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Controlling the bullwhip effect in a supply chain system with constrained information flows

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ABSTRACT

The bullwhip effect problem is one of the most important issues in supply chain management. Limited information sharing increases the difficulty of reducing the bullwhip effect and leads to inefficient supply chain management. The purpose of this paper is to explore new ways to reduce the bullwhip effect in supply chain systems that face uncertainties with respect to information sharing. We first present a supply chain state transition model, based on which we explore the endogenous mechanism of bullwhip effect, especially those related to impacts from limited information sharing. Then we propose a novel inventory control method and study the corresponding control optimization problem, with the aim of reducing inventory volatility in supply chains. Both quantitative analysis and simulation study are conducted. Simulation results show the effectiveness and flexibility of our proposed method in reducing bullwhip effect and in improving supply chain performance, even under conditions of limited information sharing.

1. Introduction

As a general topic in the process of economic globalization with intensifying competition between companies, supply chain management (SCM) has received considerable attention from both supply chain (SC) practitioners and scholars. Improving supply chain performance and achieving agility in SCM, namely, quick responding to customer demands, increasing products variety, reducing production cost etc., become essential to enterprises [1,2]. Issues in SCM have been addressed in literatures, such as demand forecasting (e.g. [3,4]), resource planning (e.g. [5–7]), scheduling and production process optimization (e.g. [8–10]). Having its root in Forrester's industrial dynamics [11], the bullwhip effect (or Whiplash effect) phenomenon has been recognized as one of the main obstacles in improving supply chain performance and received increasing attention in SCM [12,13]. Studying the endogenous dynamical mechanism of inventory volatility will not only improve our understanding of the bullwhip effect phenomenon but also be helpful in finding countermeasures to such problem.

In the field of SCM, most studies are carried out by building mathematical models. Pishvaee et al. proposed a robust optimization model for handling the inherent uncertain input data problem in designing a market to market closed-loop supply chain network (MMCSCN) [14]. Based on a supply chain channel coordination model, He et al. found that returns policy with sales rebate and penalty contract can bring about the channel coordination and lead to the Pareto-improving win–win situation among supply chain members [15]. Similar research can be found in [16]. In our literature review, we find that, to the bullwhip effect problem, most researches focus on modeling its causes, such as the pricing strategy [17,18] and the ordering policies [19,20], and relatively less on modeling its impact on inventory system [21,22]. In this paper, we propose a supply chain inventory network model based on analyzing the material flows between SC members. This model provides

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us opportunity to investigate the endogenous mechanism of bullwhip effect and its dynamical characteristics from the perspective of inventory system.

On the other hand, it is well known that information flow is an important element in SC networks. Both the accuracy and the availability of information play a vital role in SC operation and in SCM improvement [23,24]. Effect of information sharing on reducing SC operation uncertainty and inventory variability has been studied by Wong et al. [25], Disney et al. [26] and Janamanchi and Burns [27], for instance. In real world, complete information sharing is unrealistic due to various technical, economic and social reasons. So in this paper, uncertainty with respect to information sharing and its effect on inventory dynamics are introduced into our model, which can then better represent the supply chain dynamics as well as the emergence of the bullwhip effect phenomenon.

Given the dynamical characteristics of a supply chain, a natural question arises: can we find appropriate inventory control policy that can suppress the bullwhip effect and reduce its negative impact on the SC stability? Different methods have been proposed and studied, such as the synergistic decentralized production planning proposed by Caramanis et al. [28], and the function transformation techniques applied by Venkateswaran and Son [29]. In recent years, more and more methods and techniques from control theory, for instance, the classical linear control theory, optimal control methods and model predictive control methods, have been applied in SC studies (please refer to [30–33]). However, very little work has been done from the viewpoint of centralized inventory control, which takes into consideration the impact of constrained information flows. So in this paper, based on the proposed supply chain state transition model, we develop a stability-based inventory control method which makes use of information of inventory position. Under this inventory policy, we further explore the conditions (or more precisely the order optimization) which can ensure the suppression of bullwhip effect and the improvement of supply chain stability in inventory replenishment. Results show that the inventory policy design problem can be transformed into the optimization problem of linear matrix inequalities (LMIs). This improves the solvability and practicality of the proposed method.

The rest of this paper is organized as follows: Section 2 introduces the SC state transition model and its inventory control method. Section 3 extends model into SC networks where there are constraints on information flows, and presents the stability analysis of supply chain system under the proposed inventory policy. Section 4 extends analysis to simulation study. Finally, conclusion with future research direction is presented in Section 5.

2. Basic supply chain state transition model

In this section, we build the supply chain state transition model and describe the inventory control method proposed in this study. A typical supply chain system involves several entities: customers, retailers, distributors, manufacturers, and

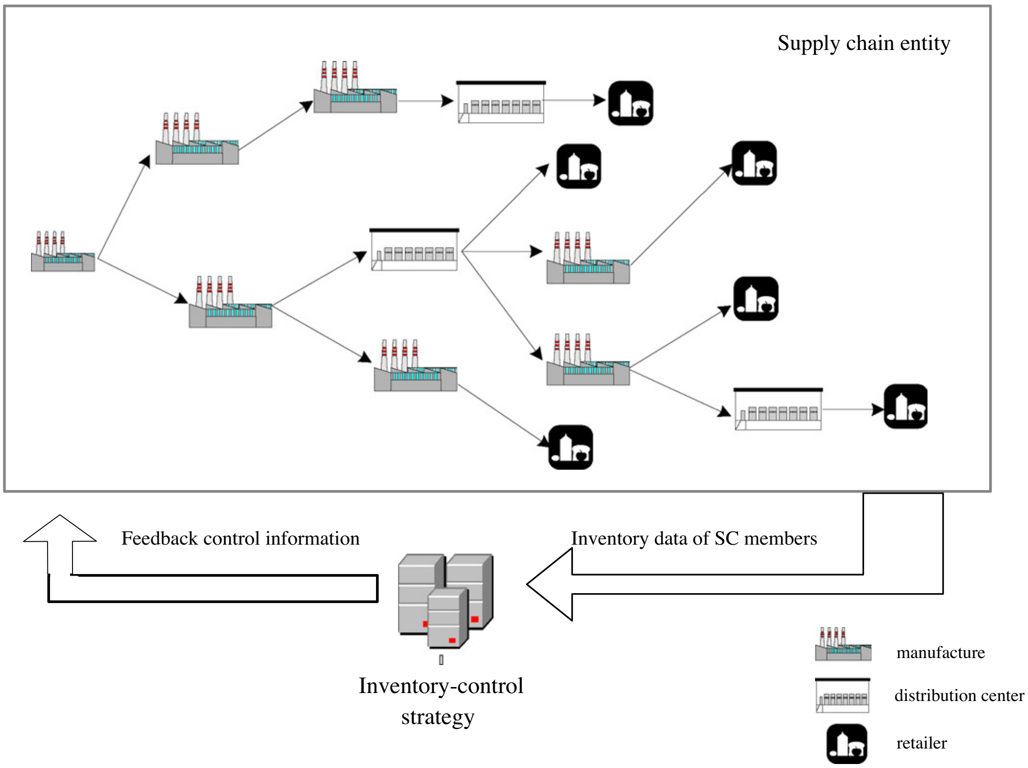

Fig. 1. Supply chain structure.