation-based evolutionary algorithm approach for deriving the operational planning of global supply chains from the systematic risk management, which proactively deals with the negative consequences of random and hazardous risk events in sourcing, production, distribution, and transportation in an integrated way. The proposed approach incorporates the production lot size of the plant, order quantity and reorder point of DC, and five response coefficients as decision variables to potential risks. The proposed approach is successfully applied to an industrial example of a consumer electronics manufacturing company. The results of the computational study show that the systematic risk management of global supply chains using the proposed approach increases the profit by 20% and 16.1% in the industrial example in comparison with passive and active risk management, respectively. In addition, a mixed strategy for the inventory management of distribution centers is suggested to improve the profits of global supply chains subject to substantial risks.

1. Introduction

The current business environment is characterized by increased uncertainty of supply and demand, globalization of the market, shorter product and technology life cycles, long material flows, and increased use of outsourcing, making supply chains more vulnerable to serious disturbances arising from supply chain risks. Supply chain risk is defined as the potential for unwanted consequences to arise from an event or activity. It involves negative effects on the goal achievement of the whole supply chain with respect to end customer value, costs, time, capacity, inventory, or quality, which can be attributed to disturbance of operation or flow within the goods network. It is a complex phenomenon that is hard to accurately predict and effectively control [1]. The sources of supply chain risk may be divided into two types: random and hazardous events. Random events cause rapid changes in demand, capacity, time, cost, and quality over a short period and generally result from composite internal and external malfunctions. The probability of occurrence can be estimated based on historical data. Hazardous events cause supply chain disruptions over a long period. They include natural and man-made disasters such as earthquakes, floods, and hurricanes or economic crises such as currency evaluation or strikes. They are rare and repetitive, where the likelihood of occurrence can be estimated based on historic information. A risk event affecting one supply chain member or process may interrupt the operation of other supply chain partners. Therefore, it is important to consider the entire supply chain when managing risks. How to successfully manage the risks in todays globalized and highly-uncertain business environment becomes more and more critical to firms.

A lot of research on supply chain risk management (SCRM) has been reported. Tang and Musa [2], Jüttner et al. [3], and Kasemset et al. [4] have provided reviews of recent works on SCRM. Gurnani et al. [5] presented a state-of-art perspective addressing the

* Corresponding author.
E-mail address: ybpark@khu.ac.kr (Y.-B. Park).

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management of supply chain disruptions. Although there has been a significant amount of work on the operational planning problem of global supply chains under risk, most of the studies have focused on the development of the conceptual framework. Tuncel and Alpan [6] showed how a timed Petri-net framework could be used to model, analyze, and evaluate the operational planning of a supply chain network under various risks. Tummala and Schoenherr [7] presented a framework for managing risks in supply chains, which consisted of three major phases. Giannakis and Louis [8] developed a framework for the design of a multi-agent-based decision support system that facilitated collaborative operational planning and risk mitigation in manufacturing supply chains. Xia and Chen [9] proposed a decision making framework based on internal triggering and interactive mechanisms in a supply chain risk system, considering the operational process cycle and product life cycle. Singh et al. [10] presented a mathematical model for the facility location-allocation problem of the global supply chain network, incorporating a set of risk factors expressed as additional costs. Klibi and Martel [11] proposed a risk modeling framework for the design and operational planning of supply chain networks, which used Monte Carlo methods to generate plausible future scenarios incorporating extreme events such as disruptions. Sofyalıoğlu and Kartel [12] conducted a study to determine the most important supply chain risks and the corresponding operational planning strategies in the iron and steel industry of Turkey using a fuzzy analytical hierarchy process. Schmitt and Singh [13] analyzed the inventory placement and back-up methodologies in a multi-echelon supply chain network using a discrete-event simulation model, showing that systematic proactive planning enables significant reductions in disruption risk impact. Atoei et al. [14] proposed a non-dominated sorting genetic algorithm with an application of Lingo in order to solve the configuration and operational planning problems of a reliable capacitated supply chain network with random disruptions. Ohmori and Yoshimoto [15] described the operational planning problem and developed a framework for assessing the impact of each mitigation strategy of stabilization, absorption, and duplication on the entire supply chain's protection against operational disruptions, using network reliability. Micheli et al. [16] developed a framework of a quantitative decision support system to select appropriate mitigation measures for operational problems within a given budget for supply chain risks.

Although the operational planning of global supply chains from the systematic risk management would have great values concerning flexibility and safety stocks and enables the reduction in supply chain risk impact, as confirmed by Thun et al. [17] in their survey results, little research has been conducted on the development of the algorithm approach for it. Some researchers [10,18,19] have formulated the operational planning problem as stochastic mathematical models, which are not easily solvable. They considered the usual uncertainties in supply or demand as risks and ignored the dynamics of global supply chain systems. These simplifications were primarily due to the difficulty in formulating those factors.

Evolutionary algorithms have been shown to be highly effective tools for solving NP hard optimization problems due to their capability and speed of handling large-scale search spaces [20]. In recent years, genetic algorithm (GA) has been advocated for use in solving the design and planning problems of supply chains. Though the GA is suitable for very general optimization problems, it is not an ideal tool for uncertainty estimation. Some researchers have used the simulation optimization methodology to take care of the uncertainty in the problems. The methodology couples a simulation model with a meta-heuristic such as GA, by using results of simulation experiments for estimating the performance of the candidate solutions generated by the meta-heuristic. Ko et al. [21] proposed a hybrid GA and simulation approach to design a distribution network for third party logistics service providers in consideration of the performance of the warehouses. The GA determines dynamic distribution network structures and subsequently the simulation model is applied to capture the uncertainty in demand and time. Hochmuth and Köchel [22] used a GA with elitism for the simulation optimization approach in order to solve the highly complex, multi-location inventory problem with lateral transshipments in multi-echelon supply chains. By applying the proposed model to a special case problem, they showed its validity and generality. Azadeh et al. [23] presented an integrated approach of simulation and GA for selecting suppliers and locating new facilities in a supply chain based on the collective information of the supply chain operation, while minimizing total cycle time and production cost simultaneously.

More research is needed to develop an effective stochastic algorithm approach for the operational planning of global supply chains in a risk environment, which maximizes the supply chain profit. While the simulation optimization methodology is an excellent tool used to solve the operational planning problem, its application to the stochastic and dynamic environment involving random and hazard risk events remains a challenge. This paper proposes a simulation-based evolutionary algorithm approach for deriving the operational planning of global supply chains from the systematic risk management, which proactively deals with the negative consequences of random and hazardous risk events in sourcing, production, distribution, and transportation in an integrated way. The proposed approach incorporates the production lot size of the plant, order quantity and reorder point of DC, and five response coefficients as decision variables to potential risks. The proposed approach is applied to an industrial example of a consumer electronics manufacturing company. The effectiveness of the systematic risk management is evaluated using the proposed approach. Furthermore, the mixed strategy for the inventory management of distribution centers is compared with the pure strategy for it in the global supply chain subject to substantial risks. The proposed approach is motivated by Hochmuth and Köchel [22]. To the best of our knowledge, it is the first full-scale application of the simulation optimization methodology to the operational planning of global supply chains in the stochastic and dynamic environment, dealing with risks in various operational areas in an integrated way.

2. Global supply chain under risk

The global supply chain subject to substantial risks studied in this paper is a simplified version of that of a major consumer electronics manufacturing company in South Korea. The company currently faces unpredictable demand, supplier-related delays or disruptions, production challenges, and an unstable transportation schedule, which makes it very vulnerable to risks.

2.1. Supply chain operation

The global supply chain network of the company consists of six core part suppliers, six plants, 12 distribution centers (DCs), and 24 regional product-markets scattered over several continents. The regional market includes numerous retailers that order from the assigned DC in an aggregated manner. The bi-modal freight of air and container trucks is used for intercontinental transport. In this study, the base time unit of the supply chain operation is one week.

Each supplier is dedicated to an adjacent plant for part supply. The plant manufactures on a lot basis. The plant cooperates with its supplier for just-in-time purchasing, resulting in negligible order cycle time. The DC is responsible for fulfilling the market demand assigned to it, thus generating the revenue for the company. Stock-