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On bullwhip-limiting strategies in divergent supply chain networks ☆

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ABSTRACT

The amplification of demand variation in a supply chain network (SCN) is a well-known phenomenon called the bullwhip effect. This effect generates a large volume of inefficiencies as it moves a greater number of units than necessary, increases stock and generates stock-outs. There are two different approaches for avoiding and/or limiting this detrimental phenomenon that have received attention in the literature: Collaboration and information sharing in SCNs on one hand, and the adoption of smoothing replenishment rules on the other. The effectiveness of both approaches have been often analyzed only for "serial linked" SCNs, which is a supply network structure rarely found in real-life. In order to give an insight of how these techniques would perform in more generic SCNs, a divergent SCN has been benchmarked against the classical serial SCN. The computational experience carried out show that the bullwhip effect can be considerably reduced by collaboration or the smoothing replenishment rules in divergent SCNs, but it always performs worse than the serial SCN due to its inherent complexity.

1. Introduction

Managing a supply chain network (SCN) is a dynamic decision task shown to be prone to systematic errors, collectively referred to as the bullwhip effect (Cantor & Katok, 2012; Lee, Padmanabhan, & Whang, 1997). This effect refers to the phenomenon occurring when the orders from the supplier have larger variance than the ones from the customers, i.e. variance amplification (Strozzi, Noè, & Zaldívar, 2012). This is known to inevitably lead to excessive inventory investment, poor customer service, lost revenues, misguided capacity plans, ineffective transportation, and missed production schedules (Chen, Hao, Li, & Yiu, 2012). As a consequence, this effect increases the cost of operating the SCN. Indeed, it has been estimated that a potential 30 billion dollar opportunity exists in streamlining the inefficiencies of the grocery supply chain, which has more than 100 days of inventory supply at various nodes in its supply chain (Subramanian, Rawlings, Maravelias, Flores-Cerrillo, & Megan, 2012).

The Bullwhip Effect is commonplace in contemporary SCNs (Li & Liu, 2013) and, as reported by Ali, Boylan, and Syntetos (2012), any further contribution in this area is of considerable importance to SCN practitioners.

Research related to the bullwhip effect in SCNs has a long tradition which can be broadly divided into three streams (Nepal, Murat, & Babu Chinnam, 2012). The first stream of research focuses on determining the impact of forecasting techniques employed by SCN players on the bullwhip effect. The other two streams of research in the bullwhip effect analysis include an examination of the impact of operations management parameters (such as ordering policy, inventory management policy, and production variation and batching) and SCN dynamics (such as information sharing) on the bullwhip effect (Nepal et al., 2012). The latter streams have mainly focused on the dampening techniques to reduce this detrimental phenomenon. Specifically, two different approaches for avoiding and/or limiting the bullwhip effect have received attention: collaboration and information sharing in the SCN and the adoption of the smoothing replenishment rules (Cannella & Ciancimino, 2010).

Information sharing is the practice of making strategic and operation information available for other partners of the network. It creates visibility along the network and helps suppliers to plan their replenishment and delivery schedules (Prajogo & Olhager, 2012). Information sharing is regarded as one of the main drivers to improve or even optimize the overall SCN performance (Voigt & Inderfurth, 2012). More specifically, by using information sharing, SCN members can manage their inventory on the basis of customers' demands, thus removing or mitigating harmful problems resulting from the bullwhip effect (Cho & Lee, 2011).

A smoothing replenishment rule is a (S,R) policy in which the entire deficit between the S level and the available inventory is

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not recovered in a review period (Boute, Disney, Lambrecht, & Van Houdt, 2009). For each review period R the quantity O is generated to recover only a fraction of the gap between the target on-hand inventory and the current level of on-hand inventory, and a fraction of the gap between the target pipeline inventory and the current level of pipeline inventory (Cannella, Ciancimino, & Framinan, 2011). As reported by Wang, Disney, and Wang (2012a) this ordering policy was found to mimic real-life decisions made by players of the Beer Game, Sterman (1989). The rationale for the smoothing replenishment rule is to limit the tiers' over-reaction/under-reaction to changes in demand (Cannella & Ciancimino, 2010). This policy is able to solve the detrimental consequence of the adoption of the classical Order-up-to (OUT), as it is well recognized that this policy may lead to the bullwhip effect (Disney & Towill, 2003a; Wei, Wang, & Qi, 2013).

The aforementioned studies attest that there is scientific evidence that the practices of information sharing and smoothing replenishment rules lead to a reduction of the bullwhip effect. However, when quantitatively assessing the efficacy of these bullwhip avoidance strategies, most of the studies are confined to the classical mono-echelon structure, or the two-echelon supply chain (Bhattacharya & Bandyopadhyay, 2011). Even though many researchers have argued that the results obtained for a single-echelon environment should work in a multi-echelon environment, it has been shown recently that this assumption does not necessarily hold (Cattani, Jacobs, & Schoenfelder, 2011). Similarly, in studies devoted to analyze the impact of bullwhip reduction strategies in multi-echelon SCNs, it has been adopted a "serially linked" echelon structure (Disney, Naim, & Potter, 2004; Sterman, 1989) (i.e. Retailer, Wholesaler, Distributor and Manufacturer). This modeling assumption is also adopted because it is assumed that any SCN can be simplified to a serially linked SCN. In fact, by modeling each echelon as a transfer function (please see Dejonckheere, Disney, Lambrecht, & Towill, 2003, 2004; Disney & Lambrecht, 2008; Disney & Towill, 2003a, among others), two parallel echelons can be simplified to a single echelon. Even though several countermeasures to the bullwhip effect have been studied and implemented in real businesses using this modeling assumption, it is seldom verified in real SCNs (Bhattacharya & Bandyopadhyay, 2011). In fact, as recently advocated by Moser, Kern, Wohlfarth, and Hartmann (2011), and Xuan, Du, Li, and Wu (2011), it would also be interesting to assess the dynamics of SCNs with multi-retailers condition that better reproduce the real-world SCNs, such as the divergent or arborescent SCN (Beamon & Chen, 2001). This structure is characterized by a tree-like structure, where every stock point in the system receives supply from exactly one higher level stock point, but can supply to one or more lower level stock points (Hwarng, Chong, Xie, & Burgess, 2005).

In summary, to the best of our knowledge, there is a lack of consistent studies and experimental reports assessing the bullwhip dampening features of the information sharing and smoothing replenishment rule in divergent SCNs and, in general, in no-serial SCNs. Thus, there is the need of study the impact of these strategies on SCNs characterized by more than one member in the same level of the supply chain. Motivated by these observations, the aim of this paper is twofold: (1) to analyze the impact of these bullwhip reduction strategies on a divergent SCN and (2) to compare this impact with the effect of these techniques on the widely used serial SCN.

To fulfill these research objectives, we first model a classical four-echelon serial SCN structure (i.e. 1 Retailer, 1 Wholesaler, 1 Distributor and 1 Manufacturer) as in Chatfield, Kim, Harrison, and Hayya (2004), and a new complex multi-echelon SCN (i.e. 8 Retailer, 4 Wholesaler, 2 Distributor and 1 Manufacturer), and we perform a comparative analysis between the two SCNs for four scenarios, i.e. (1) classical OUT, no info-sharing; (2) smoothing replenishment rule, no info-sharing; (3) classical OUT, info-sharing; (4) smoothing replenishment rule, info-sharing.

To perform the analysis we adopt the shock lens input demand as described in Towill, Zhou, and Disney (2007). This approach can be viewed as a "crash test" or a "stress test", i.e.: studying the system performance under an intense and violent solicitation test to determine the resilience of a given SCN structure (Cannella & Ciancimino, 2010). SCNs are modeled using SCOPE, a multi-agent based simulation platform.

The results confirm that the bullwhip avoidance features of the strategies are also significant for the arborescent SCN. Furthermore, we encounter several differences in the dynamic behavior between the serial SCN and the arborescent SCN, particularly for the no information sharing under OUT scenario. In general, the divergent SCN performs always worse than the traditional structure. However, the discrepancies in performance between the structures can be considerably reduced by the adoption of the two bullwhip avoidance strategies analyzed. Thus, we show how these strategies not only reduce the bullwhip effect in SCNs but also increase the robustness of complex SCNs.

The rest of the paper is organized as follows: Section 2 presents a literature review. Section 3 describes the methodological approach. Section 4 presents the serial SCN and the divergent SCN to be modeled. Section 5 presents the metrics system employed to compare the SCNs and the design of experiments. Section 6 presents the results together with their discussion. Section 7 includes the findings and managerial implications, while in Section 8 the conclusions and future research lines are pointed out.

2. Literature review

The role of information sharing and the smoothing replenishment rule has been largely demonstrated in literature. Concerning the former, there is a common agreement that enforcing cooperation between supply-chain participants is an effective tool to increase SCN performance (Audy, Lehoux, D'Amours, & Rönnqvist, 2012; Hall & Saygin, 2012; Stank, Dittmann, & Autry, 2011). This practice allows eradicating variability in SCNs, preventing costly dynamic distortions such as the "bullwhip" (Lee, 2010), and spreading the operational risk (Christopher & Holweg, 2011).

At the operational level, SCN collaboration concerns with the alignment of decisions amongst SCN partners in their planning and inventory management. This alignment is enabled by the exchange of information in the SCN (Stadtler, 2009). Firms can share real-time market demand data for the generation of conjoint forecasting, or even real-time information on inventory levels and in-transit items for centralized replenishment activities. In any case, each member of the SCN is able to generate order patterns based not only on the information at a local level, but also on further data incoming from partners. This visibility allows limiting the classical information distortion of the traditional SCN (Prajogo & Olhager, 2012).

Perhaps the information sharing strategy studied in the literature is the so-called Information Exchange Supply Chain (Holweg, Disney, Holmström, & Småros, 2005). Unlike in a traditional SCN, in this collaborative structure all echelons receive information on market demand in the information exchange and include this information in the order policy. Thus, retailers and suppliers order independently, yet they exchange demand information and action plans in order to align their forecasts for capacity and long-term planning.

Regarding smoothing replenishment rules, these have been designed to avoid the side-effect of the OUT policy, which is the most commonly used order policy in practice (Teunter & Sani, 2009). It is well-known that the classical OUT policy minimizes inventory fluctuations, but may lead to increasing the bullwhip