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Development of risk based dynamic backorder replenishment planning framework using Bayesian Belief Network

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ABSTRACT

Due to the rapid changes in circumstances of cooperates such as globalization, technical innovation and competition, inter-dependence among cooperates which compose supply chain has been intensified. This make cooperates be exposed to various risk and even a small uncertainty can disrupt the balance of whole supply chain. Therefore, in this paper, the framework to develop alternative backorder replenishment plan to minimize the total replenishment cost and expected risk cost has been devised. In order to model the relationship between risks and risk propagation, Bayesian Belief Network has been applied. Moreover, with the fast heuristic algorithm, breath first search and elementary stepwise system based reverse Dijkstra, the alternative backorder replenishment plan can be established. The numerical example shows how to apply the proposed framework and make dynamic backorder replenishment plan considering impact of risk.

1. Introduction

Recently, supply chain management becomes more complex in the phase of planning and operation due to the integration and globalization. Therefore, the academia and the industry have shown a growing interest for efficient supply chain management, which come from the rising of manufacturing and transportation cost and the globalization of market economics. These business trends are leading to complex, dynamic supply network. One consequence is that uncertainties are increasing, and shifting around supply network (Harland, Brenchley, & Walker, 2003). Also, the increasing uncertainty requires companies to spend more resources to anticipate for demand, supply, as well as internal uncertainties for better sustainability of their supply chain. Interestingly, such an increasing uncertainty is not solely induced by the external business environments, but also due to the increasing complexity of the supply chain structure and variety of mechanisms initiated by the supply chains in their business (Vanany & Pujawan, 2009). These uncertainties and factors that have negative impact on the business outcomes can be defined as the supply chain risk.

Accordingly, the supply chain risk management (SCRM) is rapidly developing into a favoured research area for academicians as well as practitioners in global environment (Manuj & Mentzer, 2008), and it was introduced in the Supply Chain Operation Reference (SCOR) model since the version 8.0 (Supply-Chain Council, 2008). But, these business trends are not the only reason that SCRM has been highlighted. During military operations, it is the vital necessary condition for the victory to design the optimal strategies to flexibly cope with the risk factors like designing optimal route of arms or war supplies. The Gulf war is the most typical example (Matthews & Holt, 1995).

A great deal of researches proposed risk management strategies to develop the optimal counter plans for the supply chain operations in the planning phase to deal with the independently identified risk. And the ultimate object, to enhance the flexibility of the supply chain, can be accomplished by reducing the probability of occurrence, the severity of impact, or both. Here, the more interesting characteristic of supply chain risk not to be ignored is that the risk shifts around the supply network. Also, the supply chain linkage has great impact on the supply chain performance such as benefit and risk reduction (Zelbst, Jr, Sower, & Reyes, 2009). Thus, with the increased complexity of supply chain network, the location of risk has shifted and changed through the whole networks (Harland et al., 2003). The case of Daimler Chrysler may be the most famous practice. It was Hurricane "Floyd" which flooded a plant producing suspension parts in Greenville, North Carolina. As a result, seven of the company's other plants across North America had to be shut down for seven days (McGillivray, 2000).

However, a few researches to proactively cope with risk in the execution phase have been conducted in the limited area such as inventory management considering dynamics of demand (Clark & Scarf, 1960; Iglehart & Karlin, 1961; Kim, Jun, Baek, Smith, & Kim, 2005; Lingxiu & Hau, 2003; Song & Zipkin, 1993) or coping

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with disruption risk (Altay & Ramirez, 2010; Skipper & Hanna, 2009). Therefore, more attention and effort need to be paid to the execution phase of the supply chain management. Especially, impact or expected loss over the entire supply chain when the risk breaks out should be understood. In addition, both internal and external risk should be controlled in the balance.

The main objective of this paper is to propose a novel risk management approach that considers the inter-relationship between supply chain risk and the structure of network at the same time. The risk propagation is modelled by using Bayesian Belief Network (BBN), which is widely applied to various areas such as biology, genetics, medical science, enterprise risk management and financial engineering (van der Gaag, 1996). With the backorder replenishment problem, we demonstrate how to practically apply the proposed approach and reduce the expected cost from supply chain risk.

The rest of this paper is organized as follows. In the Section 2, basic definition, concepts and previous researches related to BBN and SCRM are introduced and analysed. And then we explain how to model the risk propagation with BBN, to develop dynamic backorder replenishment problem, and to design a heuristic algorithm to find the optimal solution in Section 3. The numerical example is presented to explain the way to apply the proposed framework in Section 4. Finally, we conclude with the contributions and further work in Section 5.

2. Backgrounds and related work

In this section, the concept, characteristics and applications of BBN are presented at first. In addition, the basic definitions and concepts for SCRM are explained. Some contributions and limitations of previous researches related to SCRM are pointed out as well.

2.1. Bayesian Belief Network

A BBN is a graphical model that combines elements of graph theory and probability theory. A BBN describes a set of causal relationships among a set of variables of interests, as set of conditional independence assumption, and their related joint probabilities. A directed acyclic graph (DAG) portrays the causal relationships among the variables (nodes). A BBN can be defined by combining belief network and conditional probability distribution as described in Definition 2 and Proposition 1 (VanderGaag, 1996).

Definition 1. A belief network can be defined with a tuple $B = (G, \Gamma)$ where

- $G = (V(G), A(G))$ is a directed acyclic graph with nodes $V(G) = \{V_1, \ldots, V_n\}$, $n \geqslant 1$, and arcs $A(G)$:
- $\Gamma = \{\gamma_{V_i} | V_i \in V(G)\}$ is a set of real-valued non-negative functions

$$\gamma_{V_i} : \{C_{V_i}\} \times \{C_{PG(V_i)}\} \rightarrow [0, 1]$$

called (conditional) probability assessment functions, such that for each configuration $C_{PG(V_i)}$ of the set $PG(V_i)$ of (immediate) predecessors of node V_i in G.

Proposition 1. Let $B = (G, \Gamma)$ be a belief network. Then,

$$\Pr\{C_{V(G)}\} = \prod_{V_i \in V(G)} \gamma_{V_i}(V_i | C_{PG(V_i)})$$

defines a joint probability distribution Pr on $V(G)$.

The real power of BBN manifests itself as the network applies the rules of Bayesian inference to propagate the impact of evidence on the probabilities of selected outcomes. As BBN can answer *what-if* questions, about the variables that appear in the network, it may include diagnostic reasoning, predictive reasoning, or inter-causal reasoning. When used in this way, BBN can be thought as powerful probabilistic inference engines (Lauría & Duchessi, 2006). Parameterized BBNs may be used for several different inferential tasks, including classification, prediction, and diagnosis. Due to the characteristics of BBN, it has applied to wide range of research areas such as ecology (Marcot, Holthausen, Raphael, Rowland, & Wisdom, 2001; Pollino, Woodberry, Nicholson, Korb, & Hart, 2007), project management (Fan & Yu, 2004; Hui & Liu, 2004; Lee, Park, & Shin, 2009), IT system implementation (Hu, Chen, Huang, Liu, & Xie, 2007; Hui & Liu, 2004; Lauría & Duchessi, 2006; Neil, Littlewood, & Fenton, 1996) and ERM (Bonafede & Giudici, 2007; Nyberg, Marcot, & Sulyma, 2006; Trucco, Cagno, Ruggeri, & Grande, 2008).

2.2. Definition of supply chain risk and SCRM

Generally, the definition of supply chain risk gets different from the objectives of SCRM and the variety of business environment. For example, risk can be defined as the variance of return (Markowitz, 1952), potential for unwanted negative consequences to arise from an event or activity (Rowe, 1980), the negative variation in business outcomes (March & Shapira, 1987), variance in outcomes or performance that cannot be forecasted ex-ante (Miller, 1992), and possibility of loss (Chiles & McMackin, 1996). It has been expanded to possibility which can have negative impact on achievement of business goals in supply chain management (Bart & Maurice, 2007; Jüttner, Peck, & Christopher, 2003; La Londe, 1997). Several terminologies related supply chain risk such as disturbance, disruption and vulnerability are used to describe slightly different actions or events which have negative impact on the supply chain operations. And opposite terminologies such as resilence, safety, security and sustainability are used to prevent, react on or recover from the state related to the risk. However, these terminologies are utilized to secure achieving the ultimate goal of supply chain management (Pfohl, Köhler, & Thomas, 2010). In this paper, we defined the supply chain risk as following Definition 2 considering general characteristics and objectives of supply chain (Harland et al., 2003).

2.2.1. Definition 2. supply chain risk (SCR)

Supply chain risk is the disconnection of product or information flow which comes from internal or external uncertainties which are not easy to efficient forecast, control and manage in supply chain network.

Like the terminology, supply chain risk, SCRM has been defined in lots of literatures (Kajüter, 2003; Pfohl et al., 2010; Rao & Goldsby, 2009; Tang, 2006). Among of these definitions, we follow the definition of SCRM provided by Kajüter (2003), a collaborative and structured approach to risk management, embedded in the planning and control processes of the supply chain, to handle risk that might adversely affect the achievement of supply chain goals (Kajüter, 2003).

2.3. SCRM framework and strategies

The SCRM framework of a global consulting firm may be the most representative example. This framework has the important procedure which develops the strategy to deal with risks defined in terms of relationships among suppliers, corperates and customers. The result should be fed back into suppliers and customers which is depicted in the Fig. 2 (Bart & Maurice, 2007). US Army has applied its own risk management framework that includes the task of evaluating risk, which is added to the framework developed in (Headquater, 1998). Apparent from these two cases, the