Expert Systems With Applications 44 (2016) 304–319

Contents lists available at ScienceDirect

Expert Systems With Applications

journal homepage: www.elsevier.com/locate/eswa

Smoothing inventory decision rules in seasonal supply chains

Francesco Costantino[a], Giulio Di Gravio[a], Ahmed Shaban[b,*], Massimo Tronci[a]

[a] Department of Mechanical and Aerospace Engineering, University of Rome "La Sapienza", Via Eudossiana, 18, 00184 Rome, Italy
[b] Department of Industrial Engineering, Faculty of Engineering, Fayoum University, 63514 Fayoum, Egypt

A R T I C L E I N F O

Keywords:
Supply chain
Seasonal demand
Order-up-to
Smoothing
Holt-Winters
Bullwhip effect

A B S T R A C T

A major cause of supply chain deficiencies is the bullwhip effect, which implies that demand variability amplifies as one moves upstream in supply chains. Smoothing inventory decision rules have been recognized as the most powerful approach to counteract the bullwhip effect. Although several studies have evaluated these smoothing rules with respect to several demand processes, focusing mainly on the smoothing order-up-to (OUT) replenishment rule, less attention has been devoted to investigate their effectiveness in seasonal supply chains. This research addresses this gap by investigating the impact of the smoothing OUT on the seasonal supply chain performances. A simulation study has been conducted to evaluate and compare the smoothing OUT with the traditional OUT (no smoothing), both integrated with the Holt-Winters (HW) forecasting method, in a four-echelon supply chain experiences seasonal demand modified by random variation. The results show that the smoothing OUT replenishment rule is superior to the traditional OUT, in terms of the bullwhip effect, inventory variance ratio and average fill rate, especially when the seasonal cycle is small. In addition, the sensitivity analysis reveals that employing the smoothing replenishment rules reduces the impact of the demand parameters and the poor selection of the forecasting parameters on the ordering and inventory stability. Therefore, seasonal supply chain managers are strongly recommended to adopt the smoothing replenishment rules. Further managerial implications have been derived from the results.

1. Introduction

A supply chain is an integrated system wherein a set of organizations/partners; e.g. suppliers, manufacturers, distributors, retailers and customers; are connected by material, financial and information flows in both upstream and downstream directions to satisfy customer demand. A supply chain is a complex and dynamic system that should be designed and managed properly to match supply and demand at minimum cost. The lack of coordination among supply chain partners and the unavoidable uncertainty usually result in severe deficiencies in the supply chain. An example of such deficiency is the bullwhip effect which implies that orders variance amplifies as one moves upstream in the supply chain (see, Fig. 1). Lee, Padmanabhan, and Whang (1997a), (1997b) have indicated with providing some real examples from different industries that, even if the customer demand is stable and stationary, a supply chain will face the bullwhip effect for any case of misalignment between demand and supply. This can be attributed to the tendency of supply chain partners to update their forecasts and inventory control parameters in response to demand uncertainty which may subsequently lead to a propagation of distorted demand information across the supply chain (Disney & Lambrecht, 2008; Lee et al., 1997a, 1997b). Forrester (1958) was almost the first to study the bullwhip effect through a set of simulation experiments utilizing system dynamics modeling, and concluded that the structure, policies and interactions within supply chains are the main drivers of demand variability amplification. Subsequent researchers developed simulation games to illustrate the bullwhip effect existence as well as its negative effects in supply chains (Sterman, 1989).

The bullwhip effect has attracted the attention of academics and practitioners because of its potential negative consequences in supply chains such as excessive inventory investment, poor customer service, lost revenues, misguided capacity plans, ineffective transportation, and missed production schedules (Chatfield, Kim, Harrison, & Hayya, 2004; Lee et al., 1997a, 1997b). Lee et al. (1997a), (1997b) have identified five major operational causes of the bullwhip effect: demand signal processing, lead-time, order batching, price fluctuations and rationing and shortage gaming. Of our particular interest is the demand signal processing which includes the rational practice of adjusting the demand forecasts and accordingly adjusting the parameters of the inventory replenishment policies, where

* Corresponding author at: Department of Industrial Engineering, Faculty of Engineering, Fayoum University, 63514 Fayoum, Egypt. Tel.: +20 842154762; fax: +20 842154760.
E-mail addresses: francesco.costantino@uniroma1.it (F. Costantino), giulio.digravio@uniroma1.it (G. Di Gravio), ahmed.shaban@uniroma1.it, ahmed.shaban@fayoum.edu.eg (A. Shaban), massimo.tronci@uniroma1.it (M. Tronci).

http://dx.doi.org/10.1016/j.eswa.2015.08.052
0957-4174/

Fig. 1. An example of demand variability amplification in supply chain (Costantino et al., 2015a).

doing this rationale adjustment may cause under/over-reactions to short-term fluctuations in demand, inducing the bullwhip effect (Costantino, Di Gravio, Shaban, & Tronci, 2015a, 2015b, 2015c; Dejonckheere, Disney, Lambrecht, & Towill, 2004). Extensive research has been devoted to quantify the impact of the demand signal processing and the other bullwhip effect causes, utilizing several modeling approaches (Chatfield, 2013): statistical modeling (Chen, Drezner, Ryan, & Simchi-Levi, 2000a, 2000b; Cho & Lee, 2013), simulation modeling (Chatfield et al., 2004; Chatfield, 2013; Costantino, Di Gravio, Shaban, & Tronci, 2014a, 2014b, 2014c) and control theoretic modeling (Dejonckheere, Disney, Lambrecht, & Towill, 2003; Dejonckheere et al., 2004; Jakšič & Rusjan, 2008). The summary of the relevant literature is presented in Table 1 showing clearly this classification.

Previous research has emphasized the importance of selecting accurate forecasting methods and proper ordering policies (inventory decision rules) in order to counteract the bullwhip effect in supply chains (Costantino, Di Gravio, Shaban, & Tronci, 2015b; Costas, Ponte, de la Fuente, Pino, & Puche, 2015; Dejonckheere et al., 2004; Jaipuria & Mahapatra, 2014; Shaban, Costantino, Di Gravio, & Tronci, 2015; Wright & Yuan, 2008). The majority of the bullwhip effect studies have been considering the order-up-to inventory policies in their models motivated by its common use in practice (Chen et al., 2000a, 2000b; Costas et al., 2015; Dejonckheere et al., 2004). Most previous studies have shown that the bullwhip effect is guaranteed when the order-up-to inventory policy (OUT) is employed in supply chains irrespective of the forecasting method integrated with it and without making any assumptions about the demand process (Bayraktar, Koh, Gunasekaran, Sari, & Tatoglu, 2008; Dejonckheere et al., 2003, 2004). Costas et al. (2015) have recently confirmed the same conclusions for the OUT inventory control policy and proposed the Goldratt's Theory of Constraints to reduce the bullwhip effect.

The bullwhip effect implies information distortion in the sense of demand variability amplification as one moves upstream in the supply chain, causing severe inefficiencies such as high production and transportation costs. In traditional supply chains, each supply chain partner relies on the incoming orders from the adjacent downstream echelon to make his forecasting and inventory planning which means that the upstream echelons receive distorted demand information. To achieve intelligent supply chain system, the first step should be allowing the upstream echelons to have accurate information (or less distorted information) on the customer demand. Most importantly, smoothing replenishment rules have been recognized as the most powerful approaches to avoid/eliminate the bullwhip effect. Many researchers have been attempting to evaluate their dynamic performance compared to other traditional ordering policies, under various operational conditions. The available smoothing replenishment rules have been developed mainly based on the periodic review order-up-to policy by incorporating smoothing terms in the OUT replenishment rule where their rationale is to avoid the over/under-reaction to short-run fluctuation in demand and thus limiting the bullwhip effect (Costantino et al., 2015a; Dejonckheere et al., 2003, 2004). In traditional OUT, the replenishment order decision is generated to recover the entire gaps between the target and current levels of net inventory (safety stock) and supply line inventory, while in smoothing OUT only a fraction of each gap is recovered (controlled by the smoothing terms/parameters), where the target levels are dynamically updated according to demand forecast in every review period. However, some research works have shown that dampening the bullwhip effect might increase inventory instability causing low service level (Costantino et al., 2015a; Disney & Lambrecht, 2008; Jaipuria & Mahapatra, 2014). In Table 1, we provide further details on the previous research related to the context of this paper, focusing on the modeling aspects and the scope of study.

The majority of the bullwhip studies have assumed that the demand process is non-seasonal and stationary process, e.g., modeling it as autoregressive moving average (ARMA) and its variants (Cho & Lee, 2012, 2013; Costantino, Di Gravio, Shaban, & Tronci, 2013b; Wang & Disney, 2015). In particular, most of the previous studies have quantified the bullwhip effect in supply chains facing customer demand follows the autoregressive AR and ARMA demand processes; and employing the traditional OUT policy with different forecasting systems such as moving average (MA), exponential smoothing (ES), and mean squared error optimal forecasting (MMSE) methods (Chandra & Grabis, 2005; Chen et al., 2000a, 2000b; Costantino et al., 2015a, 2015b; Disney, Farasyn, Lambrecht, Towill, & de Velde, 2006; Hussain, Shome, & Lee, 2012; Ma, Wang, Che, Huang, & Xu, 2013; Zhang, 2004). Many other studies have adopted the normality assumption for modeling the external demand in similar supply chain models (Chatfield, 2013; Chatfield et al., 2004; Costantino, Di Gravio, Shaban, & Tronci, 2013a, 2013b; Costas et al., 2015; Dejonckheere et al., 2004). The same conclusions are valid for the previous studies on the smoothing replenishment rules where previous studies have been considering step demand (Ciancimino, Cannella, Bruccoleri, & Framinan, 2012; Dejonckheere et al., 2004) or other common non-seasonal demand process such as normal and autoregressive (Costantino et al., 2015b; Dejonckheere et al., 2004). In general, there is a lack of studies that have been devoted to study the bullwhip effect in seasonal supply chains, either for traditional OUT or for smoothing OUT inventory decision rules (Bayraktar et al., 2008; Cho & Lee, 2012; Costantino et al., 2015a). This can easily be seen in Table 1 that summarizes the relevant literature according to some categories, modeling technique, inventory control policy, forecasting method, demand model, performance metrics and scope of study. This table is adapted from Costantino et al. (2015b) but with incorporating the proper changes to support the context of this research.

The seasonality phenomenon of demand is a common occurrence in many supply chains where it is common that a supply chain faces demand process contain a seasonal cycle repeats itself after a regular period of time (Wei, 1990). The seasonality may stem from multiple factors such as weather, which affects many