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Intelligent contingent multi-sourcing model for resilient supply networks

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ABSTRACT

As the complexity and uncertainty of supply networks (SNs) increase, strategic management for resilient SNs becomes significant. An intelligent contingency plan, rather than a direct and constant back-up plan, is more suitable for flexible and effective management. In this research, we introduce a unique contingent multi-sourcing decision protocol for effective response when disruptions occur. It is called the Intelligent Contingent Sourcing (ICS) protocol. Unlike previous research, which has mostly considered the constant multi-sourcing[1] among internal suppliers, our model is developed for contingent multi-sourcing by collaboration with external suppliers. (When both the supplier and buyer are managed/controlled by the same company, that supplier is considered an internal supplier; in case each supplier is independent in terms of buyers and is self-interested, such supplier is considered an external supplier). Such contingent multi-sourcing requires the theoretical analysis of each participant's economic aspect, because each external supplier is independent and thus self-interested. The ICS protocol forms a contingent collaborative coalition based on a distributed decision making process. To evaluate the performance of the ICS protocol, three sourcing models are compared: (1) Single sourcing, (2) Constant multi-sourcing, and (3) Contingent multi-sourcing by the ICS protocol. Statistical analysis reveals that, with statistical significance, the ICS protocol performs at least equal to or better than single sourcing, in terms of less lost sales and less total costs; ICS protocol also outperforms constant multi-sourcing under specific conditions (stated in the article).

1. Introduction

As the complexity of supply network increases and the connectivity among its participants becomes denser, a sudden disruption in some parts can cause serious chain effects. For example, Ericsson, a leading company in telecommunication industry, faced a huge shortage of cellular phone component, due to a fire in suppliers in New Mexico; therefore, they lost significant market share within a short period of time. Apple also failed to deliver computer components on time, due to earthquakes that hit their main factories in Taiwan. It made them lose a huge amount of customers. Soon after 9/11, some trucks of automobile company loading in Canada and Mexico were delayed several weeks because cross-border shipments necessary for just-in-time inventory system were delayed at the border (Briand & Huzurbazar, 2008; Chopra & Sodhi, 2004; Sheffi & Rice, 2005).

In such situations, studies have been paying attention to ways to mitigate the impact of supply network disruptions. Rodger has analyzed the dynamics of supply chain as a complex system prone to uncertainty (Rodger, 2014). Lavastre et al. have investigated an empirical study of French companies to emphasize the importance of supply chain risk management (Lavastre, Gunasekaran, & Spalanzani, 2012). In general, there are four types of basic mitigation strategies: demand management, supply management, product management, and information management (Tang, 2006). In this research, we have focused on the supply management for resilient SNs – especially the intelligent contingent multi-sourcing when disruption occurs. Various studies about multi-sourcing have been conducted so far (Anupindi & Akella, 1993; Dada, Petruzzi, & Schwarz, 2007; Lara Gracia & Nof, 2009; Swaminathan & Shanthikumar, 1999; Tomlin & Wang, 2005). Especially, Kristianto, Gunasekaran, Helo, and Hao (2014) have proposed a model to find shortest path when disruption occurs. According to the previous

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[1] In this paper, constant multi-sourcing means that each manufacturer is supplied from only pre-determined suppliers and the amount of materials supplied from each of them is fixed. Only disrupted supplier cannot supply until recovery is finished. On the other hand, in case of contingent multi-sourcing, the suppliers and the amount of materials supplied can be changed according to the current condition.

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research, resources have been distributed to multiple suppliers, in order to minimize the damage from disruption. The remaining issue is the trade-off between cost-effectiveness and reliability of this strategy – a resource allocation to multiple suppliers. Although reliability increases by adding more suppliers, a company has to pay more pre-operational expenses, such as additional set up cost, maintenance cost, and transportation cost. Hence, many sourcing algorithms have been developed in order to decide the optimal number of suppliers and appropriate order quantity.

However, most previous research has only considered the multi-sourcing among internal suppliers that are controlled by a centralized headquarter (under the same company as that of buyers) in order to achieve a common goal. The contingent sourcing with external suppliers, which are independent and have self-interested goals, has not been sufficiently studied so far. Because of the conflict of interests among members, collaboration with external suppliers is recognized as difficult to be conducted in reality. However, as the probability of disruptions in SNs increases and its chain effect becomes serious, companies are starting to consider a contingent sourcing from external suppliers, e.g., other manufacturers' suppliers, by intelligent win–win collaboration. Such collaboration can achieve more resilient and cost-effective performance when disruption occurs. First of all, a contingent sourcing from external suppliers can reduce the risk of excessive investment in fixed safety stock. Moreover, under specific conditions, selective contingent collaboration tends to outperform constant multi-sourcing. For example, as disruption is rarer, the selective and temporary collaboration can be more profitable than constant multi-sourcing, for which a company has to keep its connection with multiple suppliers by paying excessive maintaining costs. Thirdly, as the number of participants in collaboration increases, the damage from disruption can be compensated more efficiently. Similar concept of collaboration with external partners has been applied in capacity sharing among manufacturers (Seok & Nof, 2014a, 2014b; Yoon & Nof, 2010).

Another critical reason is that many causes of disruptions in SNs, e.g., hurricanes, earthquakes, and floods, are difficult to be accurately predicted. When based on such incomplete prediction, the performance of sole sourcing and constant multi-sourcing also can be unreliable. On the other hand, in case of contingent collaborative multi-sourcing, companies use real-time information; therefore, they can response more appropriately.

In this paper, we have developed the decision protocol for an intelligent contingent multi-sourcing with external suppliers – we call this the Intelligent Contingent Sourcing (ICS) protocol. The ICS protocol designs the contingent sourcing coalitions according to the current condition, by estimating expected profits and costs. We have estimated its performance under various conditions, e.g., with different prices/costs and under different frequency of disruptions, and compared the performance with those of single sourcing and constant multi-sourcing strategies. In general, there are two types of manufacturers in collaboration: (1) the one who faces supply deficiency due to the disruption in the suppliers, and (2) the ones who are able to help 1). Because we assume that each manufacturer and their suppliers are self-interested and independent, the ICS protocol simultaneously considers the profitability of each supplier in a distributed decision making process.

The remainder of this article is organized as follows. The background of the proposed study is presented in Chapter 2, and the mechanism of contingent collaborative sourcing and detailed procedure of the ICS protocol are described in Chapter 3. After empirically demonstrating the performance of this protocol in Chapter 4, the conclusion and necessary future work are discussed in Chapter 5.

2. Background and motivation

2.1. Resilient SNs

Because major operational disruptions have increased at double digit rates by complex reasons, the significance of appropriate strategies and management for resilient SNs has become greater (Anupindi & Akella, 1993). In such a situation, many researchers have studied various ways to reduce, and avoid serious effects of disruptions, e.g., use of reliable inventory management, production planning and capacity allocation, and so on. Parlar and Berkin have revised the EOQ model including uncertainty duration parameters in order to consider risks in SNs (Parlar & Berkin, 1991). Gupta has developed the (Q, r) inventory policy under consideration of unreliable suppliers (Gupta, 1996). Qi et al. have suggested the coordination model between one supplier and one retailer in order to accommodate demand disruptions (Qi, Bard, & Yu, 2004). Both supplier and retailer cooperatively adjust their plan/policy in order to adapt the changed market conditions, such as having well-timed wholesale quantity discount when demand disruptions occur. In a similar study, Xiao and Qi have studied the coordination model to be used in case production cost is disrupted (Xiao & Qi, 2008). They have modeled the coordination between manufacturer and two retailers, specially focusing on the effective discount policy by price competition between retailers. Also, they have considered the extended coordination model, which deals with cost and demand disruptions by equilibrium strategies. On the other hand, general analyzes of disruption itself have also been conducted. Wu et al. have presented the network-based disruption model on a system-oriented view (Wu, Blackhurst, & O'Grady, 2007). They have used Disruption Analysis Network (DA_NET) model which estimates the possible disruptions and analyzes how these will be propagated through the SNs. Pai et al. have reviewed various techniques used in SNs decision making; especially, various risk analyzes, applied with fuzzy logic, Bayesian network, and hybrid-fuzzy logic, have been described (Pai, Kallepalli, Caudill, & Zhou, 2003). Han and Chen have used Bayesian approach in analyzing SNs risks based on expert's knowledge (Han & Chen, 2007). Lockamy and McCormack have applied Bayesian model in estimating outsourcing suppliers' external, operational and network risk probabilities, and the associated revenue impacts (Lockamy and McCormack, 2010).

In such ways, various types of risk analyzes and strategies for resilient SNs have been discussed; in this research, we have focused more on supply-side management.

2.2. Various sourcing strategies in SNs

Research of multi-sourcing for a reliable supply against sudden disruptions has been extensively studied in previous works. Deciding the optimal number of suppliers is the fundamental research problem. Dan and Yuan have designed the associated model which decides the appropriate number of suppliers, minimizing the total costs. They have analyzed the trade-off between supplier management cost and penalty cost of supply failure (Dan & Yuan, 2007). In a similar approach, Berger and Zeng have decided the optimal number of suppliers by considering the probability of suppliers' disruption and constant financial loss (Berger & Zeng, 2006); they have validated the effectiveness of their approach by comparing the case of single sourcing and multiple sourcing when the optimal number of suppliers is applied. Ruiz-Torres and Mahmoodi have also determined the optimal number of suppliers, by using decision tree under various cases (Ruiz-Torres & Mahmoodi, 2007). Also, various supplier selection models have been developed based on multi-criteria analyzes by Fuzzy technique and AHP (Amin, Razmi, & Zhang, 2011; Vinodh et al, 2011). Especially, Chai, Liu, and Ngai (2013) have reviewed various decision making