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Supply chain optimization under risk and uncertainty: A case study for high-end server manufacturing

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ABSTRACT

This paper presents an approach and a software application for supply chain optimization under risk and uncertainty. The proposed approach combines simulation and optimization techniques for managing risks in supply chains. A multi-objective optimization model is developed which considers the deterministic features of the supply chain. A simulation model is used to represent the stochastic features of the supply chain. Both models communicate to achieve the best values for profit, lead time and risk reduction by selecting a combination of mitigation strategies and allocating orders and inventory. A case study from a high-end server manufacturing environment is used to demonstrate the validity of the proposed approach. The analytical results show clear trade-offs among the three objectives where changing the risk reduction goal value will affect the total profit and lead time. The proposed approach helps decision makers identify the best risk mitigation strategies and allocate inventory and customer orders effectively.

1. Introduction

Risk events represent a daily challenge to supply chain and logistics management. The ability to respond to and mitigate these risk events puts a company ahead of its competitors and reduces the expected long-term damage to its business. The key drivers for supply chain profitability are responsiveness, efficiency, and reliability (Hendricks & Singhal, 2005). To maintain their profitability, supply chains must be able to quickly respond to external and internal risk events, and keep their businesses efficient and dynamic. Furthermore, supply chains have to be resilient to unexpected catastrophic events. Risk exists in supply chain because of the uncertainty about future risk events, which can appear at any point in time in the supply chain. Supply chain performance can be negatively impacted because of the occurrence of risk events in different stages of the supply chain system. The management of such events is known as supply chain risk management (SCRM), which has become a critical part of the organizational strategy. SCRM has gained more attention with the movement to global supply chains and the increasing occurrence of internal and external events that cause disruptions of supply chain operations.

SCRM is an important part of supply chain management due to the fact that risks can cause unanticipated changes in material flow in the supply chain. SCRM is a systematic approach for identifying, assessing, mitigating, and monitoring potential disruptions in the supply chain in order to reduce the negative impact of these disruptions on supply chain operations. An essential step for risk management is the understanding of the different categories of risks, and the events and conditions that drive these risks. The goal of SCRM is to prepare the company to be able to respond to different types of risks in such a way that minimizes the impact on its operations. The art of risk management is to "identify risks specific to an organization and to respond to them in an appropriate way" (Merna & Al-Thani, 2005). For risk management to be effective, all levels of the organization need to be considered. According to Wu and Blackhurst (2009), most of the definitions of SCRM include the following activities: (1) risk identification and modeling, (2) risk analysis, assessment and impact measurement, (3) risk management, (4) risk monitoring and evaluation, and (5) organizational and personal learning including knowledge transfer.

Similar to other management approaches, SCRM requires good quality of knowledge, abilities, experiences, and skills. It ensures that the principles established by managers are applied to logistics' risk (Waters, 2007). According to Chopra and Sodhi (2004), there is no silver-bullet strategy to protect organizational supply chains against risks; managers need to choose the proper mitigation strategy for each risk. Mitigation strategies can be divided into four main categories (Zsidisin & Ritchie, 2009): (1) eliminate the risk, (2) reduce the frequency and consequences of the risk, (3) transfer the risk by means of insurance and sharing, and (4) accept the risk.

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Managers typically choose the proper mitigation strategies based on several factors, such as the nature of the risk, origin of the risk, and company resources. Liu (2009) discussed some management policies that can be used as a protection against supply chain risks, including (1) inventory, (2) capacity, (3) flexibility, and (4) insurance. Inventory is perhaps the easiest way to manage supply chain risks. However, inventory can be expensive (e.g., logic cards for servers in server manufacturing companies), highly customized (e.g., prototypes), or perishable (e.g., medical supplies). Nonetheless, inventory can always be used as a protector against supply chain risks. Capacity can be in the form of excess capacity within the firm or with the outside suppliers. In some cases, excess capacity can be very expensive (e.g., server manufacturing test cells). Flexibility provides virtual capacity and represents one of the effective means to mitigate supply chain risks; this includes product flexibility, process flexibility, and price flexibility. Insurance is used to defray the economic consequences of the risk event. Insurance can be expensive and should be considered as a supplementary, rather than primary, mitigation strategy. Risks that are internal to the organization are mostly controllable (e.g., quality risks, capacity and flexibility risks) or at least partially controllable (e.g., occupational risks).

Supply chain risk modeling is an important topic that needs more investigation due to the fact that having quantitative measures for the risks enables companies to assess and prioritize the risks and develop proper mitigation plans. Modeling approaches of supply chain risks can be divided into: (1) qualitative models, (2) quantitative models, and (3) hybrid models that incorporate both qualitative and quantitative techniques. Simulation and optimization models can be combined to quantitatively analyze supply chain risks. In this case, optimization models can be used to consider the deterministic characteristics in the supply chain whereas simulation models consider the stochastic characteristics of the supply chain.

The problem considered in this study is motivated by a case study about a high-end server manufacturing environment which requires a close alignment and coordination among all the parties of the supply chain. High-end server manufacturing supply chain has several characteristics that make it very complex and prone to many risks that impact its performance. Examples of these characteristics include: high customer expectations, short turnaround times, high inventory carrying costs, short product life cycles, long lead times, constant engineering changes, and unpredictable customer demand. Identifying and analyzing the risks in high-end server manufacturing supply chain is a challenging task due to the uncertainty in customer demands and product failures and the unique production models employed by sever manufacturers. High product failures that are attributed to product complexity and constant design changes can occur at any phase of the product life cycle. Furthermore, there is a continuous quest by customer for decreasing time to market and cycle time.

In order to study and analyze the high-end server manufacturing supply chains and manage their associated risks, analytical and simulation models can be used. However, because of the high complexity of the server manufacturing supply chain, it is difficult to build accurate analytical models that account for uncertainty and the interactions among all the parties as well as the risk correlation and mitigation. In this case, simulation models can be utilized to account for both complexity and uncertainty and model the risks. This study integrates simulation and optimization models to analyze high-end servers supply chain and identify the best mitigation strategies for risks. A deterministic multi-objective optimization model is formulated which considers the three main performance measures of supply chain: cost, time, and risk. To deal with the complexity and uncertainty, a simulation model is developed and an iterative approach is used to connect the simulation and optimization models to achieve the best solution. Once the optimal solution is obtained, it is translated into recommended actions to support management decisions. The integrated simulation–optimization risk modeling used in this research combines the advantages of both simulation and optimization by modeling the stochastic and dynamic supply chain and testing the effectiveness of risk mitigation strategies.

The rest of this paper is organized as follows: Section 2 discusses the related literature. Section 3 presents the proposed simulation–optimization approach for supply chain optimization under risk and uncertainty. Section 4 provides a case study from a high-end server manufacturing environment. Finally, Section 5 discusses the conclusions and future work.

2. Related literature

SCRM has gained significant attention in the last few years due to the increase in the number of risk events that impact the supply chains. Examples of these risk events include international terrorism (Sheffi, 2002) and economic crises and wars (Lim, 2010). Supply chain risk modeling provides quantitative measures for the risks which enable companies to assess and prioritize the risks and develop proper mitigation plans. Several studies in the literature discussed the use of analytical models for supply chain risks. Analytical and simulation models help the decision makers in making the right decision to mitigate the risks. Depending on the supply chain area, the risks can be related to supply, demand, product, system, or information. Mitigating risks can be conducted through an effective management of these areas. Optimization models for analyzing supply disruptions and selecting the optimal mitigation strategies were discussed in several studies. Sarkar and Mohapatra (2009) developed an optimization model to determine the optimal supply base (number of suppliers) under the risk of supply disruption. A stochastic model for managing risks in global supply chains was developed in Goh, Lim, and Meng (2007). Their model considered supply, demand, exchange, and disruption risks. A multi-stage supply chain network problem was formulated for a supply chain operating under risks with the objective of maximizing profit and minimizing the risks. Viduto, Maple, Huang, and Lopez-Perez (2012) proposed a novel risk assessment and optimization model to solve a security countermeasure selection problem. A multi-objective tabu search algorithm was used to solve the model. Simulation models can be used to quantify supply chain risks and their impacts, and allow for testing different scenarios under the effect of risks. Simulation modeling techniques that are commonly used to study supply chain risks include discrete-event simulation (Carvalho, Barroso, Machado, Azevedo, & Cruz-Machado, 2012; Finke, Schemitt, & Singh, 2010; Schmitt, 2009), agent-based simulation (Cao & Chen, 2012; Giannakis & Louis, 2011; Mele, Guillen, Espuna, & Puigjaner, 2007) or multi-agent based simulation, Monte Carlo simulation (Hong & Lee, 2013; Schmitt, 2009), and Petri nets (Tuncel & Alpan, 2010). Other methods for modeling supply chain risks include fuzzy logic (Aqlan & Lam, 2015) and bow-tie analysis (Aqlan & Ali, 2014).

A study of supply chain resilience was conducted by Carvalho et al. (2012). Zhang, Shah, Wassick, Helling, and van Egerschot (2014) presented an optimization study for sustainable supply chain. Simulation and optimization models can be combined to analyze supply chains. In this case, optimization models can be used to consider the deterministic characteristics in the supply chain whereas simulation models consider the stochastic characteristics of the supply chain. For example, Chen, Mockus, Orcun, and Reklaitis (2012) developed deterministic mixed-integer programming models for demand forecasting. Discrete event simulation models were then used to assess the robustness