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A multi-objective approach to supply chain risk management: Integrating visibility with supply and demand risk

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ABSTRACT

This paper investigates the relationship among supply chain visibility (SCV), supply chain risk (SCR), and supply chain cost of new and seasonal products. We assume that demand is probabilistic and comes from different scenarios such as forecasting, benchmarking, and market analysis data. For utilizing multi-attribute decision modeling, we build a model to maximize SCV and minimize both SCR and supply chain cost from an operational perspective. A heuristic algorithm based on a relaxation method on decision variables is proposed to solve an NP-hard model, and to show how a multi-objective approach provides near-optimum solutions. The results show that more visibility is desirable, because it increases efficiency in a supply chain and decreases both cost and risk.

1. Introduction

The last few years have seen significant events around the world that have increased the awareness of how detrimental risk can be to a business (Elzarka, 2013; Hüner et al., 2014). The impact of such incidents has led to a growing interest in the area of supply chain risk and its management, as evidenced in the number of industry surveys, practitioner conferences, and consultancy reports devoted to the topic (e.g., Muthukrishnan and Shulman, 2006; Chopra and Sodhi, 2014). This has caused supply chain risk management to become central to organizational survival and prosperity (Wildgoose et al., 2012).

Supply chain risk management (SCRM) is a new area emerging from a growing appreciation for supply chain risk by both practitioners and researchers (Ghadge et al., 2012; Sodhi et al., 2012; Tang et al., 2013). This area has been on the agenda for many supply chain scholars and practitioners for the past 10 years. This includes books on SCRM (e.g., Brindley, 2004; Zsidisin and Ritchie, 2008; Wu and Blackhurst, 2009; Sodhi and Tang, 2011), special issues on SCRM (e.g., Ritchie and Brindley, 2007; Narasimhan and Talluri, 2009; Tang et al., 2012), and literature reviews of SCRM (e.g., Paulsson, 2004; Tang, 2006; Simangunsong et al., 2012). According to a study conducted by Computer Sciences Corporation, 60% of the firms surveyed acknowledged that their supply chains are vulnerable to disruptions. Supply chain executives in IBM believe that SCRM is the second most important issue for them (IBM, 2008). Furthermore, research conducted by AMR in 2007 reported that 46% of the executives believe that better SCRM is needed (Hillman and Keltz, 2007). However, few companies have taken commensurate actions to build supply chains that are capable of responding to disruptions (Muthukrishnan and Shulman, 2006).

Supply chain risk management is not just about responding to natural disasters. There are many other risks associated with doing business on a daily basis; examples are daily fluctuations in demand and supply and rapid growth (Sodhi, 2005; Sodhi et al., 2008). In order to properly assess supply chain risk and respond to disruptions, visibility across the supply chain is required (Hendricks and Singhal, 2012). Supply chain visibility is the capability of sharing on-time and accurate data on customer demand, amount and location of inventory, cost of transportation, and other logistics dimensions throughout an entire supply chain (Hendricks and Singhal, 2005a, b). Christopher and Lee (2004) suggest mitigating supply chain risks through improving "end-to-end" visibility of the supply chain. Supply chain visibility should also include the capability for forward-looking, predictive views of the supply chain (Hendricks and Singhal, 2005a, b). By enabling comprehensive visibility in a single unified system, many situations that could lead to disruptions in the supply chain can be identified and defused long before they reach a critical state. Good visibility in the supply chain can yield benefits in operations efficiency and more effective supply chain planning (Yu and Goh, 2014).

The above discussion suggests that one of the main considerations in supply chain risk (SCR) management is the visibility of the risk. While we acknowledge that SCR is wide ranging, we limit our scope of SCR in this paper to supply risk and demand risk. We extend prior

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studies in supply chain risk and supply chain visibility through using a multi-objective approach to supply chain visibility and risk as recommended by Yu and Goh (2014). In this approach, SCV has been connected to the capability of obtaining up-to-date information on demand, quantity and location of inventory, transport-connected cost, and other logistics activities throughout an entire supply chain. Similarly, SCR can be regarded as risks associated with incidents such as an unanticipated event within a supply chain and the associated negative outcomes of that event on the supply chain. There are conflicting challenges between supply chain visibility and supply chain risk. Our proposed model combines the objectives of SCV maximization, SCR minimization, and supply chain cost minimization under the constraints of budget, probabilistic customer demands, production capacity, and supply availability assuming time parameter.

In this paper, we follow the recommendation and suggestion in the literature provided by Yu and Goh (2014), considering a triple objective of cost, risk, and visibility for the downstream supply chain. We assume a condition that new time-dependent products with demand under risk are included in the model. New seasonal products (e.g., automotive, electronics) with demand under risk and other time-dependent parameters increase the total complexity of our model. Practically, our model is more applicable where we are not sure about demand in each time period. In such a dynamic and evolving market, we need to keep our supply chain visibility at a high level while we face supply risk. This type of model can be used for new products (e.g., automotive and electronic devices) where products are newly developed and produced. New products have such characteristics that when they arrive to the market for the first time, they should maintain high visibility.

The remainder of this paper is organized as follows. First a review of the literature on supply chain risk management and supply chain visibility is provided. Then, the model is specified. In order to examine how the model behaves, a numerical example with limited variables is presented. Later, a heuristic algorithm is developed to solve the numerical example with some analytical discussion on results. Finally, we provide limitations and future research directions.

2. Literature review

The study of supply chain visibility (SCV) has drawn considerable interest from both researchers and practitioners in supply chain management (Barlett, et al., 2007). In their analysis of supply chains, Harland et al. (2003) report that half of the risk was visible to the focal company. The central question in the relationship between supply chain risk and supply chain visibility is how to choose suppliers in order to minimize the supply risk and how to enhance visibility without exceeding the production or total budgets. According to Enslow (2006), about 79% of the large companies surveyed globally cited lack of SCV as their top concern. Furthermore, an alarming 90% of the responding supply chains asserted that their existing supply chain technology is incapable of providing timely information to prepare budget and cash flow plans for the finance department. Delen et al. (2007) and Zhou (2009) argue that through the implementation of RFID, SCV can be enhanced to eliminate supply chain barriers by enabling and sharing information and eventually improving supply chain performance. Ouyang (2007) further shows that SCV implementation can enhance supply chain stability and mitigate the bullwhip effect. This concurs with Goh et al. (2009), who define SCV as the capability of a supply chain actor to access to or to provide the required timely information/knowledge in the supply chain from/to relevant supply chain partners for better decisions.

While some work on visibility in supply chains has been undertaken, this area is still nascent (e.g., Smaros et al., 2003). Zhang et al. (2010) have also reported that global supply chain and logistics operators clearly seemed to benefit from end-to-end visibility of the supply chain. Thus, there is a need to better understand and properly examine the overall impact of supply chain visibility, supply chain risk, and supply chain cost in the context of multiple objectives. In a review of the current status of research and scholarly work in supply chain risk management, Sodhi et al. (2012) refer to the methodological gap in this area. Our study addresses this issue from the methodological aspect, while providing insight for practitioners on how to address risk, visibility, and cost in the context of a supply chain.

This study extends prior research in supply chain risk and supply chain visibility in several ways. We define demand as a probabilistic parameter that comes from known scenarios (Lau et al., 2000). Moreover, we define risk in based on any type of supplier risk. Each supplier imposes risk on our model, and we need to minimize total risk from the supply side. We consider specifically the context of a focal firm that has to strategically consider the triple objectives of cost, risk, and visibility for the downstream supply chain (push strategy), while demand is probabilistic for new products along with the complexity that comes from the time-dependent parameter.

3. Model development

A mathematical model is developed incorporating SCV and SCR as well as supply chain cost, so that the appropriate suppliers can be identified. The proposed multiple-objective integer programming model includes three objectives: visibility maximization, risk minimization, and cost minimization. The formulation of the model is described as follows.

Index variables
- i index of products
- j index of suppliers
- t index of time

Decision variables
- Q_{ijt} quantity of product i provided by supplier j in period t
- Y_{ijt} a binary variable determined by whether product i is supplied by supplier j in period t

Parameters
- B_{it} budget available to enhance SCV for product i in period t
- C_{jt} production capacity of supplier j in period t
- CR_{ijt} cost of reducing supply risk for product i from supplier j in period t
- CV_{ijt} cost of enhancing SCV to current level for product i from supplier j in period t
- D_{it} demand of product i in period t
- m_{ijt} minimum order quantity for product i required by supplier j in period t
- P_{ijt} purchase price for product i supplied by supplier j in period t
- IR_{ijt} impact (financial loss) caused by supply risk for product i from supplier j in period t
- R_{ijt} supply risk for product i from supplier j in period t
- R_{it} maximum allowable supply risk for product i in period t
- V_{ijt} supply chain visibility incurred if product i is supplied by supplier j in period t
- V_{it} minimum amount of visibility needed for product i in period t

Model:

$$\text{Max visibility} = \sum_i \sum_j \sum_t V_{ijt} Y_{ijt} \quad (1)$$

$$\text{Min Risk} = \sum_i \sum_j \sum_t R_{ijt} Y_{ijt} \quad (2)$$